RELATIVE RESPONSE OF FINGER MILLET - SOYBEAN ROTATION TO APPLICATION OF ZINC, BORON AND MICROBIAL INOCULANTS

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in

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BANGALORE **APRIL, 2009**

Affectionately Dedicated
to My Beloved Parents
Late Shri S. V. Nagaraju,
Smt. Susheelamma
and loved brother
Late Mr.S.N.Babuprasad

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CERTIFICATE

This is to certify that the thesis entitled **"RELATIVE RESPONSE OF FINGER MILLET-SOYBEAN ROTATION TO APPLICATION OF ZINC, BORON AND MICROBIAL INOCULANTS"** *submitted by* **Mr. ANANDA N.**, *bearing I.D. No.* **PAK 4022** *in partial fulfillment of requirements for the award of degree of* **DOCTOR OF PHILOSOPHY** *in* **AGRONOMY** *to the University of Agricultural Sciences, Gandhi Krishi Vignana Kendra, Bangalore, is a record of research work carried out by him during the period of his study in this university, under my guidance and supervision, and the thesis has not previously formed the basis for the award of any degree, diploma, associateship, fellowship or other similar titles.*

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APRIL, 2009
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(ANANDA N.)

RELATIVE RESPONSE OF FINGER MILLET-SOYBEAN ROTATION TO APPLICATION OF ZINC, BORON AND MICROBIAL INOCULANTS

ANANDA N.

THESIS ABSTRACT

A field investigation on "Relative response of finger millet-soybean rotation to application of zinc, boron and microbial inoculants" was carried out at Dry Land Agricultural Project, GKVK, UAS, Bangalore during *Kharif* 2005 and 2006 as finger millet– soybean and vice versa rotation. The experimental site was sandy clay loam in texture, slightly acidic in pH with medium fertility. The experiments were laid out in randomized complete block design with three replications. The first experiment consists of nine treatments, with a combination of macro and micronutrients (with or without FYM), whereas in the second experiment there were ten treatments which comprised of application of different microbial inoculants (*Azospirillum brasilense* @ 1 kg/ha in 10 liter of water as seedling dipping method for finger millet, *Bradyrhizobium japonicum* @ 375 g/ha for soybean as seed treatment and VAM @ 10 kg/ha as soil application for both the crops) and micronutrients (Zn and B) were used along with recommended fertilizer and FYM.

The pooled analysis of the results revealed that application of NPK + FYM + $ZnSO_4$ + Borax recorded significantly higher growth, yield parameters of both the crops, grain (3613 kg/ha) and straw yield (5566 kg/ha) of finger millet, seed (1936 kg/ha) and haulm yield of soybean (3152 kg/ha) as compared to control. Seed quality parameters *viz.,* germination percentage seed vigour index and uptake of nutrients (N, P, K, Zn and B) in both the crops, protein and oil yield in soybean were also higher when conjunctive use of micronutrients (Zn and B) with recommended NPK and FYM were used. Indeed, the same treatment also maintained higher microbial and enzymatic activities.. In addition, a higher net income of Rs.44,138 and 47,825 per ha with a B:C ratio of 2.14 and 2.29 was realized due to application of NPK + FYM + $ZnSO_4$ + Borax in finger millet – soybean and soybean – finger millet based cropping system, respectively.

In the second experiment, the pooled analysis indicated that the growth, yield parameters of both the crops, grain (4143 kg/ha) and straw yield (6467 kg/ha) of finger millet; seed (2081kg/ha) and haulm yield of soybean (3304 kg/ha) were significantly higher with the application of NPK + FYM + $ZnSO_4$ + borax + *A. brasilense/ B. japonicum* + VAM as compared to control. The same treatment showed significantly higher seed quality parameters *viz*., protein and oil yield of soybean, germination percentage, vigour index and uptake of nutrients (N, P, K, Zn and B) in both the crops. Indeed, the same treatment also maintained higher microbial and enzymatic activities indicating an overall improvement in soil fertility. Application of NPK + FYM + $ZnSO_4$ + *A.brasilense / B. japonicum* + VAM recorded higher net returns of Rs. 50,753 per ha and B: C ratio (2.13) in finger millet-soybean based cropping system. Similarly, in soybean-finger millet cropping system higher net returns was recorded with the application of NPK + FYM + $ZnSO_4$ + *B. japonicum /A. brasilense* + VAM (Rs. 53,629/ha). The B: C ratio was also higher (2.25) with the application of NPK + FYM + $ZnSO_4$ + *B. japonicum / A.brasilense.* Further, it is noteworthy to state that under rainfed condition, soybean-finger millet rotation is highly economical and effective cropping system as compared to finger millet-soybean in order to improve the soil fertility and crop productivity

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INTRODUCTION

I. INTRODUCTION

Finger millet [*Eleusine coracana* (L.) Gaertn.] is an important coarse cereal of tropical climate grown mostly under rainfed and risky conditions during monsoon season in arid and semi-arid regions of India. It ranks third in importance among millets in the country in area (2 million ha) and production (2.8 million tonnes) after sorghum and pearl millet (Krishne Gowda *et al.*, 2006). One of the striking features which made finger millet an important dryland crop is its resilence and greater ability to withstand harsh climatic factors when grown in soils having poor water holding capacity.

Finger millet grain is extensively used as poor man's diet and straw as animal feed. Finger millet is the richest source of calcium (300-350 mg/100 g grain) whereas wheat and rice are having 41 and 45 mg/100 g, respectively. Indeed, finger millet contains around 65-70 per cent carbohydrates, a high proportion of which is in the form of non-starchy polysaccharides and also rich in dietary fiber (3.6 g/100 g) compared to wheat (1.2 g/100 g) and rice (0.2 g/100 g) which helps in prevention of constipation, lowering of blood cholesterol and slow release of glucose to blood stream during digestion. The regular finger millet consumers are having low incidence of cardiovascular diseases, duodenal ulcer and diabetes. Realizing the nutrient composition of the grain, it is now considered as nutri-cereal (nutritious grain).

The major finger millet growing states in India are Karnataka, Tamil Nadu, Andhra Pradesh, Orissa, Jharkhand, Maharashtra and Uttaranchal. Karnataka state has the largest area of around one million hectare (50% of the total area) followed by Maharashtra, Orissa, Tamil Nadu, Andhra Pradesh and Uttaranchal each having 10-12 per cent of the area. Finger millet is ranking third both in area (7.08 lakh ha) and

production (8.19 lakh tonnes) next to sorghum and rice with a productivity of 1833 kg per ha in Karnataka.

Soybean [*Glycine max* (L.) Merrill] is an important leguminous crop of economical and dietary value in India. It is mainly grown in tropical and sub-tropical regions for food, feed, oilseed and beverages. Like most other legume crops, soybean fits well into sequence and intercrop systems. Soybean has emerged as an important oilseed crop in India with an average total production of about 7.5-8.0 million tonnes in an area over 8.00 million ha (Chauhan, 2007). Soybean is called as "Gold of Soil" due to atmospheric nitrogen fixation in soil to an extent of 65 to 100 kg per ha depending on the soil type and climatic conditions (Srivastava *et al.*, 1984; Kausadikar *et al.*, 2003).

Soybean, a low input cost legume has became the third largest oilseed crop in India (Bhatnagar and Tiwari, 1991).It is referred as proteinous boon from heaven to human and poor man's meat to vegetarians due to its high protein (40-42%) content well balanced in amino acids and oil (18-21%) content, rich in polyunsaturated fatty acids specially omega 6 and omega 3 fatty acids. It is known as 'Golden bean' or 'Miracle crop' of twenty first century because of its versatile nutritional qualities. It contains good amount of minerals (Ca, P, Mg, Fe and K), vitamins (A, B, C, D and K) and isoflavones such as daidzein, genistein and glycitin. Presence of good amount of calcium and iron makes it highly suitable for women who suffer with osteoporosis and anemia. The isoflavones of soybean have been found to possess health benefits, as they exhibited properties like cancer prevention (particularly hormonal based cancers), combating menopausal problem. It also contains good quality dietary fiber, which enables the human body to fight against diabetes (Chauhan and Joshi, 2005). Recent research has established soybean as functional food on account of phytohormone it contains,

which provides an overall health security to human beings. The crop besides being utilized as a food products like oil, soyflour, soymilk, soypaneer, soynuts, candy, sauce, extruded products, fortified traditional products, it is also used for non-food purposes, *viz.,* manufacturing ink, cosmetics, bio-diesel, textiles, fiber glass *etc.* Because of all these benefits, the crop has been established as an industrially vital and economically viable oilseed crop in many areas of India (Singh *et al.*, 2001).

The major soybean growing states in India are Madhya Pradesh, Maharashtra, Rajasthan, Karnataka and Andhra Pradesh. Karnataka's contribution to soybean production is very marginal with a cropping area of 1.78 lakh ha with an annual production of 1.14 lakh tonnes and the productivity is 642 kg per ha (Anon., 2005a).

Among the several management practices, nutrient supply is one of the most important practice that determines the growth of the crops and ultimately the productivity. The practice of continuous addition of large amount of high analysis macronutrient fertilizers with much decreased use of organic manures, little recycling of crop residues depletes top soil of organic matter. This affects the physico-chemical properties of soil which leads to micronutrient hunger in crops. The need of the micronutrients has been essentially and entirely met through its native reserve of the soil, and thereby decreases the crop yields. Such observations were made in the long term experiments in AICRP for Dryland Agriculture, Bangalore Centre (Anon., 2001). As such chemical fertilizers cannot be replaced to get higher yields. However, but continuous and indiscriminate use of chemical fertilizers destroy soil fertility and causes imbalance in the microbial activity of the soil. Thus, in order to sustain the yield, conjunctive use of organic manures, biofertilizers and fertilizers is inevitable. Organic manures ameliorate the

problem created by continuous use of fertilizers, as organic matter helps in increasing adsorptive power of soil for cations and anions particularly phosphorus and nitrates. These adsorbed nutrient ions are released slowly for the benefit of crop during its entire growth period (Dhar, 1953). It helps to improve the soil physical (Biswas and Khosla, 1971) and chemical properties (Lal and Mathur, 1988). Organic manures application also improves the organic carbon, primary and secondary nutrients (Badanur *et al.*, 1990). Besides this, they also supply sufficient amount of micronutrients in available forms (Kher, 1993). However, due to its lower nutrient status and slow releasing nature, FYM alone may not be able to meet the high nutrient requirements of crops. Likewise the use of only NPK fertilizers under modern intensive farming will not be sufficient.

The optimum level of NPK failed to maintain the desired yield level owing to deficiency of other essential elements especially micronutrients (Kamath and Sarkar, 1990). Among the micronutrients, Zinc plays a significant role in various enzymatic and physiological activities and performs many catalytic functions in plant system besides transformation of carbohydrates, chlorophyll and protein synthesis. Now the deficiency of zinc has become so widespread that it ranks next to N and P (Takkar and Randhawa, 1980). Deficiency of boron is recognized as one of the widespread problem second only to zinc (Shrotriya and Martin Phillips, 2002). Boron is a micronutrient of special importance because of its role in the fertilization and flowering processes of crops. Boron is known to influence carbohydrate metabolism, the nucleic acid (RNA and DNA) and protein household, nitrogen metabolism in general, the central information system controlling cell development and differentiation, membrane permeability, the transport of substances, flower formation and pollen germination, fruit setting, water household, phytohormone metabolism and the transport of phytohormones in

particular (Werner Bergmann, 1992). As such usage of zinc and boron might prove beneficial in increasing finger millet and soybean yields and quality.

Besides mineral nutrition, microbial inoculants play an important role in crop production as these are eco-friendly, low cost, non-bulky agricultural inputs. *Azospirillum brasilense*, a micro-aerophillic diazotrophic bacterium colonizes the roots of monocot plant and fixes the atmospheric nitrogen. By the use of *Azospirillum* as a seed inoculant, economy of 20-30 kg N per ha equivalent could be achieved in crops like cereals and millets. Besides nitrogen fixation, it also produces growth hormones such as auxins, gibberellins and cytokinins (Chunchun Kumar *et al.*, 1998). Soybean is known as natural fertilizer factory because of its high nitrogen fixing potential. *Bradyrhizobium japonicum* is one of the cheapest, eco-friendly strategy being widely used as biofertilizer which colonizes the roots of soybean to form root nodules which acts as a factories of nitrogen fixation (Balasubramanian, 1996). Bradyrhizobia is also known to synthesize growth promoting substances like indole acetic acid, indole-3 butyric acid, abscisic acid and cytokinins. Soil inoculation of VAM (*Vesicular arbuscular* mycorrhiza) fungi are known to increase the nutrient uptake, by helping the plants to acquire mineral nutrients from soil especially immobile elements such as P, Zn and mobile elements such as S, Ca, K, Fe, Mg, Mn *etc.* Synergistic effects of dual inoculation of VAM with *Azospirillum brasilense* (Rattan *et al.*, 1999) and *Rhizobium* (Barea and Azcon- Aguilar, 1983) in cereals and legumes respectively have also been reported.

Crops grown in a sequence should aim at maintaining soil fertility and productivity because of the large quantities of fertilizer nutrients required and removed by intensive cropping systems (Bobde *et al.*, 1998). The practice of cereal-cereal rotation continuously might have an adverse

effect on physico-chemical properties and fertility status of soil (Deka and Singh, 1984). Inclusion of legumes in the sequence improves the soil fertility better than cereal-cereal sequence (Yadav, 1985).

Besides increased production, quality of produce is also important and is one of the criterion for the acceptability of the produce in national as well as in the international market. The quality of the produce depends on inherent genetic makeup and environmental factors. Among the environmental factors, balanced crop nutrition approach which envisages judicious balance of organic and inorganic fertilizers along with microbial inoculants at appropriate physiologicaly responsive growth stages plays a vital role in determining the yield as well as the quality of the produce.

In the context of the above evidences, present investigation was carried out to study the "Relative response of finger millet-soybean rotation to application of zinc, boron and microbial inoculants" at AICRP for Dryland Agriculture Centre, UAS, GKVK, Bangalore with the following objectives:

1. To study the effect of zinc and boron nutrition on the growth and productivity of finger millet and soybean with or without FYM.
2. To study the effect of microbial inoculants in conjunction with zinc and boron on the growth and productivity of finger millet and soybean and their rotation.
3. To study the effect of microbial inoculants, zinc and boron on the quality of finger millet and soybean.
4. To study the effect of zinc, boron and microbial inoculants on soil nutrient status and soil microbiological properties.
5. To study the economics of growing finger millet soybean in rotation under different nutrient management systems.

REVIEW OF LITERATURE

II. REVIEW OF LITERATURE

Published literature pertaining to the investigation entitled "Relative response of finger millet-soybean rotation to application of zinc, boron and microbial inoculants" is briefly reviewed in this chapter on the following aspects.

2.1 Response of crops to zinc
2.2 Response of crops to boron
2.3 Response of crops to farmyard manure (FYM)
2.4 Effect of microbial inoculants (*Rhizobium*/*Azospirillum*/VAM) on crop growth, yield, quality, uptake of nutrients and nutrients status in soil
2.5 Interactive effect of FYM, zinc, boron and microbial inoculants on crop growth, yield, quality, uptake of nutrients and nutrients status in soil
2.6 Conjunctive use of FYM, micronutrients and microbial inoculants on nodulation and soil microbiological properties
2.7 Response of cereal-legume and legume-cereal crop rotation on crop growth, yield, quality, uptake of nutrients and nutrients status in soil
2.8 Economics of cropping rotations under different nutrient management systems

2.1 RESPONSE OF CROPS TO ZINC

Balanced fertilization is the key to crop production. There are reports that inspite of liberal application of N, P and K fertilizers, maximum yields are not realized due to little appreciation of the use of micronutrients (Khanday *et al.,* 1990). Due to over exploitative agriculture, soils are becoming deficient in macro and micronutrients. Among the different micronutrients the role of zinc (Zn) application in

improving the crop productivity is as important as that of major nutrients in present day agriculture. Zinc is now being regarded as the third most limiting nutrient element in crop production after N and P (Gupta, 1995). Zinc is essential for several enzyme systems that regulate various metabolic activities in plants. It is involved in auxin production, transformation of carbohydrates and regulation of sugar in plants.

2.1.1 Effect of zinc application on the availability, crop growth, yield, quality, uptake of nutrients and nutrients status in soil

The soil factors such as pH, soil organic matter, temperature and moisture affect the availability of micronutrients to crop plants. Zinc solubility is highly soil pH dependent and decrease 100–fold for each unit increase in pH and uptake by plants decrease as a consequence (Fageria *et al.,* 1990). Temperature lower than optimum normally decreases zinc acquisition by crop plants. Zinc deficiency symptoms were relatively severe at low soil temperature but zinc concentration increased when the temperature was increased (Martin *et al.*, 1965). Since zinc moves to roots mainly by diffusion, zinc deficiency is common also in crops grown under dry conditions (Warncke and Barber, 1972). The increase in light intensity enhanced the release of phytosiderophores by cereal roots, which could increase uptake of zinc (Cakmak *et al.*, 1998).

2.1.1.1 Cereals

In a study at Coimbatore on black clay loam soils, application of $ZnSO_4$ @ 12.50 kg per ha was found to be optimum for increasing Zn content of finger millet straw(Devarajan *et al.,* 1980).

On study on red sandy loam soil, at Hyderabad, soil application of zinc at 24 kg per ha had favourable effects on the chemical composition, protein content and uptake of nutrients (N and P) by maize as compared to control (Soundara Rajan and Yassen 1981).

On loamy sand, at Jobner (Rajasthan) zinc application at 10 kg per ha, promoted plant height, effective tillers per plant, ear length, number of grains per ear, 1000-grain weight and grain yield of pearl millet than zero and five kg Zn per ha and the response was linear to zinc application (Maliwal *et al.,* 1985).

On a sandy loam soil, application of 12 kg $ZnSO_4$ per ha to rainfed wheat crop significantly increased N and K concentration and uptake by grain and straw over no zinc application (Venkateswarlu and Misra 1987).

Aftab Hussain *et al.* (1988) in their study revealed that the leaf area, total dry matter, yield and yield attributes *viz.,* tillering, 1000-grain weight and grain density of finger millet were affected by varying levels of zinc.

Yadav *et al.* (1989) in their study at Jobner on loamy sand soil concluded that application of 10 kg Zn per ha significantly increased the content and uptake of zinc, which resulted in significant increase in grain and stover yield of pearl millet as compared to no or 5 kg Zn per ha.

Jat (1990) observed significantly higher number of tillers per plant due to application of 10 kg Zn per ha in pearl millet.

Khanday *et al.* (1990) on silty clay loam soil at Palampur (Himachal Pradesh) noted that application of $ZnSO_4$ @ 25 kg per ha increased all the yield contributing characters of maize resulting in 8.5 per cent more yield over control.

Keshwa and Jat (1991) at Jobner on loamy sand soil, while working with forage pearl millet found that application of zinc @ 10 kg per ha showed significant increase of 14.9 and 14.7 per cent in the

number of shoots, 9.5 and 7.2 per cent in the number of leaves and 12.1 and 10.3 per cent in dry matter per plant during first and second cuttings, respectively compared to control.

Yadav *et al.* (1991b) in their study at Jobner on loamy sand soils, noted that application of zinc at 10 kg per ha significantly increased the number of shoots, number of leaves, dry matter, ear bearing shoots per plant, test weight, grain and stover yield of pearl millet as compared to control and 5 kg zinc per ha.

Keshwa and Jat (1992) noticed significant increase in content and yield of protein, crude fibre yield and green fodder yield of pearl millet with zinc application as compared to control.

Malleasam *et al.* (1992) in a pot culture experiment found that increased levels of zinc enhanced the concentration of zinc in maize plants significantly with both Zn-EDTA and $ZnSO_4$ sources.

Patel and Patel (1992) found that application of Zn @ 25 kg per ha, either alone or in combination with 10 t of FYM per ha significantly increased the Zn uptake of sorghum compared with the control, which ultimately increased green forage and dry matter yields.

Srinivasan (1992) on red lateritic soil at Vamban (Tamil Nadu) noted that application of zinc at 30 kg per ha, significantly increased the plant height, cob length, number of rows per cob, number of seeds per row, grain and straw yield of maize as compared to control.

Indulkar and Malewar (1994) in the study at Latur (Maharashtra) on topic chromustert soil, concluded that use of 4 kg zinc per ha through various inorganic sources improved the direct and residual effects of zinc on sorghum-wheat yield, uptake and available zinc in soil.

Grain yield of pearl millet was higher with 90 kg N + 60 kg P_2O_5 + 60 kg K_2O + 25 kg Zn per ha (Patel and Karelia, 1994).

Purushotham *et al.* (1994) in a field trial found that application of 90 kg N + 60 kg P + 25 kg $ZnSO_4$ resulted in higher grain yield of finger millet.

On silty clay loam soil at Palampur, maize responded significantly to the zinc application. Grain yield of 5.57, 6.60, 6.59 and 6.18 t per ha was obtained under 0, 3.3, 6.6 and 9.9 kg per ha levels of zinc application respectively and further they noticed higher uptake of zinc due to its application (Sankhyan and Sharma, 1997).

On loamy sand soil at Jobner (Rajasthan), significantly higher green fodder yield of pearl millet was obtained with the increase in zinc level upto 10 kg per ha as compared to control (Dadhich and Gupta, 2003).

Application of 10 kg zinc per ha significantly increased plant height, tillers, leaves, stem girth, leaf area, green fodder yield and crude protein yield in pearl millet over the control (Dadhich and Gupta, 2005).

Soil application of $ZnSO_4$ @12.50 kg per ha along with recommended NPK recorded significantly higher vigour index (535), seedling dry weight (5.4 mg), germination (99%) and test weight (2.86 g) in finger millet as compared to application of recommended NPK alone (Shankar *et al.,* 2005).

On loamy sand soil at Jaipur (Rajasthan), Jakhar *et al.* (2006) reported that application of increasing levels of zinc (0, 5 and 10 kg Zn/ha) showed significant improvement in plant height, grain, stover yield and protein content of pearl millet upto 5 kg Zn per ha. The increase in grain yield under 5 kg Zn per ha was 8.09, 7.98 per cent and

a protein content of 1.96 and 2.88 per cent in the year 2000 and 2001 over zero kg Zn per ha respectively.

Foliar application of Zn and Fe resulted in higher plant height, LAI, dry matter production and yield attributes of maize *viz.,* number of seeds and grain weight per cob, 100-seed weight and seed yield, which were comparable with the soil application of Zn and Fe. Similar trend was observed with respect to protein, tryptophan of grain and crude protein content of the stover (Reddi Ramu and Reddy, 2007).

2.1.1.2 Legumes

Shivashankar *et al.* (1974) at Bangalore indicated that application of zinc sulphate at 15 kg per ha in addition to fertilizers significantly increased the seed yield of soybean to an extent of 9.2 per cent.

Kapur *et al.* (1977) recorded maximum protein content (37.02%) at 5 ppm of zinc over control (33.15%) in soybean. Further, they observed that increase in seed weight of soybean by 1.46 times with the application of 5 ppm of zinc over control.

Kumar and Singh (1979) reported that the total zinc uptake was higher with application of 80 ppm sulphur and 10 ppm zinc at 45 days after sowing (DAS) and at maturity of soybean.

Sakal *et al.* (1980) reported that zinc uptake by grain and straw of chickpea progressively increased with increasing levels of zinc from 2.5 to 10 kg per ha.

Rose *et al.* (1981) found that foliar spray of 4 kg zinc sulphate per ha before flowering stage increased the plant height. Further, they found that two foliar sprays of zinc sulphate ($ZnSO_4$ $7H_2O$) @ 4 kg per ha increased the soybean yield by 208 per cent over control.

Rosalind Michael (1983) observed a favourable response of 38 per cent in terms of grain yield of bengal gram to seed coating with 4 grams of zinc per kg seed.

Ahmed *et al.* (1986) observed progressive improvement in plant height, number of pods per plant, grain and straw yield of mungbean when zinc was applied alone. Further, P and Zn content of grain, straw and protein content of mungbean were significantly affected by P and Zn application upto 60 kg P and 5 kg Zn per ha.

Devarajan *et al.* (1987) suggested that soil application of 25 and 50 kg zinc sulphate per ha, significantly increased the grain yield and uptake of zinc in greengram.

At Pantnagar on silty loamy soil, application of zinc increased the plant drymatter, grain yield and yield attributes and quality parameters (protein and oil content) of soybean. Further, Zn content of shoot and residual Zn after harvest of crop increased with increasing levels of Zn upto 10 ppm (Jha and Chandel, 1987).

Sharma and Dixit (1987) reported that soil application of 25 kg $ZnSO_4$ per ha increased the protein content of soybean.

Kalia and Sharma (1988) at Palampur on clay loam soil, found that application of 5 kg zinc per ha significantly affected the number of pods per plant, yield per plant, 100-grain weight and grain yield of soybean over control.

Puste and Jana (1988) found that application of $ZnSO_4$ @ 20 kg per ha to pigeonpea greatly influenced the LAI, dry matter accumulation in leaf, stem, pod and crop growth rate. Increased zinc levels were also found to produce higher values of these growth parameters significantly.

Soil application of 20 kg zinc per ha reported to increase plant height, nodulation and pod yield of groundnut (Kulkarni *et al.*, 1989).

Anil *et al.* (1990) reported that zinc at 5 ppm stimulated the uptake of nitrogen by chickpea but increasing levels of zinc upto 10 ppm had a depressing effect.

Sarkar and Aery (1990) in a pot trial found that application of 10 µg zinc per g soil in soybean increased the root and shoot growth, dry matter accumulation, leaf area, number and weight of nodules per plant, seed yield and 100-seed weight.

Tomar *et al.* (1990) corroborated that groundnut crop responded significantly to zinc sulphate application upto 40 kg per ha by increasing the plant height and dry weight.

Yadav *et al.* (1991a) demonstrated that the zinc composition in groundnut plant parts increased with zinc application.

Dev *et al.* (1992) noticed that zinc application significantly increased the concentration of zinc in grain of all the pigeonpea cultivars. However, it was found varied among the cultivars.

Krishnappa *et al.* (1992) found that application of 5 kg Zn per ha enhanced the protein content of groundnut significantly over control.

Ibrahim (1992) reported that seeds sprayed with 100 ppm zinc gave the higher oil and protein content of soybean seeds.

Channabasavanna and Setty (1993) observed that application of 10 kg $ZnSO_4$ per ha at sowing gave significantly higher kernel yield in groundnut over control.

Kushwaha (1993) showed that zinc sulphate at 25 kg per ha improved the number of pods per plant and resulted in increased seed yield in urdbean over control.

Gupta and Vyas (1994) noticed that the oil content of soybean increased with the application of zinc upto 15 kg per ha which might be due to activation of NADPH dependent dehydrogenase enzyme, involved in fat synthesis. Further, they obtained higher yield of soybean with combined application of 40 kg P_2O_5 and 15 kg $ZnSO_4$ per ha.

Singh and Singh (1994) at Kanpur on sandy loam soil, found that application of zinc oxide @ 20 kg per ha significantly increased the yield of soybean and improved the potassium uptake.

Devarajan and Palaniappan (1995) opined that application of zinc at 5 kg per ha significantly increased the zinc uptake in soybean.

Puste and Jana (1995) reported that application of 20 kg $ZnSO_4$ per ha produced significantly higher plant height, more number of pods per plant, length of pod and yield of pigeonpea over control.

Singh and Singh (1995) reported that application of 20 kg zinc oxide per ha in soybean significantly increased the number of pods per plant, number of seeds per pod over control.

Tomar *et al.* (1995) observed that 20 kg zinc per ha resulted in increased seed protein and oil content in groundnut.

Wang *et al.* (1995) reported that soil application of 2 kg zinc sulphate per m.u. (1 m.u. = 0.067 ha) increased the number of branches, plant height, seed number per pod and 100-seed weight in soybean.

Nagaraju and Yadahalli (1996) reported that application of $ZnSO_4$ at 12.5 kg per ha increased the 100-seed weight, number of pods per plant and number of seeds per pod compared to control (without zinc). Further, there was marked and significant improvement in seed yield of cowpea.

Raghuwanshi *et al.* (1997) at Indore on typic haplusterts soil found that application of $ZnSO_4$ @ 5 and 10 kg per ha increased the soybean yield by 33 and 43 per cent respectively over control.

Saxena and Chandel (1997) in their study at Pantnagar on silty clay loam soil revealed that application of zinc @ 10 kg per ha resulted in higher plant biomass, soybean grain yield and maximum N-fixation in soil over control.

Barman *et al.* (1998) concluded that the buildup in the available zinc content in soil was linearly related to the quantity of fertilizer zinc application and 21.5 to 33 per cent of the applied zinc contributes towards available pool of zinc. Further, optimum dry matter yield of soybean was obtained at the build up DTPA-Zn level of one ppm in all the soils.

Sakal *et al.* (1998) found that application of Zn progressively increased the grain yield of chickpea from 14.5 to 19 q per ha and straw yield from 16 to 22 q per ha. The grain yield response ranged between 150 to 450 kg per ha as Zn dose increased from 2.5 to 10 kg per ha. Application of zinc @ 5 kg per ha was found as ideal dose for chickpea.

Vasavi Rani *et al.* (2000) in their study at Machavaram (Andhra pradesh) on black soil revealed that graded levels of P and Zn significantly increased the dry matter production both in stover and seed yield of soybean at harvest.

Gurkirpal Singh *et al.* (2001) in a field experiment at Ludhiana (Punjab) observed higher number of pods per plant (68.9) and seed yield (24.8 q/ha) of soybean with combined application of NPK (90:80:60 kg/ha) and zinc (25 kg/ha).

Kuldeep Singh and Hans Raj (2001) recorded significant increase in dry matter yield of cluster bean shoots with the addition of Zn either individually or in combination with Cu, Fe, and Mn compared to control.

Thakur *et al.* (2001) in a long-term experiment to evaluate the influence of S and Zn in soybean-wheat cropping sequence concluded that application of 50 kg S per ha and 10 kg Zn per ha every year was essential to realize the higher productivity of soybean and wheat.

Soil application of $ZnSO_4$ @12.50 kg per ha along with recommended NPK recorded significantly higher vigour index (144), seedling dry weight (1.47 g), germination (98%) and 100 kernel weight (26.91 g) in groundnut as compared to application of recommended NPK alone (Shankar *et al .,* 2005).

The literature on zinc nutrition clearly indicates that significant increase in grain yield of cereal and legumes could be obtained by zinc nutrition. The response to level of zinc application varied significantly depending upon soil type, crops and other management practices.

2.2 RESPONSE OF CROPS TO BORON

Deficiency of the micronutrient boron is recognized as one of the most widespread, second to zinc (Shrotriya and Martin Phillips, 2002). It is of special importance because of its role in the fertilization and flowering processes of crops. Due to the vital role it plays in these processes, if it is deficient, one of the first adverse effect is on flowering and fruiting inturn on the yield and/or quality of the seeds and fruits.

Boron deficiency in plants decreases the biomass and disturbs the carbohydrate and phenol metabolism (Dugger, 1983). In many plant species including cereals and legumes, inadequate supply of boron decreases the economic yield (Misra and Patil, 1987), mainly because of the marked reduction and retardation in flowering and fruit development under boron deficiency.

2.2.1 Effect of Boron application on the availability, crop growth, yield, quality, uptake of nutrients and nutrient status in soil

The lower soil pH favours the absorption of boron. The availability and uptake of boron decreases dramatically at pH >6.0. The uptake of boron is greatly influenced in the plants which are grown under hot and dry conditions. Increased temperature in nutrient solution enhanced boron concentrations in shoots of plants by increasing boron uptake with increased transpiration (Moraghan and Mascagni, 1991). The availability of boron decreases under drought conditions most likely because of reduced mobility of boron by mass flow to roots (Barber, 1995). Boron can move relatively long distances by mass flow and diffusion to roots. Soil drying reduces boron diffusion by reducing the mobility of soil solution and increasing the diffusion path length (Scott *et al.,* 1975). Boron deficiency in crops generally occurs during drought periods, because of restricted water flow to roots and boron deficiency may also restrict root growth to reduce acquisition of water and intensify drought stress effect (Bouma,1969)

2.2.1.1 Cereals

Pal *et al.* (1991) opined that foliar application of boron as borax at 2.5 kg per ha increased the plant height of wheat as compared to control.

Sinha *et al.* (1991) in a field experiment at Dholi (Bihar) concluded that the optimum level of boron (B) for *kharif* crops was 1.5 kg per ha

and the order of yield response to boron was onion > maize > sweet potato > groundnut > Vam bean. Further, they also noticed that application of boron progressively increased the boron concentration and uptake by crops.

Field and pot trials at Liaoning province of NE China indicated that application of urea containing borate enhanced the uptake of nitrogen and phosphorus by crops and increased the nitrogen utilization rate by 4.7 per cent compared with urea without borate. Further, it also increased the yields of rice, maize, sorghum, millets, soybean, groundnut and sugarbeet in arable soil (Wang *et al.*, 1992).

Mandal (1994) reported that application of boron @ 1.356 kg per ha significantly increased the grains per spike and its content at boot leaf stage of wheat as compared with control.

In a glass house experiment higher weight of inflorescence (69.8 g/plant), grain yield (50.9 g/plant), 100-grain weight (1 g) and biomass (117.1 g/plant) of pearl millet were recorded with the application of boron @ 0.33 mg per litre (Pratima Sinha and Chatterjee, 1994).

Soil application of borax @10kg per ha along with recommended NPK recorded significantly higher vigour index (256), seedling dry weight (2.7 mg), germination (95%) and test weight (2.50 g) in finger millet as compared to application of recommended NPK alone (Shankar *et al.,* 2005).

2.2.1.2 Legumes

Dongale and Zinde (1978) noticed that application of boron and sulphur increased oil content in groundnut seed from 47.16 to 52.26 per cent and protein content from 23 to 27 per cent over control. Further, they found that foliar application of boron in two sprays at 35 and 50

days after sowing of groundnut increased the pod yield significantly under field condition.

Singh and Singh (1976) found that seed oil content of groundnut increased from 47.8 per cent to 49 per cent with increased borax application from zero to 30 kg per ha. Similar findings were reported by Sankaran *et al.* (1977).

Shukla *et al.* (1983) observed significant improvement in oil and protein content of groundnut by application of boron alone or in combination with sulphur and zinc.

Tripathi and Singh (1984) showed that boron uptake by gram as well as groundnut increased markedly with increasing concentration of boron in the soil solution.

Shinde and Kale (1985) reported that boron application through foliar spray and soil has increased the yield of groundnut, as well as total boron uptake compared to control. Further, available boron content of soil at harvest was significantly higher in plots where boron was applied at the rate of10 kg per ha.

Golakiya and Patel (1986) observed that the number of developed pods increased with increase in boron levels which resulted in corresponding increase in shelling percentage of groundnut.

At Palampur on clay loam soil, Kalia and Sharma (1988) found that application of boron significantly increased the number of pods per plant, yield per plant, 100-grain weight and grain yield of soybean over control.

Chandel *et al.* (1989) in a field experiment indicated that application of boron @ 4 kg per ha gave higher seed yield of soybean which was significantly (79.73%) more than the control.

Datta *et al.* (1994) in a pot culture experiment revealed that critical concentration of boron in soybean plant was 21.5 mg per kg. Further, they noticed that application of boron @ 1 mg per kg in boron deficient soils was found to be optimum for soybean.

On clayey soil at Dapoli (Maharashtra), Mahajan *et al.* (1994) found that soil application of boron @ 0.5 kg per ha through boronated superphosphate recorded significantly higher yield of dry pods (3200 kg/ha), harvest index (42.84), higher yield of oil (1156 kg/ha) and protein (659 kg/ha) and showed higher uptake of nitrogen (127.4 kg/ha) and phosphours (11.7 kg/ha) in kernels of groundnut as compared to control.

Pabitra Kumar Mani and Haldar (1996) reported that application of boron resulted in increase in dry matter, concentration as well as uptake of boron in shoot of greengram.

Rahman *et al.* (1999) in a pot culture experiment indicated that a concentration of 0.4 mg boron per liter was most beneficial for all the growth characters including nodule formation at the early stage (20 DAS) of development of soybean plants.

Masood Ali and Mishra (2001) revealed that foliar spray of 0.2 per cent borax at 50 and 60 DAS increased the plant height and number of branches per plant in chickpea.

Application of recommended dose of NPK + boron at 2.0 kg per ha significantly increased the test weight, seed germination and vigour index of soybean over the control (Deosarkar *et al.*, 2002).

Liu Peng and Yang Yuai (2003) in a pot experiment found that application of boron increased the leaf area of soybean plants, enhanced their photosynthetic and respiration rates and soluble sugar content in

their pods, delayed and declined chlorophyll in their later growth stages and decreased soluble sugar content in the stem and leaves, thus improving photosynthetic efficiency.

Pratima Sinha and Chatterjee (2003) observed depressed growth, biomass, pod and seed yield concentration of boron and ribonuclease activity in leaves and increased peroxidase, acid phosphatase and starch phosphorylase activity in soybean due to boron deficiency. Further, the quality of seeds was deteriorated with low boron as reflected in decreased content of boron, starch, protein and oil along with stimulated concentrations of sugars and phenols.

At Pantnagar, Sumit Chaturvedi and Chandel (2005) found that integrated use of recommended fertilizers with supplementary nutrients (Fe and B) increased the yield attributes (pods/plant and 100-seed weight), harvest index, grain yield of soybean as well as higher uptake of N, P and K.

Koti and Sanjana (2006) indicated that manganese sulphate at 0.4 per cent and boric acid at 0.1 per cent was optimum with regard to higher germination and vigour index in soybean.

At Darisai (Jharkhand) on acidic upland soil, Singh *et al.* (2006) reported that the seed, stover yield, oil and protein contents in soybean seed increased with successive increase of sulphur and boron levels. Further, the total sulphur and boron uptake by crop was increased significantly with increase levels upto 60 kg sulphur and 2 kg boron per ha.

The literature on boron nutrition indicates a positive response of cereals and legumes to its application. Borax can be supplied either through foliar spray or soil application.

2.3 RESPONSE OF CROPS TO FARM YARD MANURE

Farm yard manure occupies an important position among bulky organic manures. The estimated potential and the availability of nutrients from cattle based FYM in India is about 3.4 to 5.7 and 1.0 to 1.7 million tonnes of $N+P_2O_5+ K_2O$ per year, respectively (Subash Chandra and Chauhan, 2004).

The FYM seems to act directly by increasing crop yields either by acceleration of respiratory process by cell permeability or by hormone growth action. It supplies N, P, S and micronutrients in available forms to the plants through biological decomposition.

Addition of FYM increases the soil organic matter status in the soil. Soil organic matter appears to affect the availability of zinc by increasing the solubility of zinc through the formation of complexes with water soluble compounds of organic matter (amino or fulvic acids) ; forming insoluble zinc organic complexes that decrease the solubility of zinc ; roots releasing exudates and ligands that may complex zinc in the rhizosphere and microbes immobilizing and mineralizing leading to decreased or increased soil available zinc. Increased levels of organic matter increase exchangeable and organic fractions of zinc and decrease oxide fractions of zinc in soil because of reducing conditions to enhance zinc bioavailability (Lindsay, 1972).

Organic matter is the main source of boron in acid soil as relatively little boron is adsorbed on mineral fractions at low pH. Boron adsorption by soil composed organic matter increases with increased soil organic matter content and soil pH, because boron is so closely associated with organic matter. It is usually more available in surface compared to subsurface soils because of higher amounts of organic matter in surface soil (Tisdale *et al.,* 1985).

Gaur *et al.* (1992) reported that FYM contained 0.5 to 1.0 per cent N, 0.15 to 0.2 per cent P_2O_5 and 0.5 to 0.6 per cent K_2O and it has been estimated that a tonne of FYM would supply 3.6 kg N + 1.90 kg P_2O_5 and 1.8 kg K_2O to soil when incorporated. Organic manures by nature are store house of several micronutrients.

2.3.1 Effect of farmyard manure with or without inorganic fertilizers on crop growth, yield, quality, uptake of nutrients and nutrients status in soil

2.3.1.1 Cereals

Ramaiah *et al.* (1970) reported that application of 30 kg P_2O_5 per ha along with 10 t of FYM, 70 kg N and 35 kg K_2O recorded significantly higher grain yield (3572 kg/ha) of finger millet, the increase being 9.8 per cent over no phosphorus at Coimbatore.

Muthuvel *et al.* (1977) recorded higher available nitrogen content in soil due to continuous annual application of cattle manure at the rate of 5660 kg per ha which would have brought up optimum environment for microbial population thus enabling quicker mineralization of organic nitrogen under rainfed conditions at Coimbatore.

The yield of finger millet grain and straw was increased with increased levels of N either as farmyard manure or ammonium sulphate. Combined application of farmyard manure at 30 kg N per ha and ammonium sulphate at 90 kg N per ha gave the higher yield of grain (4234 kg/ha) and straw (4808 kg/ha) (Chellamuthu and Kothandaraman, 1980).

Application of FYM at 10 t per ha significantly increased the plant height and yield attributes *viz.,* grains per ear, 1000-grain weight,

effective tillers per plant, ear length and grain yield of pearl millet over no FYM application (Maliwal *et al.*, 1985).

Rahman (1986) reported that application of 100 per cent NPK + FYM (10 t /ha) recorded 42, 2.42 and 9.12 kg per ha in case of grains and 34, 2.88 and 12.8 kg per ha of N, P and K uptake by straw of finger millet, respectively at Bangalore.

At Coimbatore, application of N @ 60 kg per ha as FYM had significantly increased the phosphorus content of finger millet grain, but not so in finger millet straw. The probable reason would be increased nucleic acid content which was primarily responsible for the increase in P content required for grain formation. (Chellamuthu *et al.*, 1987).

Thimma Reddy (1987) reported that application of FYM (10 t/ha) recorded 43.64, 3.47 and 14.91 kg N, P and K uptake per ha by finger millet under long-term manuring under Bangalore conditions. Further, he opined that continuous application of FYM at 10 t per ha, has helped in buildup of soil phosphorus, hence lowered the phosphorus fixation in *alfisols* of Bangalore, setting higher proportion of applied phosphorus for crop utilization.

Virupakshi (1988) recorded higher grain yield (2180.54 kg/ha) of finger millet due to application of 100 per cent NPK along with FYM (10 t/ha) as compared to 150 per cent NPK (1916.61 kg/ha) at Bangalore.

Kavalappa (1989) reported that application of 100 per cent NPK plus FYM (10 t/ha) recorded significantly higher uptake of N (62.24 kg/ha), P (9.23 kg/ha) and K (30.16 kg/ha) by finger millet grain and 117.84, 7.16 and 105.01 kg N, P and K per ha by finger millet straw, respectively at Bangalore.

Subramanian and Kumaraswamy (1989) recorded highest dry matter production of finger millet at active tillering and flowering stages under 100 per cent NPK + FYM @ 10 t per ha at Coimbatore under finger millet- cowpea- maize cropping sequence.

Mani (1991) reported that application of FYM @ 10 t per ha with 40 kg N per ha significantly increased the plant height (59.2 to 71.6 cm), number of tillers (1.30 to 3.45), number of fingers per ear (6.47), number of productive tillers per hill (3.3), grain and straw yield (1432 and 2098 kg/ha, respectively) of finger millet under sandy loam soils of Paiyur.

Srinivasan (1992) reported that the plant height, cob length, number of rows per cob, number of seeds per row, grain and straw yield of maize were significantly higher in farm yard manure application at 10 kg per ha as compared to control.

The results of long-term fertilizer experiments conducted at Bangalore revealed that application of FYM along with 100 per cent NPK resulted in an increase in the mean yield to an extent of 11 per cent as compared to the application of only NPK fertilizers at 100 per cent recommended level in finger millet due to considerable increase in the organic carbon content and a marginal increase in cation exchange capacity of soil (Anon., 1996a).

At Bangalore, application of 25 kg N through FYM along with 25 kg N per ha (inorganic) recorded higher grain yield (2262 kg/ha) of finger millet as compared to only FYM to provide 50 kg N per ha (1254 kg/ha) (Anon., 1997b).

Dwibedi and Singh (1997) revealed that FYM + urea (50:50 per cent N) alone with P and K at 50 per cent recommended dose was significantly superior to FYM or NPK and recorded higher grain (23.16

q/ha) and straw (101.0 q/ha) yield of finger millet under rainfed hill farming system at Ranichuri (UP).

Gulshan *et al.* (1999) reported that application of FYM @ 10 t per ha increased N, P and K uptake in wheat by 9, 13.8 and 9.7 per cent, respectively over control.

Shivakumar (1999) reported that application of 50 per cent NPK per ha through fertilizer along with 50 per cent NPK through FYM recorded higher uptake of N (139.42 kg/ha), P (82.94 kg/ha) and K (57.97 kg/ha) by finger millet at Bangalore.

A field trial conducted at Majhera (UP) by Singh (1999) revealed that application of 10 t FYM per ha recorded maximum grain yield of finger millet and return per rupee investment but it was at par with 7.5 t FYM per ha.

At Bangalore, application of FYM (10 t/ha) along with 100 per cent recommended NPK recorded significantly higher mean grain yield (3356 kg/ha) of finger millet compared to 2255 kg per ha due to recommended NPK (Anon., 2000a).

Gajanana *et al.* (2000) reported that continuous application of FYM (10 t/ha) for 20 years recorded higher available N (193 kg/ha), P_2O_5 (141 kg/ha) and K_2O (140 kg/ha) content in soil as compared to 161, 30 and 59 kg N, P_2O_5 and K_2O per ha respectively in plots without FYM at Bangalore, while combined application of 100 per cent NPK + FYM registered higher available N (203 kg/ha), P_2O_5 (168 kg/ha) and K_2O (158 kg/ha) content in soil as compared to 167, 142 and 107 kg N, P_2O_5 and K_2O per ha respectively under 100 per cent NPK treatment.

Application of 5 t FYM per ha and 17.47 kg P per ha significantly enhanced the plant height, yield attributes (ear head length and test

weight) grain yield, stover yield, protein content of pearl millet grain (Jakhar *et al.*, 2006).

2.3.1.2 Legumes

Sharma and Dixit (1987) reported that at Indore, combined use of fertilizer and FYM had recorded higher yield in soybean than in inorganic fertilizer treatment alone.

Nimje and Seth (1988) reported higher yield of soybean with increasing rates of P_2O_5 (0, 40 and 80 kg/ha) and farmyard manure (15 t/ha) increased the dry matter production in soybean. Further, they noticed significantly higher nitrogen concentration with increased levels of nitrogen upto 40 kg N per ha, whereas P and K contents were significantly increased with 80 kg P_2O_5 per ha + FYM.

At Ranchi, in a long-term experiment the average seed yield of soybean was 23 per cent lower with only N compared to control. The use of nitrogenous fertilizer alone for a long period caused deterioration of physical condition, lowered organic matter status and reduced the yield. The favourable influence of FYM together with NPK fertilizer in improving the soil fertility may be attributed to mineralization of organic N, P and K towards availability (Singh, 1989).

Badeyala and Verma (1991) recorded higher soybean yield on application of farmyard manure at the rate of 12 t per ha for the experiments conducted at mid hills of Himachal Pradesh. At Bangalore, application of FYM @ 4 t per ha significantly increased the yield in soybean (Geethakumari and Shivashankar, 1991).

Singh (1991) reported that yield in soybean was higher in the plots receiving NPK + farmyard manure. Further, they noticed higher available soil N in the same treatment. Available P was higher in the plots given

150 per cent of the standard NPK rates and lower in the control (no fertilizer plots), while available K was higher in the plots receiving NPK + FYM.

The higher photosynthetic rate and physiological efficiency of nitrogen was obtained with the application of 80 kg P_2O_5 + 10 t FYM per ha which increased the leaf area index of soybean on clay loam soil of Pantnagar (Bisht and Chandel, 1991).

Field experiments at Coimbatore indicated that, application of FYM registered significantly higher grain yield of soybean in soybean-safflower sequence and had medium available N and high available P after soybean harvest as compared to no FYM treatment (Gopalakrishnan and Palaniappan, 1992).

Reddy *et al.* (1991) stated that combined application of FYM along with recommended N and P increased all the growth parameters like plant growth, number of branches, number of leaves, leaf area and total dry matter production in greengram over other treatments.

Reddy *et al.* (1992) reported that combined application of FYM along with recommended N and P increased the nutrient uptake at all the growth stages of greengram. Nutrient content *i.e.* N, P, K in the plant tissues at harvest was also maximum with the treatment of FYM + NP.

At Bangalore in Hebbal, application of FYM @ 4 t per ha significantly increased the uptake of N, P and K in soybean. The marked increase in N uptake was due to mineralization and reduced losses through volatalization, leaching etc. (Geethakumari *et al.*, 1993).

Application of FYM @ 5 t per ha significantly enhanced the plant height, number of leaves per plant, number of pods per plant, 100-seed weight and finally the yield. The increase in growth might be ascribed to

increased availability of major as well as minor elements in soil and increase in the population of nodule forming bacteria (Jain *et al.*, 1995).

At Bangalore, during summer, application of increased level of organic matter (FYM + paddy straw) and P_2O_5 significantly increased the soybean yield (Ramamurthy and Shivashankar, 1996). Further, increase in oil and protein yield was observed with integrated application of FYM and paddy straw. Patil *et al.* (1997) reported that application of FYM @ 7.5 t per ha significantly increased the grain yield of soybean. FYM treatment at the rate of 2.5 and 5 t per ha was on par with each other.

Sharma and Mishra (1997) reported that soybean seed yield, water use efficiency, uptake of N, P, K, S, Ca and Mg, seed protein content were higher with the application of 6 t FYM + 20 kg N per ha.

Bobde *et al.* (1998) reported that higher grain yield of soybean as well as monetary returns was obtained with the application of recommended dose of fertilizer + FYM. Continuous use of FYM at 6 t per ha every year increased the yield of soybean which ranged from 361-532 kg per ha in soybean-safflower sequence (Anon., 1999).

Navale and Gaikwad (1998) reported that application of FYM @ 2.5 t per ha recorded higher growth attributes (plant height, plant spread, number of branches, leaf area per plant, LAI) of soybean. Further, the grain and stover yield increased to an extent of 24 and 13 per cent respectively over control.

Aruna and Narasa Reddy (1999) found that with every increase in the rate of application of FYM (5, 10 and 15 t/ha), LAI and dry matter production increased significantly over its lower level. The higher rate of FYM application significantly enhanced the NPK uptake by seed and haulm and seed yield of soybean over its lower level.

The studies by Babhulkar *et al.* (2000) indicated that significant improvement in soil properties and the higher yield of soybean obtained with the application of 7.5 t FYM per ha with half the recommended rates of N and P, gave 26.81 and 20.10 per cent increase over the control and the full recommended fertilizer rate respectively.

Alok Tiwari *et al.* (2002) found that application of recommended rate of N, P and K with FYM at 15 t per ha resulted in sustained yields of soybean and wheat over the years. The inclusion of FYM in the treatment schedule improved the organic carbon status and available N, P, K and S in soil, thereby sustaining the soil health.

Dikshit and Khatik (2002) at Jabalpur, while working with soybean crop noticed that application of 50 per cent recommended dose of NPK + 10 t FYM per ha enhanced the availability of N, P, K and S in soil and uptake by soybean. Further, they recorded higher energy yield (127.1 MJ/ha), protein content (49.96%), oil content (21.28%) and oil production (337.2 kg/ha) with same treatment.

A study conducted at Raipur (Chattisgarh) revealed that application of 5 t of FYM per ha resulted in significantly higher yield of blackgram (599 kg/ha) and wheat (1347 kg/ha) than without FYM. Further, the wheat equivalent yield also followed the similar trend under this treatment (Shrivastava *et al.*, 2003).

Singh *et al.* (2003) in their study at Bhopal found that application of 75 per cent NPK + 5 t FYM per ha recorded higher protein (34.93%), oil content (17.87%) and mineral content (4.93%) in soybean.

Application of recommended rate of NPK fertilizer in combination with 10 t FYM per ha resulted in taller plants (43 cm) and more number of branches per plant (5), number of pods per plant (32), 100-seed weight

(14.9 g), root length (13.1 cm), root weight (1.2 g/plant), number of root nodules (67/plant), nodule weight (0.34 g/plant) and pooled soybean seed yield (1479 kg/ha) (Paradhakar and Deshmukh, 2004).

The integration of organic (50%) and inorganic (50%) management system resulted in higher seed yield of soybean over 100 per cent inorganic and 100 per cent organic at most of the AICRP centers of soybean. At Dharwad and Pune, higher grain yield of soybean was recorded with 100 per cent organic followed by 50 per cent organics + 50 per cent inorganics (Anon., 2005a).

Deshmukh *et al.* (2005) in their study revealed that application of recommended dose of NPK (20:40:20 kg/ha) along with FYM (2.5 t/ha) gave the higher grain yield (12.49 q/ha), energy (183.60 MJ/ha) and protein (502.30 kg/ha) yield of soybean as compared to other treatments and farmers practice.

Rajshree *et al.* (2005) reported significant improvement in soil properties and higher yield of soybean with application of 7.5 t FYM per ha combined with half the recommended dose of N and P fertilizers.

Wandile *et al.* (2005) in their study observed a significant improvement in soil properties and the higher yield of soybean with the application of 7.5 t FYM per ha with half dose of N and P fertilizers.

Sanjay Kumar Nayak *et al.* (2006) found that application of FYM @ 15 t per ha had significant effect on shoot dry weight per plant, CGR at 60 DAS and RGR at 90 DAS and yield attributes except number of seeds per pod and test weight of soybean.

The literature on FYM application to crops clearly indicates that application of FYM increases the microbial activity in soil and resulted in improving the physical properties of soil (*viz.,* structural status, water

retention, bulk density of soil) which are reflected on getting higher grain, straw and biomass yields. This could be owing to higher availability of nutrients over no FYM application. Combined application of FYM with inorganic fertilizers further enhanced the yield and improved the soil fertility status.

2.4 EFFECT OF MICROBIAL INOCULANTS (*AZOSPIRILLUM* / RHIZOBIUM / VAM) ON CROP GROWTH, YIELD, QUALITY, UPTAKE OF NUTRIENTS AND NUTRIENTS STATUS IN SOIL

In recent years biofertilizers have emerged as a supplement to mineral fertilizers and hold a promise to improve the yield of crops. Biofertilizers help in increasing crop productivity by way of increased biological N fixation, enhanced availability of nutrients through solubilization especially P or increased absorption, stimulation of plant growth through hormonal action or antibiosis or by decomposition of organic residues.

2.4.1 Response of cereals to *Azospirillum brasilense* inoculation

Azospirillum brasilense, a biological asymbiotic nitrogen fixing micro-organism, has been proved and reported as beneficial and economical on several cereals and millets. *Azospirillum* being asymbiotic nitrogen fixing bacteria, contributes to soil fertility not only by supplying nitrogen to crops, but also has many other advantages. It improves the seedlings emergence, growth as well as the productivity of the crop. This biofertilizer is a low cost input and useful for finger millet to enhance the productivity and income from the crop.

At Karnal, on clay loam soil Sahab Singh *et al.* (1980) reported that inoculation of *Azospirillum brasilense* + N_{90} showed an increase in plant height, number of leaves, length and breadth of leaf and stem diameter of sorghum over the control.

In an experiment on foxtail millet (*Setaria italica*) at the Hebrew University of Jerusalem, Israel, significant increase in shoot dry weight, panicle weight and length were obtained in plants inoculated with *Azospirillum brasilense* and fertilized with optimal ammonium nitrate level. The increase in nitrogen content of inoculated plants was due to nitrogen fixation. The bacterial inoculation with *Azospirillum brasilense* also increased the branching and development of roots, the plant yield and nitrogen economy (Yorum Kapulnik *et al.*, 1981).

Application of *Azospirillum* with soil over the seed furrows showed great promise and was found to be as good as application of 10 kg nitrogen along with inoculation or 20 kg nitrogen alone in kodo millet. Thus there was a net saving of 20 kg nitrogen per ha by using *Azospirillum* as a biofertilizer at Dindori. At Dholi centre, *Azospirillum* application without nitrogen fertilizer did not increase the grain yield of cheena (Proso millet). But application of 10 kg nitrogen per ha either with seed or soil or farmyard manure and inoculation of *Azospirillum* significantly increased the grain yield. However, a dose of 20 kg nitrogen per ha produced maximum grain yield (Anon., 1985).

Venkateswarlu and Rao (1984) in an experiment conducted at Central Arid Zone Research Institute, Jodhpur, pointed out that inoculation of *Azospirillum* on pearl millet led to an increase in the formation of root hairs and lateral roots in the seedlings. The root biomass, shoot dry weight and nitrogen uptake significantly increased in inoculated plants. Also there was increase in the grain yield by 10 to 12 per cent.

On sandy loam soil, at New Delhi, Gautam *et al.* (1985) found that inoculation of *Azospirillum brasilense* and N significantly increased the plant height, tillers per plant, number of ears per m^2, length of the ear,

grains per ear, test weight, grain and stover yield of pearl millet as compared to control.

Purushothaman and Oblisami (1985) reported that *Azospirillum* inoculation enhanced the yield of pearl millet, finger millet, cotton and sorghum to the tune of 20 to 40 per cent.

Inoculation of *Azospirillum* in sierozomic soils of Hisar increased the straw yield of pearl millet to the tune of 20 per cent and grain (15%) in the arid soils of Jodhpur (Venkateshwarlu, 1985).

Vaishya *et al.* (1986) conducted an experiment on little millet (*Panicum miliare*) at Narendra Deva Agricultural University and indicated that seed inoculation with *Azospirillum brasilense* or application of 20 kg nitrogen per ha gave grain yield of 1.71 and 1.99 t per ha respectively compared with 1.14 t per ha without inoculation or nitrogen. They further reported in kodo millet that application of *A. brasilense* inoculants mixed with soil to the furrows or 20 kg nitrogen per ha gave grain yields of 0.86 and 0.99 t per ha respectively, compared to 0.65 t per ha under without inoculation or nitrogen application.

Rao and Venkateswarlu (1987) observed increase in the grain yield of pearl millet (0.64 to 0.87 t/ha) with *Azospirillum brasilense* inoculation.

Sardar Singh and Brahm Singh (1987) noticed significantly higher grain and stover yield of pearl millet with inoculation of pearl millet seed with *Azospirillum* over no inoculation. The increase in grain yield due to inoculation was to the tune of 11 per cent.

Gautam and Kaushik (1988) in their study at New Delhi in sandy loam soil revealed that inoculation with *Azospirillum* and 20 kg N per ha gave significantly higher grain yield of pearl millet. Besides, the grain

yield of pearl millet was significantly influenced due to the combined application of *Azospirillum* and VAM over control.

Pareek and Shaktawat (1988) reported that inoculation of seeds of pearl millet with *Azospirillum* did not showed any significant effect on yield and quality parameters of pearl millet due to poor organic matter and high soil pH.

Seed coating of little millet with *Azospirillum brasilense* and super sorb coating @ 20 g per kg seed along with 20 kg nitrogen, 20 kg phosphorus and weeding gave the higher grain yield in an integrated production technology study at Kanke and Semiliguda (Anon., 1989a).

It was concluded that the seed treatment with *Azospirillum* had an effect equivalent to the application of 20 kg nitrogen per ha in finger millet, in several locations over six years (from 1980 to 1985), either as seed treatment or seed treatment combined with FYM. The foxtail millet (variety Arjuna) gave higher yield with *Azospirillum brasilense*, especially in the presence of nitrogen, in a two year trial conducted at Nandyal. The influence was on both grain as well as on straw yields by increasing the number of productive tillers (Anon., 1989b).

Inoculation of pearl millet seeds with *Azospirillum brasilense* resulted in increase in tillers, heads and 1000-grain weight to the tune of 38, 44 and 31 per cent, respectively (Joshi and Rao, 1989).

Pradhan (1990) in the plateau region of Bihar on sandy loam soil, while working with finger millet noticed that yield of finger millet increased by 10 to 20 per cent over control due to *Azospirillum brasilense* in all the three years study.

Jesudas *et al.* (1992) reported that finger millet plants inoculated with *Azospirillum lipoferum* recovered more rapidly from the stress which

caused decreased leaf nitrate reductase activity and increased proline concentration.

Patil *et al.* (1992) obtained significantly higher green forage, dry matter and crude protein yields of maize with inoculation of *Azospirillum* coupled with 75 kg N per ha over control.

In a pot culture experiment, inoculating pearl millet seed with *Azospirillum brasilense* increased the grain yield and N-uptake when 40 or 80 kg N per ha was applied before sowing (Jha and Mathur, 1993).

Shankaralingappa (1993) in a field experiment at Nagamangala observed higher grain, straw yield and 1000-grain weight of finger millet with seed inoculation of *Azospirillum brasilense*, *Aspergillus awamori* and application of 100 per cent recommended fertilizer.

Alwar Arunachalam *et al.* (1995) at Killikulam reported that application of 75 per cent of recommended N as inorganic fertilizer + farmyard manure @ 5 t per ha and seed cum soil inoculation with *Azospirillum* on sandy loam soil, recorded higher plant height, number of productive tillers, ear length, grain yield of finger millet. Further, higher B:C ratio was also recorded with same treatment.

Mishra and Patjoshi (1996) noted that application of 50 per cent of the recommended NPK together with *Azospirillium* gave significantly higher growth characters (plant height, leaves/plant) yield attributes (grains/cob, 100-grain weight) grain and stover yield of maize over no fertilizer.

Chunchun Kumar *et al.* (1998) in multilocation field experiment found that simple inoculation of *Azospirillium* increased the yield of sorghum and pearl millet upto 10 to 25 per cent.

Chakraborty *et al.* (2002) obtained higher dry matter (409.8 g/m²), LAI (1.15), ear heads per m² (120.5), length of finger (7.2 cm), NPK uptake (126.2 kg/ha), grain and straw yield of finger millet (1320.7 and 2771.3 kg/ha) with *Azospirillium* + N_{80} followed by N_{80} and *Azospirillium* + N_{60}. Sole application of *Azospirillium* recorded 5.12 per cent higher grain yield than control (N_0P_0).

Ramamoorthy and Christopher Lourduraj (2002) at Coimbatore while working with finger millet on clay loam soil noticed that application of recommended N (50% through FYM and 50% through urea) and 50 per cent of recommended P and K (15 kg each per ha) along with seed inoculation of biofertilizer (*Azospirillium* and *Aspergillus* each @ 25 g per kg of seed) recorded higher values of yield attributes (productive tillers/plant, fingers/plant, finger length) and grain yield. Further, they also noticed increased B:C ratio over the farmers practice (application of complex fertilizer).

The literature brings out the fact that *Azospirillium* inoculation was more efficient in improving the crop growth and yield. Seed inoculation was found to be the best as compared to soil application.

2.4.2 Response of legumes to *Rhizobium* inoculation

Rhizobium is most extensively used as biofertilizer because of its proven ability to fix the atmospheric nitrogen by symbiosis with leguminous host plants. *Rhizobium* is a symbiotic nitrogen fixer found most effective for dicot crops like pulses and oilseeds. Soybean being a legume crop is naturally gifted with nitrogen fixing ability. Inoculation of soybean seed with *Rhizobium* is useful for enhancing the productivity of crop.

Jethmalani *et al.* (1969) obtained 40 and 50 per cent increase in the yield of Bragg and Clark 63 cultivars of soybean respectively with seed inoculation of *Rhizobium* as compared to uninoculated control.

Lokaras and Tiwari (1970) reported that significant increase in grain yield of soybean (34.6 to 81 %) due to seed inoculation of rhizobia over uninoculated control.

Seed inoculation of *Rhizobium* increased the number of pods, number of grains per pod and 1000-seed weight in soybean (Sable and Khupse, 1977).

On acidic sandy loam soil at Jorhat, Barthakur (1980) reported that inoculation of *Rhizoibum* culture resulted in 10 per cent increase in the grain yield of soybean.

Chandel *et al.* (1988) at Nainital (UP) on silty clay loam soil in their study revelaed that one and two rows of nodulated soybean association significantly increased the dry matter and grain yield of non-nodulated soybean and finger millet. Further, the beneficial effects in terms of nitrogen uptake were 61.8 and 73.1 kg N per ha with one and two rows of nodulated soybean and 32.0 and 45.1 kg N per ha to finger millet, respectively.

Seed inoculation with *Rhizobium*, increased the number of nodules, pods per plant, 100-seed weight and gave yields of 1.27 t seeds per ha in groundnut and 0.97 t in soybean, compared with 1.11 and 0.88 t, respectively, without seed inoculation (Joshi *et al.*, 1989).

Pandzou *et al.* (1990) noticed that inoculation of *Rhizobium* increased the seed yield from 21 to 41 per cent in soybean and there was no significant difference between seed treatment and soil application.

In a field trial, inoculation of soybean seeds with *Bradyrhizobium japonicum* increased the seed yield by 11.14 to 11.83 per cent.Further, number of nodules per plant and root N percentage also increased with inoculation (Chore and Shastri, 1991).

Kurundkar *et al.* (1991) in their study at Indore on vertisol found that nodulation; growth and bean yield of soybean was influenced significantly with inoculation of rhizobia. Further, number and dry weight of nodules were significantly more in all the rhizobial inoculated plants at 30 and 60 days of crop growth as compared to control.

Katiyar and Pant (1993) in their study observed higher nodule mass (25.5 mg/plant), plant dry weight (4.2 g/plant), and plant nitrogen (2.2%) by inoculation of soybean seeds with *Bradyrhizobium* inoculant.

Vara *et al.* (1994) in a field experiment at Junagadh (Gujarat) found that seed inoculation with *Rhizobium* increased the seed yield of soybean compared with no inoculation (1293 v/s 1197 kg).

Seed inoculation with *Rhizobium* alone or in combination with mycorrhizae and PSB with no fertilizer application slightly increased the number of root nodules, number of pods per plant, pod weight per plant and seed weight of soybean per plant (Kulhare *et al.*, 1996).

Prabakaran and Ravi (1996) revealed that rhizobial inoculation given to soybean had registered significant enhancement in plant biomass (1.99 g/plant), root nodulation (25/plant) and nodule biomass (87 mg/plant) over the untreated control.

At Raipur (Madhya Pradesh) on clayey soil, Sarkar and Tripathi (1996) in their study observed significantly higher N concentration in leaf, stem, pod wall and in seed due to inoculation of *Rhizobium* along

with 30 kg N and 60 kg P_2O_5 per ha. Further, the yield of soybean was also higher under $N_{30}P_{60}$ + *Rhizobium* treatment.

Rhizobium inoculation in soybean increased the soil *Rhizobium* population, nitrogen fixation, grain yield and nodule weight by 35-43 per cent (Mausumi Rayachaudhuri *et al.*, 1997).

Pramila rani and Kodandaramaiah (1997) concluded that application of an initial booster dose of 30 kg N per ha coupled with *Rhizobium* seed inoculation gave significantly higher seed yield than only with inoculated treatments in soybean. This resulted in saving of 50 per cent of the chemical fertilizer when compared with sole nitrogen treatment.

Jht *et al.* (1998) reported that *Rhizobium* inoculation resulted in significant increase in pods per plant, seeds per pod, seed yield per plant and 1000-grain weight of soybean. This might be due to increased concentration of an efficient and healthy strains of *Rhizobium* in root nodules that inturn resulted in better utilization of atmospheric nitrogen.

Krishnamohan and Rao (1998) in their study at Hyderabad on red sandy loam soil revealed that inoculation with rhizobial strains (ASR, 10, 13 and 15) significantly increased the growth interms of leaf area and dry matter production, nitrogen fixation and seed yield of soybean.

Inoculation of seeds of soybean with *Rhizobium* and incorporation of FYM one week before sowing increased the seed yield, N fixation and left a net positive N balance in soil (Muneshwar Singh *et al.*, 1998).

Rhizobium inoculation in soybean increased the seed yield by 11.87 and 13.85 per cent, straw yield by 15.87 and 18.9 per cent, protein content by 12.89 and 8.62 per cent over control during 1995 and 1996 respectively (Sudesh Kumar *et al.*, 1998).

Dubey (1999) compared effectiveness of different methods of inoculation of *Rhizobium* in soybean and found higher nodule number, weight and maximum seed yield of soybean with seed inoculation followed by soil inoculation as compared to control.

Bradyrhizobium inoculation significantly enhanced the efficiency of biological nitrogen fixation (BNF) in soybean and fixed an additional 66.1 – 74.1 kg N per ha over the control. Further, it helped in increasing the mean seed yield of soybean by 10.4 per cent (2 q/ha) through attaining early flowering, pod formation higher leaf area index, dry matter accumulation and improvement in yield traits (Praharaj and Dhingra, 2001).

Sudesh Kumar *et al.* (2001) concluded that significant increase in number of pods per plant, seeds per pod, seed index (100 seed weight) and seed yield of soybean with an increase in the levels of nitrogen, phosphorus and *Rhizobium* inoculation, which increased the seed yield of soybean by 11.87 and 13.05 per cent. This might be due to cumulative effect of rhizobium inoculation on yield attributes, which ultimately resulted in higher seed yield.

Nagar and Dadheech (2002) reported that *Bradyrhizobium* inoculation increased the seed and biological yield of soybean by 13.2 and 13.3 per cent, respectively over no inoculation. This improvement in yield might be due to cumulative effect of increased branches per plant, LAI, nodules per plant and consequently more dry matter accumulation per plant.

Taywade *et al.* (2002) in a field experiment recorded significantly higher plant dry matter at harvest, 100-grain weight and grain yield of soybean with inoculation of *Rhizobium japonicum* over control.

Inoculation of *Bradyrhizobium japonicum* strains increased the seed germination, nodulation, growth parameters (number of branches per plant, dry weight per plant) and grain yield of soybean varieties over uninoculated control (Kalhapure *et al.*, 2003).

Deshmukh *et al.* (2004) in their study at Akola (Maharashtra) revealed that *Rhizobium japonicum* inoculation increased the nodulation, dry matter production, rhizobial population and yield of soybean as compared to untreated control.

A field trial conducted by Menaria and Pushpendra Singh (2004) revealed that inoculation of *Bradyrhizobium japonicum* increased the number of nodules (29.88/plant), seed yield by 8.36 per cent, stover yield of soybean and available N in soil over no inoculation.

Chang *et al.* (2005) at Tandojam (Pakistan) studied the effect of *Bradyrhizobium japonicum* inoculation in soybean on various plant parts (roots, nodules, stems, pods, leaves and seeds) and growth stages (budding, flowering, podding and maturity. They observed higher N content in inoculated plants compared to uninoculated plants and the N content decreased later due to translocation of N for seed and protein formation.

The literature brings out the fact that inoculation of *Rhizobium* helps in improving the crop yields through biological nitrogen fixation besides improving residual fertility. The number and dry weight of nodules, N uptake, protein content and oil yield of soybean also increased with rhizobial inoculation.

2.4.3 Response of crops to VAM (Vesicular Arbuscular Mycorrhiza) application

The symbiotic association between plant roots and fungal mycelia is termed as mycorrhizae. They are mainly responsible for mobilization of phosphorus for plants. VAM posses special structures like vesicles and arbuscules within the root system. Vesicles which are sac like structure store P as phospho-lipids. VAM has shown to help plants to acquire mineral nutrients from soil especially immobile elements such as P and Zn and mobile elements such as S, Ca, K, Fe, Mg, Mn *etc.* In soils, where such elements may be deficient or otherwise less available mycorrhizal fungi increase efficiency of mineral uptake resulting in enhanced plant growth. Mycorrhizal fungi are also known to alter soil structure by increasing the extent of soil particle aggregation and structural stability (Vyas, 2006).

2.4.3.1 Cereals

Bagyaraj and Manjunath (1980) studied the effect of *Glomus fasciculatum* on the growth and nutrient uptake of finger millet, cowpea and cotton in an unsterile soil, low in available P and found higher root and shoot weight of crops inoculated with VAM over uninoculated control. The P and Zn contents of the inoculated plants were higher as compared to uninoculated control.

Muromtsev *et al.* (1990) obtained higher yield of P uptake by oat, barley with the inoculation of VAM fungus *Glomus mosseae*.

Champawat and Pathak (1993) reported that the shoot and root dry weight, P and N uptake were greater in mycorrhizal plants of pearl millet (*Pennisetum glaucum*) inoculated with *Gigaspora calospora* than in the non-mycorrhizal controls. Further, they observed slight increase in shoot and dry weight, P and N uptake in shoots and P uptake in roots

when plants were inoculated and supplied with P fertilizer in comparison with plants inoculated with *Gigaspora calospora* alone.

Inoculation of *Eleusine coracana* (Finger millet) plants with 6 different VAM fungi (*Glomus caledonium*, *G. mosseae*, *G. fasciculatum*, *G. epigaeum*, *Gigaspora calospora* and *Gigospora margariata*) increased the plant biomass, height, leaf area and absolute growth rate, but the effectiveness of the various fungi varied significantly. Further, they observed increased mineral (phosphate, nitrogen, Zn^{+2} and Cu^{+2}) content and uptake in shoots (Tewari *et al.*, 1993).

On a silty clay loam soil, inoculation of maize with *Gigaspora margarita*, *Glomus fasciculatum* and VAM mixed endophyte caused 54, 50 and 58 per cent root colonization respectively. Further, it also increased the dry matter accumulation in root at 30 days and in shoot at 30 and 45 days of plant growth. Application of P without or with mycrorhizal inoculation significantly increased the uptake of N and K over the control (Rathore and Singh, 1995).

In a pot culture experiment, inoculation of soil with VAM significantly increased shoot and root dry weight and total root length of wheat (Tarafdar, 1995).

Majjigudda and Sreenivasan (1997) found that the plant height, shoot dry biomass, seed yield, shoot P concentration and seed protein contents in wheat increased with the increase in P level upto 100 per cent of recommended P level, suggesting a net saving of 25 per cent of the recommended P with efficient VAM fungus (*Glomus fasciculatum*).

On red non-calcareous sandy loam soil, Duraisamy and Mani (2000) in their study revealed that the application of 200 per cent P_2O_5 (40 kg/ha) as rock phosphate combined with phosphobacterium and

VAM produced grain and straw yield of 1480 and 1843 kg per ha in finger millet and 365 and 462 kg per ha of grain and haulm yield in horse gram respectively in finger millet – horse gram sequence.

Roy and Rashmikumari (2002) in a pot experiment observed significant increase in growth, biomass and grain yield of VAM inoculated finger millet and kodo millet plants over control.

2.4.3.2 Legumes

Krishna *et al.* (1981) obtained two fold increase in growth of *Arachis hypogaea* inoculated with *Glomus fasciculatum* over uninoculated control. There was also significant increase in the uptake of P, Zn, Cu, Fe and Mn.

Rasal *et al.* (1988) observed a significant increase in the shoot dry weight and P uptake in vishwas cultivar of bengalgram inoculated with VAM fungi. The shoot dry weight of plants with inoculation of *Gigaspora margarita* was comparable with recommended level of P and had significantly higher P uptake than the uninoculated plants.

Mohan Singh and Tilak (1989) observed an increase in the rate of mycorrhizal development in chickpea due to inoculation with *Glomus versiformae*. The weight of nodules and number of nodules per plant were also higher in inoculated than in uninoculated plants.

Umadevi and Sitaramaiah (1991) observed higher mycorrhizal root colonization, higher root volume fresh and dry weight of shoot and root of blackgram with the inoculation of different species of endomycorrhizal fungi.

Vejsadova *et al.* (1992) found positive effects of VAM on biomass production, foliar concentration of P, Zn and Cu and dry matter yield of soybean.

VAM inoculation with different P fertilizers increased the nutrient availability, uptake and dry matter yield of soybean compared to the uninoculated P sources (Ravi and Siddaramappa, 2002).

Kumar and Chandra (2003) reported significant increase in plant dry weight and grain yield with the application of *Glomus caledonium* in mungbean.

Tufenkci *et al.* (2006) in a green house experiment observed significant effects of inoculation of VAM on the plant height, fresh and dry weights of shoot and P, K, Ca, Zn and Cu content in shoot of soybean.

The literature on VAM application to crops (cereals and legumes) clearly indicates that inoculation of VAM has positive effect on growth, biomass and grain yield of crops. This could be owing to higher availability of elements (P, K, Ca, Mg, S, Zn, Fe, Mn *etc.*,) in soil. VAM inoculation also helps in increased uptake of mineral elements.

2.5 INTERACTIVE EFFECT OF FYM, ZINC, BORON AND MICROBIAL INOCULANTS ON CROP GROWTH, YIELD, QUALITY, UPTAKE OF NUTRIENTS AND NUTRIENTS STATUS IN SOIL

The issue of micronutrient interactions between and among the various mineral nutrients, organic matter and microbial inoculants in crop production is important for balancing nutrient supplies to plants, improving growth and yield of plants and eliminating deficiencies and toxicities imposed on plant (Fageria *et al.*, 2002).

2.5.1 Cereals

Trifu (1969) showed that soaking maize seeds for 2 hours in solution containing 0.05 per cent H_3BO_3 and 0.05 per cent $ZnSO_4$ before sowing increased the absorption and accumulation of N during plant growth. The same element at 0.005 per cent decreased N accumulation.

Khanday *et al.* (1990) in their study at Palampur (HP) on silty clay loam soil reported that zinc application brought a significant increase in the nitrogen as well as in the zinc uptake in maize crop.

Gautam and Kaushik (1988) at New Delhi on sandy loam soil reported that combined application of $N_{30}P_{30}$, *Azospirillum* and VAM increased the grain yield of pearl millet over control.

Dual inoculation of *Azospirillum brasilense* and VAM fungi has synergistic effect in increasing chlorophyll content, photosynthetic rate, nitrate reductase activity and yield attributes in wheat (Panwar, 1991).

Srinivasan (1992) in his study on red lateritic soil at Vamban (TN) noticed significant increase in the yield of maize with the application of farmyard manure and zinc sulphate.

Gupta *et al.* (1993) in green house experiment using sandy soil found that zinc application increased the uptake of zinc significantly in the presence of nitrogen source i.e., ammonium sulphate in maize.

Indulkar and Malewar (1994) in their study at Latur (Maharashtra) on topic chromustart soil concluded that direct application of FYM to sorghum does not improve the yield and zinc use efficiency in medium black soil than that of 10 t of FYM per ha + 4 kg zinc per ha which recorded higher zinc uptake and yield.

Rajput (1999) in a field experiment found that application of biofertilizers (*Azospirillum* + VAM) gave 13 per cent higher yield in pearl millet than in control.

On silt loam soil at Dholi (Bihar) Sakal *et al.* (1999) concluded that application of 16 kg borax per ha in conjunction with 5 t FYM per ha was found to be an ideal combination which appreciably enhanced the cumulative grain yield response and sustained the productivity of maize – lentil cropping system. Further, significant increase of boron uptake by grain and straw of maize and lentil as well as boron content in soil at higher level of boron was noticed when borax was applied to soil either alone or in combination with FYM.

Duraisamy and Mani (2001) in their study involving an integrated package of 6.25 kg $ZnSO_4$ per ha with 12.5 kg $FeSO_4$ per ha enriched with FYM recorded 28.3 per cent increase in yield of samai (millet) over control besides accounting for better nutrition of the crop in terms of content and uptake.

Application of recommended dose of fertilizers (60:30:30 NPK kg/ha) + 5 t vermicompost per ha + 2 kg *Azospirillum* per ha + 2 kg phosphobacteria per ha + 0.125 per cent chelamin foliar spray recorded higher crop nutrient uptake and grain yield of finger millet (Raman and Krishnaprabu, 2004).

In finger millet, foliar application of $ZnSO_4$ @ 2.50 kg per ha plus borax @ 0.50 kg per ha at flowering stage of the crop recorded significantly higher vigour index of 574, 1000–seed weight of 2.40g germination (99%) and seedling dry weight (5.8 mg). Further, they observed that application of FYM @10 t per ha along with recommended NPK plus 12 kg $ZnSO_4$ per ha recorded significantly higher vigour index, seedling dry weight of shoot and root, germination per cent and test

weight (590, 5.9 mg, 100 % and 3.29 g , respectively) (Shankar *et al.*,2005).

Combined application of $ZnSO_4$ @12.5 kg per ha + borax @10 kg per ha resulted in micronutrient use efficiency (MUE) of 32.89 kg of additional yield of finger millet per kg of micronutrient applied, while the application of $ZnSO_4$ @12.5 kg per ha alone resulted in MUE of 42.4 kg and borax @10 kg per ha alone resulted in MUE of 33 kg (Anon., 2007).

2.5.2 Legumes

Shukla *et al.* (1983) found a significant improvement in oil and protein content of groundnut by the application of boron either alone or in combination with sulphur and zinc.

In groundnut, fertilization with Zn, B, Co and Mo in a medium calcareous soil, with and without rhizobium inoculation, increased the nodule number, per cent effective nodules and dry weight of nodule significantly at different stages of crop growth (Joshi *et al.*, 1987).

Jagadish Prasad and Ram (1988) in a field experiment noticed that the oven dry weight of nodules of greengram was significantly affected by Rhizobium + Zn + Cu interaction. Further, zinc application increased the oven dry weight of nodules and plants with an increase in its level.

Sojitra and Bhatt (1989) found that application of 10 kg boron and 20 kg Zn per ha increased the nodulation, plant dry weight and pod yield over control in groundnut.

Micronutrients (Zn, B, Cu and Mo) either alone or in mixture significantly increased the yield of both soybean and wheat crops over no micronutrients in soybean – wheat crop sequence (Dwivedi *et al.*, 1990).

At Tikamgarh (MP), on clay loam soil, Tomar *et al.* (1991) found that application of zinc fertilizer along with inoculation of *Rhizobium* increased the seed and pod number per plant, 100-seed weight and seed yield of soybean.

Bhuiyan and Shivashankar (1993) noticed that there was a significant increase in nodule number and nodule dry weight due to application of phosphorus, potash, molybdenum and boron at 50 kg P_2O_5, 50 kg K_2O, one kg Mo and one kg boron per ha in the presence of rhizobium strain in groundnut during the three consecutive seasons.

Application of $ZnSO_4$ at 20 kg per ha + 0.5 per cent $ZnSO_4$ as foliar spray at 40 DAS + 2.5 kg borax and 0.25 per cent as foliar spray at 50 DAS has resulted in higher pod, kernel number, oil yield and protein per cent in groundnut in addition to improving the fertility of soils (Sudarshan and Ramaswami, 1993).

Kumutha and Santhanakrishnan (1994) in their study concluded that a synergistic interaction between VA-mycorrhiza and *Bradyrhizobium* could benefit the plant system by way of dry weight, P uptake, nodulation and nitrogen fixation in soybean.

Singh (1994) in a field trial found that inoculation of soybean seeds with *Bradyrhizobium japonicum* increased the number and dry weight of nodules, organic matter accumulation in plants and seed yield. Further, he observed stimulation in the activity of native rhizobial strains resulting in a significant increase in nodulation, plant growth and seed yield of soybean with inoculation of VAM over control.

Bhuiyan *et al.* (1995) obtained significantly increased number of nodules per plant, nodule dry weight, shoot and root dry weight and seed yield of soybean with seed inoculation of *Bradyrhizobium japonicum*

compared with no inoculation. Further, they observed higher seed yield with P,K,S, Zn + inoculation as compared to control.

Application of zinc @ 10 kg + FYM at 10 t per ha significantly increased the plant height, number of pods per plant and 100-seed weight of soybean. Further, these characters in turn resulted in the higher grain yield (1514 kg/ha) over other treatments. Application of boron @ 0.5 kg + FYM @ 10 t per ha, behaved identically as zinc (Balusamy *et al.*, 1996).

Bisht and Chandel (1996) in a field trial recorded higher seed yield and protein content in soybean with application of N + P_2O_5 + K_2O + Zn.

Saxena and Chandel (1997) reported that seed yield, total biomass yield, symbiotic nitrogen fixation and organic carbon in soil after the harvest was increased significantly with micronutrients (Zn, B and Mo) application and farmyard manure application in soybean. Further, *Rhizobium* inoculation with recommended dose of N, P and K along with zinc increased the seed yield by 79.5 and 42.3 per cent over control during 1991 and 1992, respectively.

Barakah and Heggo (1998) in a green house experiment observed increase in root and shoot dry weight of soybean with dual inoculation of mycorrhizal and *Bradyrhizobium* along with the application of superphosphate. Further, they observed increased phosphatase activity, higher concentration of N, P, K, Fe, Mn, Zn and Cu in plants inoculated with both mycorrhiza and *Bradyrhizobium.* Dual inoculation of *Bradyrhizobium* and VA-mycorrhizae along with 75 per cent RDF phosphorus recorded maximum number and dry weight of nodules (38.71 /plant, 270.2 mg/plant) grain yield of chickpea (28.68 q/ha) and N and P uptake (104.75 kg N/ha; 11.34 kg P/ha) over control (Konde *et al.*, 1998).

Patra (1998) in a field experiment at Mohanpur (West Bengal) noted that application of 5 t FYM + NPK produced the higher mean seed yield of soybean (3.7 t/ha) which was 68 per cent higher than the control yield (2.2 t/ha). Further, they found that application of 2 kg B, 0.5 kg Mo and 4 kg B produced yields of 3.1, 3.1 and 2.8 t per ha respectively, which was significantly higher than the control.

Sakal *et al.* (1998) in a field trial, found that application of boron @ 2 kg per ha or Zn @ 5 kg per ha to chickpea produced grain yield response of 750 and 400 kg per ha, respectively.

Sarkar *et al.* (1998) in a field experiment noticed better physiological parameters like dry matter production, leaf area index, crop growth rate, net assimilation rate and yield components leading to higher grain yield of greengram with application of multi micronutrients (Mn, Zn, Cu, B, Mo and Fe) and followed by zinc alone compared with sole application of Mn, Cu, B, Mo and Fe.

Balachandar and Nagarajan (1999) in their study at Pudukkottai on red lateritic soil found that dual inoculation with *Glomus mosseae* and *Rhizobium* with 50 per cent recommended nitrogen fertilization resulted in maximum plant height, root length, plant biomass, number of nodules per plant, nodule weight and grain yield of greengram.

Joshi *et al.* (2000) in a field experiment noticed significant differences in branches and pod number per plant over control with application of sodium molybdate + FYM and borax @ one kg per ha alone or in combination with FYM in soybean.

Shelge *et al.* (2000) in their study revealed that application of micronutrients under the recommended level of major nutrients with FYM significantly increased the yield of soybean. Further, they reported

that application of zinc, molybdenum and boron without FYM increased the yields by 15.5 and 2 per cent respectively. With recommended level of FYM, the corresponding yield improvements due to zinc, boron and molybdenum were 45.44 and 35 per cent, respectively. Combined application of zinc + boron + molybdenum + NPK in the absence of FYM increased the relative yields by 26.38 per cent. While, the combination of zinc + boron + molybdenum + NPK + FYM increased the relative yields by 182 per cent.

Sonboir and Sarawgi (2000) reported that significantly higher uptake of nutrient in chickpea was recorded with combined application of 60 kg P_2O_5 per ha, PSB, *Rhizobium* and micronutirents which might be due to accumulation of higher concentration of nutrients in plant parts resulting in higher dry matter accumulation.

Application of 20:80:40 kg NPK per ha as soil application + 0.5 per cent $MnSO_4$ + 0.25 per cent $ZnSO_4$ + 0.02 per cent Na_2MoO_4 + 0.05 per cent borax as foliar spray resulted in higher grain yield (1832 kg/ha) stover yield (3734 kg/ha) and dry matter production in soybean at harvest (5208 kg/ha) (Thiyageshwari and Ramanathan, 1999).

Dual inoculation of *Rhizobium* and VAM improved significantly improved the plant growth of soybean and the effect was extended until the seed filling and maturity stage of the plant (Kelly *et al.*, 2001).

Dual inoculation with *Bradyrhizobium japonicum* and VAM increased the nodulation, nitrogenase activity, mycorrhizal root infection, percentage growth and macro (N, P and K) and micronutrients (Fe, Zn and Cu) contents of the plants compared to the application of each inoculum alone. The yield and yield components, protein and oil yield of soybean were significantly increased with dual inoculation (Mehasen *et al.*, 2002).

Raverkar and Tilak (2002) in their study observed that inoculation with different *Bradyrhizobium* strains had positive impact on mycorrhizal colonization by indigenous VA-mycorrhizal fungi, root nodule number, nodule dry weight, nitrogenase activity, amount of dry mass production, N and P content of soybean plant.

Dual inoculation of *Bradyrhizobium japonicum* and *Azospirillum brasilense* increased the number of nodules per plant at 30 and 60 DAS, nodule dry weight, higher rhizobial population and higher soybean yield (2856 kg/ha) compared to individual treatments with *Bradyrhizobium japonicum* (2793 kg/ha) and *Azospirillum brasilense* (2375 kg/ha). The higher yield (2916 kg/ha) and protein content (41.93%) were obtained under the treatment with *Bradyrhizobium japonicum* + urea at 30 kg N per ha (Ingle *et al.*, 2003).

Combined application of 5 kg Zn and 10 t FYM per ha increased the grain yield and uptake of NPK by soybean seed. The higher grain yield (1790 kg/ha) was recorded in Zn + FYM treatment with 18.2 per cent increase over control (1515 kg/ha) while the application of B + FYM (13.6%) was on par with seed treatment with sodium molybdate (13.1%). Further, they observed positive balance of available N, P_2O_5 and K_2O in soil when soybean fertilized either with FYM alone or along with micronutrients (Vyas *et al.*, 2003).

Wasmatkar *et al.* (2003) observed higher uptake of P (14.71 and 14.31 kg/ha), K (59.15 and 58.35 kg/ha), S (12.03 and 10.75 kg/ha) and Zn (108.23 and 101.43 kg/ha) with application of S at 30 kg per ha and Zn at 5 kg per ha respectively. Further, they recorded higher contents of oil (21.03 and 20.62 g/100 g) and protein (37.47 and 37.37%) in soybean.

Combined application of NPK + FYM at 5 t per ha + biofertilizers (*Rhizobium* or VAM) recorded higher number of pods per plant (38.45 and 37.89), seeds per pod (2.90 and 2.87), 100-seed weight of soybean in the experiments conducted during 2000 and 2001 respectively (Ranjit Singh and Rai, 2004).

Mean value for soybean yield was maximum (1951 kg/ha) for the treatment of *Bradrhizobium japonicum* + Arbascular mycorrhizae which was 18, 5.7 and 17.8 per cent increase over uninoculated absolute control, *Bradyrhizobium japonicum* inoculation and AM fungi alone respectively (Anon., 2005a).

Studies at Raipur, revealed that plant height, higher number of branches, higher value of LAI, dry matter accumulation and seed yield of soybean were found to be higher with crop residue 5 t per ha + FYM @ 5 t per ha + Zn @ 5 kg per ha application followed by FYM at 5 t per ha (Dash *et al.*, 2005).

Combined inoculation of soybean seeds with *Bradyrhizobium japonicum* + VAM showed an increase in VAM infection (28.6%), root nodulation (30.3%), fresh weight (14.5%), dry weight (15.5%) and seed weight (15.3%) of soybean compared to their use alone (Jalaluddin, 2005).

Combined application of 100 per cent NPK fertilizer, Zn, Mo, PSB and *Rhizobium* resulted in the higher number of nodules (60.2), nodule dry weight (1.19 g/plant), protein yield (885.4 kg/ha), oil yield (491.95 kg/ha) and seed yield of soybean (2165 kg/ha) (Kumar *et al.*, 2005).

Application of 50 per cent N and 50 per cent P through fertilizers + *Azotobacter chrococcum* or *Bradyrhizobium japonicum* + *Bacillus megathenium* var phosphaticum + *Glomus fasciculatum* (VAM) recorded

higher nodule dry weight, grain and stover yields of soybean and maize as compared to control and sole application of nutrient sources in soybean- winter maize crop sequence (Saini *et al.*, 2005).

The higher seed germination (100%) and vigour index of 148 was obtained with foliar application of $ZnSO_4$ @ 2.5 kg per ha and borax @ 0.5 kg in groundnut. Further, they observed that, application of FYM @10 t per ha along with soil application of $ZnSO_4$ @12.5 kg per ha recorded significantly higher vigour index, seedling dry weight, germination per cent and kernel weight (168.5, 1.72, 98% and 31.05g respectively as compared to control) (Shankar *et al.*, 2005).

Combined application of recommended NPK (30:60:0 kg/ha) + Zn at 10 kg per ha + FYM at 10 t per ha increased the values of the growth characters (plant height, leaf number, leaf area, leaf area index, branch number and total dry matter ultimately increasing the productivity of soybean (Shirpurkar *et al.*, 2005).

Shirpurkar *et al.* (2006) concluded that application of recommended dose of N, P_2O_5 and K_2O (30:60:0 kg/ha) + zinc @ 10 kg per ha + FYM @ 10 t per ha significantly contributed to in the yield and yield attributing characters (grain weight per plant, test weight, shell weight per plant) hence ultimately resulted in increased productivity of soybean.

Combined application of $ZnSO_4$ @12.5 kg per ha +borax @10 kg per ha resulted in micronutrient use efficiency (MUE) of 8.89 kg of additional yield of soybean per kg of micronutrient applied, while the application of $ZnSO_4$ @12.5 kg per ha alone resulted in MUE of 10.64 kg and borax @10 kg per ha alone resulted in MUE of 5.5 kg (Anon., 2007).

The literature on interactive behaviour of FYM, zinc, boron and microbial inoculants indicates that combined application of micronutrients, FYM and microbial inoculants had positive response on growth, yield quality and nutrient uptake in cereals and legumes. Dual inoculation of rhizobium and VAM stimulate the nodulation, dry matter nitrogen content, pod yield, root length and accumulation of phosphorus in legumes. In addition, dual inoculation of *Azospirillum brasilense* and VAM has synergistic effect in increasing chlorophyll content, photosynthetic rate and yield attributes of cereals and legumes. On equivalent zinc basis, use of zinc from organic sources is far superior to zinc sulphate. Nevertheless, because of low content of zinc, the quantities of organic materials to fill zinc needs required are abnormally large. Indeed the integration of zinc with conjunctive use of organic manures has been inevitable to develop integrated plant nutrition system which aims at maintaining soil fertility at an optimum level for sustaining the desired crop productivity.

2.6 CONJUNCTIVE USE OF FYM, MICRONUTRIENTS AND MICROBIAL INOCULANTS ON NODULATION AND SOIL MICROBIOLOGICAL PROPERTIES

Micronutrients have assumed prominence in agriculture as their deficiencies have become widespread, especially under intensive cropping systems involving progressively higher dose fertilizer application. Though micronutrients are required in limited quantities, their deficiencies as well as availability is regulated among other things by interaction with macro and micro as well as various forms of organics (FYM, biofertilizers etc.). Conjunctive use of FYM, micronutrients and microbial inoculants are known to influence the nodulation and other soil microbiological properties (Sarkar, 2003).

2.6.1 Nodulation

Micronutrients do play a significant role in crop growth as well as in the formation of nodules in legumes and nitrogen fixation. Photosynthetic bacteria require various micronutrients for growth. Micronutrient deficiencies or excess may affect nitrogen fixation in nodules or indirectly through effects on assimilate supply from the host plants.

Ruschel *et al.* (1962) observed increased nitrogen fixation due to application of boron in *Phaselous vulgaris*.

Shitao and Reisenauer (1968) studied zinc nutrition of alfalfa by growing lucerne with *Rhizobium meliloti* inoculation in solution culture containing variable levels of zinc and observed many small cylindrical nodules in zinc deficient plants, whereas plants grown with adequate supply produced the nodules that were larger in size.

Ruschel *et al.* (1969) studied the effects of seed pelleting with boron, molybdenum and zinc on symbiotic nitrogen fixation by soybean and found that seed pelleting treatments generally increased nitrogen fixation.

Tringoso and Fassbender (1974) reported that application of boron and molybdenum improved nodule production in four tropical legumes.

Childiyal *et al.* (1975) observed positive response to zinc application in nodule formation and total dry matter production in mungbean.

Soil application of 8 kg zinc per ha to soybean crop at 50 per cent flowering stage was found to increase nodule dry weight per plant (Haque *et al.*, 1980).

Golakiya and Patel (1986) showed the effects of boron application on yield and yield component in groundnut and found that boron application produced favourable effects on nodule count.

Joshi *et al.* (1987) showed that application of 20 kg $ZnSO_4$ per ha had improved the nodulation and percentage of effective nodules in groundnut.

Kulkarni *et al.* (1989) opined that application of 10 kg borax per ha gave maximum nodule number and nodule dry weight of groundnut compared to control. Further, they reported that soil application of $ZnSO_4$ @ 20 kg per ha has improved the nodulation by 35.3 per cent and nodule dry weight by 17.2 per cent and found significant at 60 days of growth as compared to control.

Anil *et al.* (1990) reported that application of 5 ppm Zn stimulated number of nodules per plant dry biomass of nodule, nitrogenase activity and nitrogen per cent in root and shoot of chickpea.

Sarkar and Aery (1990) reported that application of 10 µg per g zinc in soybean had substantially increased the nodule dry weight and nodule number but higher concentration of zinc had adversely affected the nodulation.

In a field trial at Gazipur (Bangladesh) Haider *et al.* (1995) observed higher number and weight of nodules per plant and seed yield of soybean with inoculation of *Bradyrhizobium japonicum* strains G 11-7 and application of 20 kg N per ha.

Vedram *et al.* (2002a) at Kanpur on Ustochrepts (inceptisol), while working with mungbean crop noticed that nodule number per plant, dry weight of nodules, leg-haemoglobin in fresh weight of nodules and nitrogen content of nodules were increased significantly up to flowering

stage due to application of sulphur, zinc and dual inoculation of Rhizobium and *Azotobacter* as compared to control.

Inoculation of *Bradyrhizobium japonicum* with 40 kg K_2O per ha and 5 kg boron gave the maximum mean nodule number (39/plant) mean nodule mass (95 mg/plant), mean shoot drymass of soybean (6.3 g / plant). At Indore this treatment produced 2131 kg per ha of soybean seeds which was 41, 21.7 and 9.5 per cent higher over uninoculated control, single inoculation with *Bradyrhizobium japonicum* and *Bradyrhizobium japonicum* + 40 kg P_2O_5 per ha respectively (Anon., 2005a).

2.6.2 Soil microbial population and biomass

Soil microbial biomass is defined as the living microbial component of soil, which includes bacteria, fungi, algae, actinomycetes and micro fauna (i.e. soil insects). The soil microbial biomass is also referred to as active soil organic matter pool and is related to quantity, type and placement of organics, microbial inoculants and micronutrients application. It is important to determine optimum diversities of soil microbial population in agricultural system for their sustainable management. Microorganisms form a vibrant living community in the soil contributing to a number of nutrient transformations. They are involved in organic matter decomposition, N_2 – fixation, solubalization and immobilization of several major and minor nutrients (Alexander, 1991). Microbes also play an important role in soil borne disease control and plant growth promotion through secretion of hormones and enzymes (Venkateswarlu and Srinivasarao, 2004)

The additions of organic amendments increased microbial biomass though the organic carbon content of the soil did not increase (Sneh Goyal *et al.*, 1984).

Populations of bacteria, actionomycetes, fungi and rhizobia in the soil were higher with a combination of NPK + FYM. Further, they observed higher N uptake by soybean plant and soil + plant biological N fixation with the application of NPK + FYM (Chouksey *et al.*, 1995).

Manna *et al.* (1996) opined that application of FYM at 4 t per ha increased the microbial biomass but further additions of FYM reduced the rates of biomass turnover. The N and P contents and microbial biomass were higher under soybean than under wheat crop.

Determination of microbial biomass after harvesting showed that organic manure addition and *Rhizobium* inoculation increased both biomass C and biomass N compared with no inoculation. Increasing compost rates increased soil biomass, while soil organic matter, total C and available N contents were increased over the control treatment, particularly with inoculation at the end of the growing season (Moharram *et al.*, 1999).

In a green house experiment, application of FYM along with different sources of nitrogen to soybean resulted in increase in the microbial biomass (Anon, 2000b).

Population of diversified microbes (bacteria, fungi and azotobacter) greatly influenced at pre-flowering stage due to application of sulphur, zinc and dual inoculation of rhizobium and azotobacter as compared to control in comparison to other stages of study in mungbean (Vedram *et al.* 2002a).

The population of soil microorganisms *viz.,* bacteria (55.3 $X10^5$ cfu/ g soil), fungi (30 $X10^4$ cfu/ g soil) and actionomycetes(16 X 10^3 cfu/g soil) was higher in NPK + Zn (12.5 kg/ha)+B (10 kg/ha) applied

treatment at 50 per cent flowering in soybean. Further, similar trend was observed at the harvest of the crop (Anon., 2007).

Though plethora of literature is available on rhizosphere micro organism playing growth stimulating role, no systematic research have so far been conducted to asses their relationship on the mobilization and uptake of micronutrients under simulated/controlled (*in vitro*) conditions or in natural habitat (*in vivo*) to know the complementary role expected to be played by these special group of microorganisms in plant nutrient in general, micronutrient amelioration in particular.

2.6.3 Soil enzymes

The specific roles of various micronutrients in plant and microbial growth processes are not well documented. However, it is proved that several of these trace elements have specific participation in enzymatic process of plant metabolism. For example copper, iron and molybdenum are capable of acting as electron carriers in enzyme systems which bring about oxidation and reduction in plant system. Such essential reactions for the crop for its development and reproduction will be hindered in the absence of micronutrients. While, zinc and boron are characterized by variable valencies and their involvement in enzymatic reactions with fixation of molecular nitrogen and reduction of nitrates. They act as intermediaries in the transfer of electron and hydrogen to molecular nitrogen. Zinc also plays a pivotal role in protein synthesis and formation of some growth hormones. Similarly, boron increases the rate of water absorption, root growth, translocation of sugars and differentiation of tissues particularly in growing tips. It also helps in germination and growth of pollen grains and also development of pollen tube, facilitating fertilization in crop plants (Rattan *et al.,* 2003; Shankhe *et al.,* 2004).

Enzyme phosphatases represent a broad range of intracellular as well as soil accumulated activities that catalyze the hydrolysis of both esters and anhydrites of phosphoric acid. Organic matter acts as the main source of organic P in the soil (Speir and Ross, 1978).

Activities of all three enzymes (dehydrogenase, alkaline phosphatase and urease) were positively correlated with biomass N and P with the application of FYM @ 4 t per ha. There was significant correlation between soil organic carbon and microbial biomass C, N dehydrogenase and urease activities (Manna *et al.*, 1996).

Singaram and Kamalakumari (1995) in a long term experiment at Coimbatore observed maximum enzyme activity (Amylase, catalase, cellulase, dehydrogenase, phosphatase and urease) with FYM application.

Increased soil enzymatic activities (urease, phosphatase dehydrogenase, aryl, sulphatase and catalase) were observed due to different sources of organic manures (FYM and poultry manure) application. Soil enzymatic activities were found to be more pronounced in the rhizosphere soil than the non rhizosphere soils (Anon., 1997a).

In a green house experiment, application of FYM along with different sources of nitrogen to soybean resulted in increased soil enzymatic activities. (Anon, 2000b).

The activity of enzymes *viz.,* dehydrogenase (192 µg TPF/ g soil/24 h), urease (50 µg NH_4-N/ g soil/2h), acid and alkaline phosphatase activity (180 and 69 µg PNP /g soil /h) was higher in NPK + Zn (12.5 kg/ha) +B (10 kg/ha) applied treatment followed by NPK+ FYM treatment at 50 per cent flowering in soybean based cropping system. The activity of soil enzymes was minimum in the treatments supplemented only with

NPK. Similar trend of soil enzymes activity was also observed at the time of harvest indicating that application of zinc and boron with recommended dose of NPK has encouraged the activity of enzymes to a greater extent followed by application of FYM with NPK (Anon., 2007)

The literature brings out the fact that the impact of various forms of organics on nutrient management in general and conjunctive use of organics, microbial inoculants and micronutrients (Zn and B) on their availability in soil and uptake by plants in particular suggest that there has to be a greater understanding and appreciation of the special role that the organics can play a major role in micronutrient nutrition and their management in a soil –rhizosphere-plant continuum which helps in sustaining the long term soil fertility and agricultural productivity. Further, it helps in better nodulation, nitrogen fixation and has diversified microbial populations in the rhizosphere. These are known to influence the plant growth by breaking down minerals and organic matter improving plant nutrition by forming symbiotic associations, suppressing plant pathogens and producing growth regulators, toxins and enzymes which are useful in one or the other way in promoting the growth and development of crops. The activities of enzymes are also positively correlated with biomass.

2.7 RESPONSE OF CEREAL–LEGUME AND LEGUME-CEREAL BASED CROP ROTATIONS ON CROP GROWTH, YIELD, UPTAKE OF NUTRIENTS AND NUTRIENTS STATUS IN SOIL

Legumes are wonderful gifts of nature. Their unique ability of biological nitrogen fixation, deep root system, mobilization of insoluble soil nutrients and bringing qualitative changes in soil physical properties, makes them as soil fertility restores and thereby benefits the succeeding non leguminous crop (Morey and Begde, 1982). The practice of cereal – cereal rotation continuously might have an adverse effect on

physico-chemical properties and fertility status of soil. Inclusion of legumes in the rotation improves the soil fertility better than cereal – cereal rotation.

The yield of greengram and blackgram were significantly increased with application of N upto 20 kg per ha and also with *Rhizobium* inoculation. Further, the yield of succeeding wheat crop was higher after both these pulses as compared to fallow (Yadav and Singh, 1986).

At Hyderabad, on *alfisols*, Das *et al.* (1991) reported that inclusion of short duration legumes viz., greengram, cowpea and groundnut helped to increase the yield of succeeding sorghum crop. The higher organic carbon and available phosphorus status in soil due to preceding leguminous crop might have helped in increasing sorghum yield. Pearl millet yield tended to increase by seed inoculation with Azospirillum and preceded by legumes.

Kurlekar *et al.* (1993) in their study concluded that application of legume-cereal (Soybean-Wheat) sequence with 100 per cent recommended fertilizer dose to both the crops was more remunerative and exerted beneficial effect in maintaining the available N, P_2O_5 and K_2O status of soil as compared to initial soil fertility status than cereal-cereal (Sorghum – Wheat) sequence.

Ghosh and Singh (1994) in their study at Pantnagar on sandy loam soil concluded that cowpea for fodder was more potent in improving the soil N status and productivity of subsequent maize crop.

Pawar and Jadhav (1995) observed positive N and P balance under groundnut – sorghum sequence, whereas balance of these nutrients was negative under fallow-sorghum sequences.

In legume-pearl millet cropping sequences, cluster bean (*Cyamopsis tetragonoloba*) preceding pearl millet was more productive than mungbean (*Vigna radiata*) or moth bean (*Vigna aconitifolia*) (Joshi, 1997).

Cropping systems containing mungbean or cluster bean with pearl millet improved the grain yield of pearl millet to the tune of 37 and 65 per cent and 68 and 101 per cent in two years respectively than continuous pearl millet (Praveen Kumar *et al.*, 1997).

Sharma and Bhardwaj (1998) reported that application of 90 kg P_2O_5 per ha along with 2.3 kg zinc increased wheat grain yield by 12 per cent compared to control. Further, they noticed significant residual effect of zinc application on the seed yield of soybean from 15.5 to 18.7 – 19.5 q per ha.

Prasad *et al.* (2000) in a field experiment involving legume-wheat sequences found that sequences having legumes resulted in higher N use efficiency (32.3%), N-uptake efficiency (95.5%), N utilization efficiency (34.9%), available N-use efficiency (53%) and N available efficiency (90%) than its corresponding values under rice –wheat system.

Yadav *et al.* (2002) in their study revealed that use of FYM and green leaf manure along with inorganic fertilizers improved the soil health by enhancing N and P_2O_5 content in soil. Further, they also observed that (legume based crop rotation) mungbean - pearl millet crop rotation enhanced the nutrient pool in soil as compared to pearl millet – mungbean cropping system.

Gajanan *et al.* (2003) in a field experiment involving groundnut-finger millet rotation observed increase in the yield by 91 per cent in control, 34 per cent in FYM @ 10 t per ha, 30 per cent in FYM+50 per

cent NPK, 26 per cent in FYM+100 per cent NPK and 86 per cent in only NPK treatment as compared to monocropping of finger millet.

Inclusion of legume crop in cereal based cropping system significantly enhanced the available soil nutrient status (Bajpai *et al.* 2004).

Ramesh and Sammi Reddy (2004) observed higher wheat productivity when it was preceded by sole soybean at 100 per cent RDN. Further, they also recorded higher uptake of N (519.4 kg/ha) with the same sequence.

Dhull *et al.* (2005) found that soil organic C and total N level increased by taking three crops or including green manure in the rotation than taking two crops. Microbial biomass C and dehydrogenase activity were higher in pearl millet - wheat-green manure (legume) rotation and was lower in pearl millet- wheat rotation.

Soil application of $ZnSO_4$ @ 12.5 kg per ha + borax @ 10 kg per ha along with recommended NPK recorded significantly higher plant height at 60 DAS (27.8 and 29.9 cm), number of branches per plant at harvest (5 and5.5) number of leaves per plant at harvest (27.5 and 29), number of pods (28 and 29 /plant), 100- seed weight (11.3 and 12.05 g), seed yield (10.3 and12 q/ha) halum yield (9.4 and10 q/ha) of soybean as compared to control in case of finger millet–soybean and soybean - soybean based cropping system respectively (Anon.,2007).

Soil application of $ZnSO_4$ @ 12.5 kg per ha + borax @ 10 kg per ha along with recommended NPK recorded significantly higher number of fingers per ear head (7.07 and 7.14), finger length (6.98 and 7.24 cm), grain yield (30. 3 and 31.4 q/ha) and straw yield (40.5 and 45.9 q/ ha) of

finger millet in finger millet – finger millet and pigeon pea- finger millet based cropping system respectively (Anon., 2007).

Combined application of $ZnSO_4$ @ 12.5 kg per ha + borax @ 10 kg per ha along with recommended NPK recorded significantly higher uptake of N (49.5 kg/ha), P (10.8 kg/ha), K (48.7 kg/ha), Zn (152 g / ha) and B (73 g/ha) in finger millet as compared to control. Further, soil application of $ZnSO_4$ @ 12.5 kg per ha + borax @ 10 kg per ha along with recommended NPK recorded significant increase in Zn(1.19 ppm) and B(0. 55ppm)status after harvest of finger millet in finger millet –finger millet based cropping system(Anon.,2007).

Soil application of $ZnSO_4$ @ 12.5 kg per ha + borax @ 10 kg per ha along with recommended NPK recorded significantly higher uptake of N (40.5 kg/ha), P (6.1 kg/ha), K (19.8 kg/ha), Zn (119 g/ha) and B (29 g/ha).The higher value of organic carbon was noticed in all the treatments due to soybean based cropping system. Further, combined application of $ZnSO_4$ @ 12.5 kg per ha + borax @ 10 kg per ha along with recommended NPK resulted in significant increase in Zn and B status after harvest of soybean in soybean-soybean based cropping system (Anon., 2007).

The literature brings out the fact that the practice of legume-cereal rotation will improve the soil fertility by maintaining the available N, P_2O_5 and K_2O status of soil and thereby benefit the succeeding non leguminous crop. The practice of cereal-cereal rotation continuously might have an adverse effect on physico-chemical properties and fertility status of soil.

2.8 ECONOMICS OF CROPPING SEQUENCES UNDER DIFFERENT NUTRIENT MANAGEMENT SYSTEMS

Any technology has to be technically feasible and economically viable to reach farmer's fields. Therefore, the economic analysis of the results are very important. This also gives a clear idea about the optimum level of inputs that could be recommended to obtain maximum profit.

Ramaiah *et al.* (1970) reported that application of 35 kg P_2O_5 per ha in finger millet resulted in higher response to applied P (9.54 kg grain per kg $P_2O_{5)}$ and the net returns per kg P_2O_5 was Rs.5.72.

Sinha *et al.* (1990) reported that the gross return, net return and B:C ratio differed among different fertilizer treatments. They were maximum when crop received 1.2 kg per ha as borax in combination with 20 kg S per ha as zinc sulphate. This was mainly due to the higher rape seed yield obtained under this treatment.

Gopal Gowda (1991) reported that application of zinc @ 5 ppm to soil in groundnut crop was a quite viable technology to benefit the farming community as it resulted in extra returns of Rs. 5120 per ha.

Keshwa and Jat (1991) in their study concluded that application of Zn @ 10 kg per ha in pearl millet gave the higher gross return and net profit (Rs. 12,285 and 8,270); the lowest being at the control (Rs. 11,583 and 7878).

Tomar *et al.* (1991) found that *Rhizobium* inoculation and 25 kg Zn per ha both singly and in combination gave significantly higher net return in soybean compared to control.

Manohar *et al.* (1992) in their study revealed that application of Zn @ 10 kg per ha gave net profit of Rs. 529.10 over no Zn application in fodder pearl millet.

Patel and Patel (1992) showed that application of 25 kg Zn + 10 t FYM per ha to maize crop gave maximum total return compared to no Zn (Rs. 10,740) and 25 kg $ZnSO_4$ per ha alone.

Sudarshan and Ramaswami (1993) in a field experiment concluded that in addition to NPK, soil application of $ZnSO_4$ at 20 kg per ha + 0.5 per cent $ZnSO_4$ foliar spray along with 2.5 kg borax through soil + 0.25 per cent borax as foliar spray could be recommended for getting higher net return in groundnut and best B:C ratio and for maintaining soil fertility.

Singh and Singh (1995) observed that application of 20 kg zinc oxide per ha in soybean could decrease the net return numerically in rainy season.

Basavaraju and Gururaj Rao (1997) recorded higher net income (Rs. 7642/ha) and B:C ratio (3.17) from finger millet with application of 50 per cent N through FYM and 50 per cent NPK as compared to a net income of Rs. 6,931 and B:C ratio of 3.03 in case of recommended NPK through fertilizers. Combined application of *Rhizobium*, PSB and FYM recorded higher net return of Rs. 3599 per ha in chickpea (Gupta and Namdeo, 1997).

In soybean and potato cropping system, combined application of FYM with fertilizer recorded higher net returns (Rs. 9338 and Rs. 20,308/ha, respectively) from soybean and potato than inorganic fertilizer alone (Rajput *et al.* 1995).

Sanjay Kumar and Prasad (1999) reported a saving of 25 kg N per ha in cereal cultivation was possible, when it is grown as a succeeding crop to legume and that the application of 75 kg N per ha to wheat produced a B:C ratio similar to that of application of 100 kg N per ha.

In a study at Majhera (Uttar Pradesh), Singh (1999) found that return per rupee investment in FYM application to finger millet @ 0,5, 7.5 and 1 t FYM per ha were 0.97, 1.07 1.15 and 1.17 respectively. The increase in the dose of FYM beyond 7.5 t per ha was not significant due to increased cost incurred on FYM application

Application of 40 kg N + 20 kg P_2O_5 + 20 kg Zn SO_4 per ha in pearl millet resulted in higher gross return (Rs. 13047 / ha) (Gupta *et al.*, 2001).

Pannase *et al.* (2001) observed that inoculation of *Rhizobium* or PSB cultures @ 5 g per kg seeds either alone or in combination of both proved superior than absolute control (no use of plant nutrition) with regard to net return of soybean.

Subramaniyan *et al.* (2001) found that combined application of $ZnSO_4$ @ 5 kg per ha + borax @ 5 kg per ha + ferrous sulphate @ 10 kg per ha registered a maximum net return of Rs. 20,085 per ha and a B:C ratio of 1.53 in groundnut.

Inoculation of *Rhizobium* increased the seed yield of soybean by 11.87 and 13.05 per cent with higher B:C ratio of 2.78 and 2.96 during 1995 and 1996 respectively (Sudesh Kumar *et al.* 2001).

Mohan Kumar (2002) noticed higher net return (Rs. 27,262/ ha) and B:C ratio (2.32) with the application of 100 per cent N, P_2O_5, K_2O, S + Zn + B+ M_0 + *Rhizobium* + PSB in soybean.

Jakhar *et al.* (2006) reported that the net return of pearl millet increased significantly with increase in the level of applied zinc upto 5 kg per ha in both the years. The net return (Rs. 11,138 and Rs. 12,277/ha) was 15.56 and 12.85 per cent higher over 0 kg zinc per ha in 2000 and 2001, respectively.

Soil application of $ZnSO_4$ @12.5 kg per ha +borax @10 kg per ha along with recommended NPK recorded higher B:C ratio of 2.31 and 1.43 as compared to application of recommended NPK + FYM(1.91 and 1.23) and only NPK (2.34 and 1.7) in finger millet and soybean, respectively (Anon., 2007)

From the above review, it could be concluded that combined application of organic, inorganics, micronutrients and microbial inoculants have significant and positive role in achieving the higher gross returns, net returns and B:C ratio in different crops.

MATERIAL AND METHODS

III. MATERIAL AND METHODS

A field experiment was conducted to study the relative response of Finger millet-Soybean rotation to application of zinc, boron and microbial inoculants at the All India Coordinated Research Project for Dry land Agriculture (AICRPDA) Unit, Gandhi Krishi Vignana Kendra (GKVK), University of Agricultural Sciences (UAS), Bangalore, during *kharif* seasons of 2005 and 2006. The details of material used and experimental techniques adopted during the course of investigation are furnished in this chapter.

3.1 EXPERIMENTAL SITE

The experiment was conducted at All India Coordinated Research Project for Dry land Agriculture Unit, UAS, GKVK, Bangalore. The centre is situated in the agro-climatic zone V (Eastern dry zone) of Karnataka at 12°58' North latitude and 77°35' East longitude with an altitude of 930 m above mean sea level.

3.2 SOIL CHARACTERISTICS OF THE EXPERIMENTAL SITE

The soil of the experimental site was red sandy clay loam in texture classified under the order *Alfisols*, Vijapura series, isohyperthermic family of Kandicpaleustalfs. Random soil samples from the experimental area were collected to a depth of 20 cm before sowing and composite sample was analyzed for important physical and chemical properties. The values obtained along with the methods employed for their estimation are furnished in Table 1.

The soil of the experimental site was red sandy loam in texture (coarse sand 36.10%, fine sand 28.60%, silt 6.50% and clay 28.80%) with a bulk density of 1.59 Mg/m^3. The soil pH was slightly acidic (5.8) having low cation exchange capacity (7.52 C mol/kg) with an electrical

Table 1. Physical and chemical properties of soil in the experimental site (AICRPDA, Bangalore)

Sl. No.	Particulars	Values obtained	Methods employed
I	**Physical properties**		
1	**Mechanical analysis (% oven dry weight basis)**		
a.	Coarse sand (%)	36.10	International pipette method (Piper, 1966)
b.	Fine sand (%)	28.60	
c.	Silt (%)	6.50	
d.	Clay (%)	28.80	
	Textural class	Red sandy clay loam	
2	Bulk density (Mg/m^3)	1.59	Core sampler method (Piper, 1966)
II	**Chemical properties**		
1	Soil pH (1:2.5 soil water suspension)	5.8	Potentiometric method (Piper, 1966)
2	Cation exchange capacity (C mol(P^{+})/kg)	7.52	Ammonium acetate saturation method (Piper, 1966)
3	Electrical conductivity (dS/m)	0.075	Conductivity bridge (Jackson, 1967)
4	Organic carbon (%)	0.50	Walkely and Black wet oxidation method (Jackson, 1967)
5	Available nitrogen (kg/ha)	238.00	Alkaline permanganate method (Subbaiah and Asija, 1959)
6	Available phosphorus (P_2O_5 kg/ha)	106.00	Olsen's method (Jackson, 1967)
7	Available potassium (K_2O kg/ha)	168.00	Flame photometer method (Jackson, 1967)
8	DTPA extractable Zn (ppm)	0.54	Atomic absorption spectrophotometer (Lindsay and Norwel, 1978)
9	Available boron(ppm)	0.43	Azomethine – H reagent method (Hatcher and Wilcox ,1950).

conductivity of 0.075 dSm^{-1}. The organic carbon content was 0.50 per cent. The soil was low in available nitrogen (238.7 kg /ha), high in available phosphorus (106.5 kg/ ha) and medium in available potassium (168 kg /ha). DTPA extractable zinc and hot water soluble boron were 0.54 and 0.43 ppm, respectively, and were found to be deficient.

3.3 CLIMATIC CONDITIONS

The normal as well as actual weather data on total rainfall, maximum and minimum temperature and relative humidity, wind speed and daily bright sunshine hours and open pan evaporation that prevailed during the period of experimentation are presented in Table 2 and depicted Fig.1, 2 and 3.

3.3.1 Normal climatic conditions

The normal annual rainfall of GKVK was 916.5 mm. The major portion of rain was received during May to November with two peaks in the months of September and October.

The mean maximum air temperature ranged from 26.1°C to 33.7°C and mean minimum air temperature ranged between 14.0°C to 20.5°C. The highest mean temperature (33.7°C) recorded during April and it was followed by May (33.1°C).

The mean monthly relative humidity ranged from 52 per cent in March to 73.5 per cent in August. The mean monthly open pan evaporation gradually decreased from April to December (from 7.8 to 4.6 mm). The mean wind speed ranged from 5.7 to 13.3 km per hour. The mean monthly maximum sunshine hours was maximum during April (9.7 hr/day) followed by December (7.5 hr/day).

Table 2. Meteorological data indicating normal (1972-2004) actual (2005) and deviation of rainfall and temperature (maximum and minimum) from the normal during the experimental period at GKVK, Bangalore

Year/months	Total rainfall (mm)			Mean maximum temperature (°C)			Mean minimum temperature (°C)		
2005	N	A	D	N	A	D	N	A	D
January	1.6	2.0	0.4	27.2	28.3	1.1	14.0	14.7	0.7
February	11.0	1.8	-9.2	29.8	30.4	0.6	15.5	15.2	-0.3
March	11.9	10.2	-1.7	32.6	32.8	0.2	17.9	17.2	-0.7
April	42.6	105.4	62.8	33.7	32.4	-1.3	20.4	19.6	-0.8
May	97.5	64.6	-32.9	33.1	33.9	0.8	20.5	21.0	0.5
June	82.6	40.2	-42.4	29.6	30.2	0.6	19.4	20.0	0.6
July	100.5	122.4	21.9	28.2	28.7	0.5	18.9	19.6	0.7
August	125.5	249.2	123.7	27.6	27.7	0.1	18.7	19.0	0.3
September	208.4	198.2	-10.2	28.1	27.6	-0.5	18.7	19.2	0.5
October	168.1	523.6	355.5	27.7	26.8	-0.9	18.2	18.8	0.6
November	53.5	52.4	-1.1	26.6	25.0	-1.6	16.6	16.1	-0.5
December	13.4	4.4	-9.0	26.1	25.9	-0.2	14.4	14.3	-0.1
Total	916.50	1374.4							

N = Normal (average of 1972-2004)
A = Actual (2005)
D = Deviation from the normal

Table 2. Meteorological data indicating normal (1972-2004) actual (2005) and deviation of relative humidity, evaporation, wind speed and sunshine hours from the normal during the experimental period at GKVK, Bangalore (Contd.....)

Year/months	Mean relative humidity (%)			Pan evaporation (mm)			Mean wind speed (km/hr)			Mean sunshine (hr)		
2005	**N**	**A**	**D**	**N**	**A**	**D**	**N**	**A**	**D**	**N**	**A**	**D**
January	64.0	67.0	3.0	5.2	5.1	-0.1	7.2	6.8	-0.4	9.0	8.4	-0.6
February	57.5	61.5	4.0	6.4	5.7	-0.7	7.1	8.2	1.1	9.6	9.4	-0.2
March	52.0	57.0	5.0	7.7	8.7	1.0	7.1	7.7	0.6	9.7	9.2	-0.5
April	55.5	58.5	3.0	7.8	6.5	-1.3	7.0	6.8	-0.2	9.1	7.5	-1.6
May	60.0	59.5	-0.5	7.3	7.6	0.3	8.6	8.2	-0.4	8.5	7.9	-0.6
June	69.0	66.5	-2.5	6.2	5.6	-0.6	13.3	12.9	-0.4	5.9	5.3	-0.6
July	72.5	71.0	-1.5	5.5	4.6	-0.9	12.7	12.7	0.0	4.5	3.4	-1.1
August	73.5	73.0	-0.5	5.0	4.6	-0.4	10.9	11.2	0.33	4.8	4.7	-0.1
September	72.5	73.0	0.5	5.2	4.5	-0.7	7.2	9.0	1.8	6.0	5.5	-0.5
October	72.5	76.0	3.5	4.8	3.7	-1.1	5.7	5.1	-0.6	6.2	4.0	-2.2
November	71.5	74.0	2.5	4.5	4.2	-0.3	6.4	7.1	0.7	6.6	5.2	-1.4
December	68.0	70.5	2.5	4.6	4.4	-0.2	7.2	6.5	-0.7	7.5	7.7	0.2

N = Normal (average of 1972-2004)
A = Actual (2005)
D = Deviation from the normal

Table 2. Meteorological data indicating normal (1972-2005) actual (2006) and deviation of rainfall and temperature (maximum and minimum) from the normal during the experimental period at GKVK, Bangalore (Contd...)

Year/months	Total rainfall (mm)			Mean maximum temperature (°C)			Mean minimum temperature (°C)		
2006	N	A	D	N	A	D	N	A	D
January	1.6	0.0	-1.6	27.3	27.6	0.3	14.0	13.5	-0.5
February	10.7	0.0	-10.7	29.8	29.7	-0.1	15.5	11.8	-3.7
March	11.9	91.8	79.9	32.6	31.3	-1.3	17.8	18.0	0.2
April	44.5	15.6	-28.9	33.7	33.5	-0.2	20.4	21.1	0.7
May	96.5	130.6	34.1	33.1	32.3	-0.8	20.5	20.5	0.0
June	81.4	112.6	31.2	29.6	29.2	-0.4	19.4	19.6	0.2
July	101.1	84.4	-16.7	28.2	28.1	-0.1	18.9	19.3	0.4
August	129.1	63.2	-65.9	27.6	28.5	0.9	18.7	19.4	0.7
September	208.1	61.0	-147.1	28.1	29.2	1.1	18.8	19.4	0.6
October	178.6	36.0	-142.6	27.7	28.8	1.1	18.2	18.7	0.5
November	53.4	111.8	58.4	26.6	27.0	0.4	16.6	17.8	1.2
December	13.1	1.8	-11.3	26.1	26.4	0.3	14.4	13.70	-0.7
Total	930	708.8							

N = Normal (average of 1972-2005)
A = Actual (2006)
D = Deviation from the normal

Table 2. Meteorological data indicating normal (1972-2005) actual (2006) and deviation of relative humidity, evaporation, wind speed and sunshine hours from the normal during the experimental period at GKVK, Bangalore (Contd...)

Year/months	Mean relative humidity (%)			Pan evaporation (mm)			Mean wind speed (km/hr)			Mean sunshine (hr)		
2006	**N**	**A**	**D**	**N**	**A**	**D**	**N**	**A**	**D**	**N**	**A**	**D**
January	64.0	64.0	0	5.2	5.3	0.1	7.2	6.7	-0.5	8.9	9.5	0.6
February	57.5	61.0	3.5	6.3	6.4	0.1	7.1	6.7	-0.4	9.6	10.6	1.0
March	52.0	61.0	9.0	7.7	7.6	-0.1	7.1	6.7	-0.4	9.7	9.1	-0.6
April	55.5	61.0	5.5	7.7	7.9	0.2	7.0	6.2	-0.8	9.1	8.5	-0.6
May	60.0	63.0	3.0	7.3	7.1	-0.2	8.6	9.3	0.7	8.5	8.1	-0.4
June	69.0	69.5	0.5	6.2	5.2	-1.0	13.3	10.6	-2.7	5.8	6.7	0.9
July	72.5	71.0	-1.5	5.5	4.7	-0.8	12.7	14.1	1.4	4.5	4.6	0.1
August	73.5	71.0	-2.5	5.0	4.7	-0.3	11.0	11.1	0.1	4.8	5.2	0.4
September	72.5	69.0	-3.5	5.2	4.6	0.6	7.3	9.0	1.7	6.0	6.1	0.1
October	72.5	69.5	3.0	4.7	4.6	-0.1	5.7	8.0	2.3	6.2	6.5	0.3
November	71.5	74.0	2.5	4.5	4.4	-0.1	6.4	7.1	0.7	6.5	6.1	-0.4
December	68.0	71.0	3.0	4.6	4.5	-0.1	7.2	8.1	0.9	7.5	6.2	-1.3

N = Normal (average of 1972-2005)
A = Actual (2006)
D = Deviation from the normal

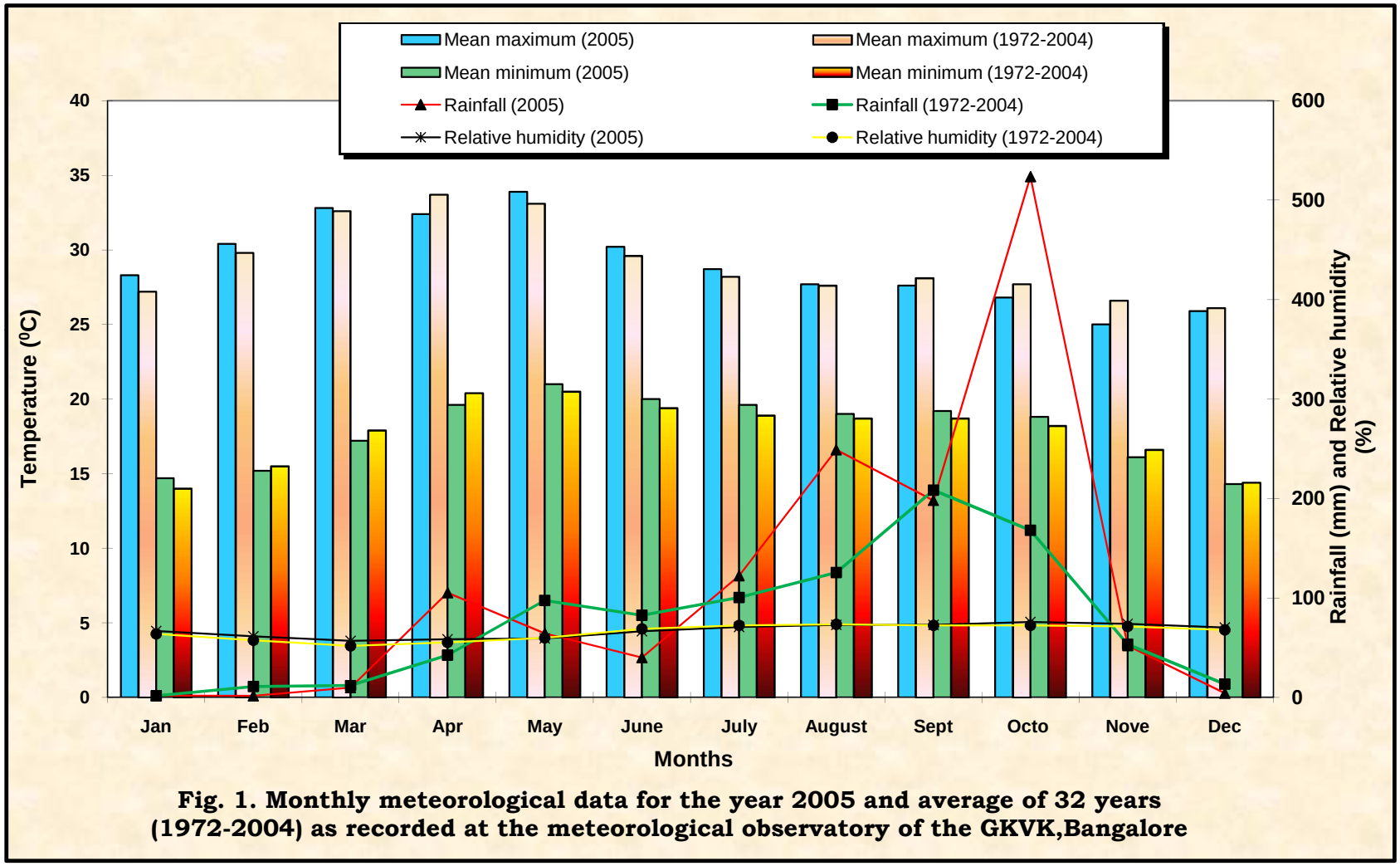


Fig. 1. Monthly meteorological data for the year 2005 and average of 32 years (1972-2004) as recorded at the meteorological observatory of the GKVK,Bangalore

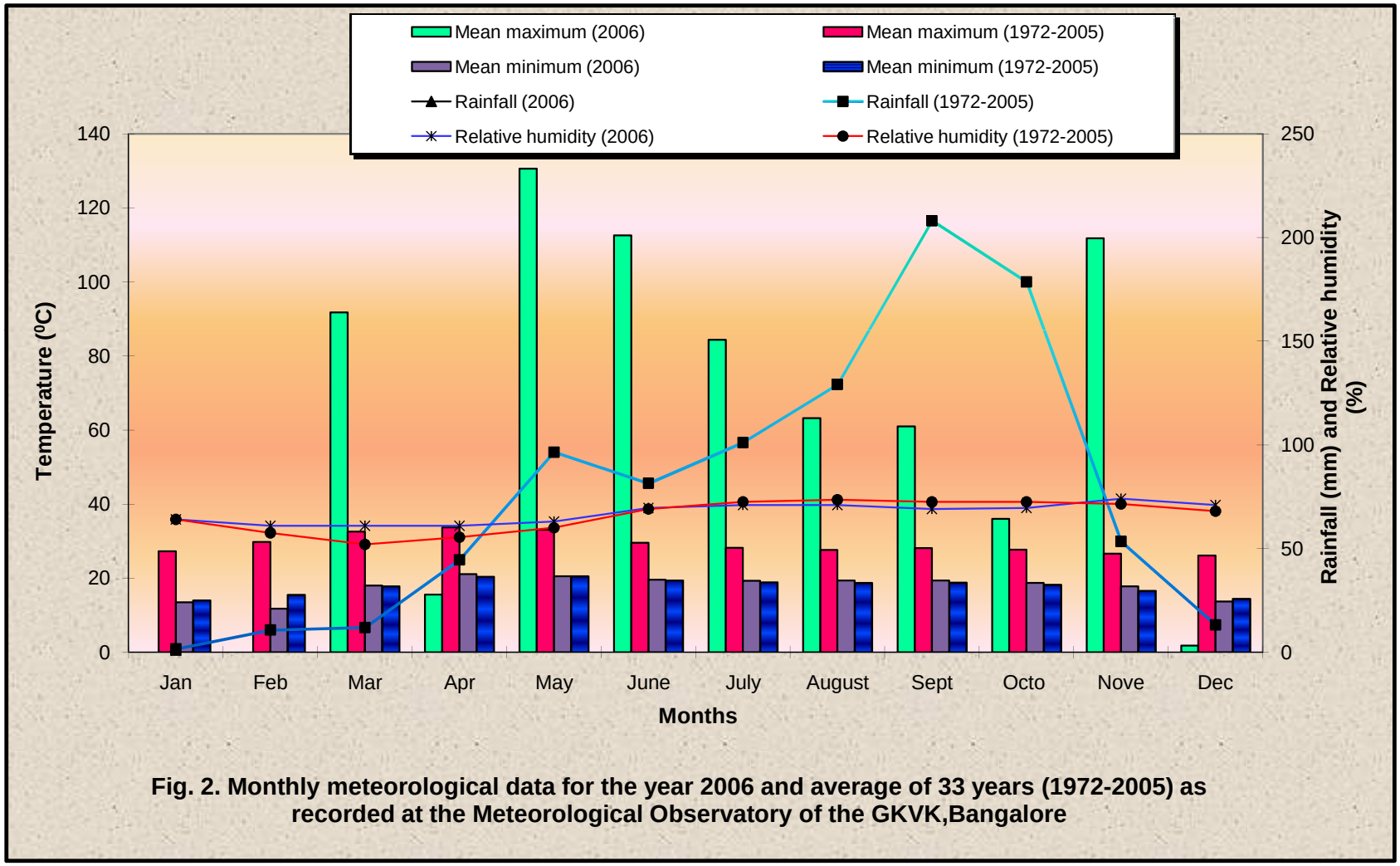


Fig. 2. Monthly meteorological data for the year 2006 and average of 33 years (1972-2005) as recorded at the Meteorological Observatory of the GKVK,Bangalore

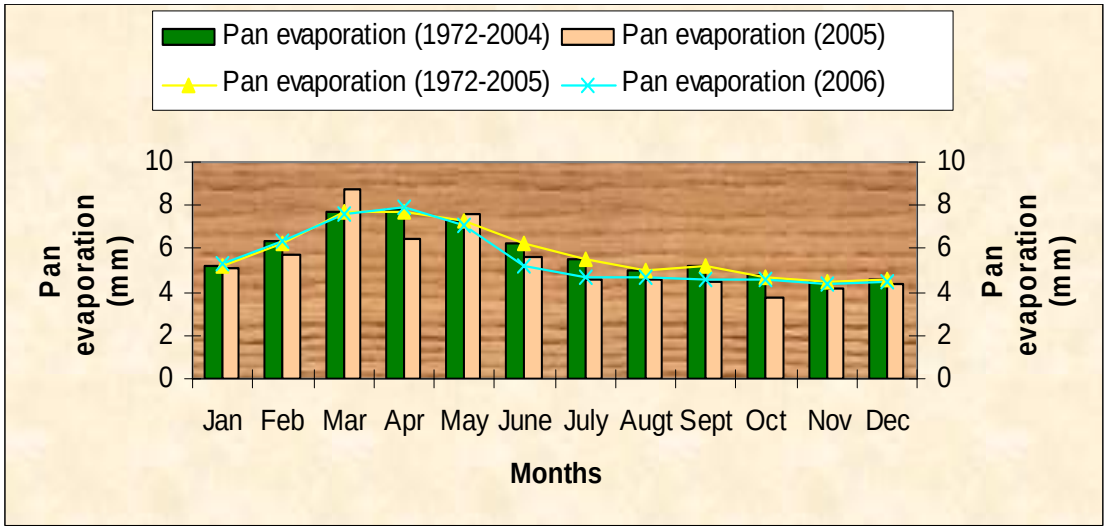


Fig. 3a : Pan evaporation recorded during the years 2005 and 2006 at GKVK, Bangalore

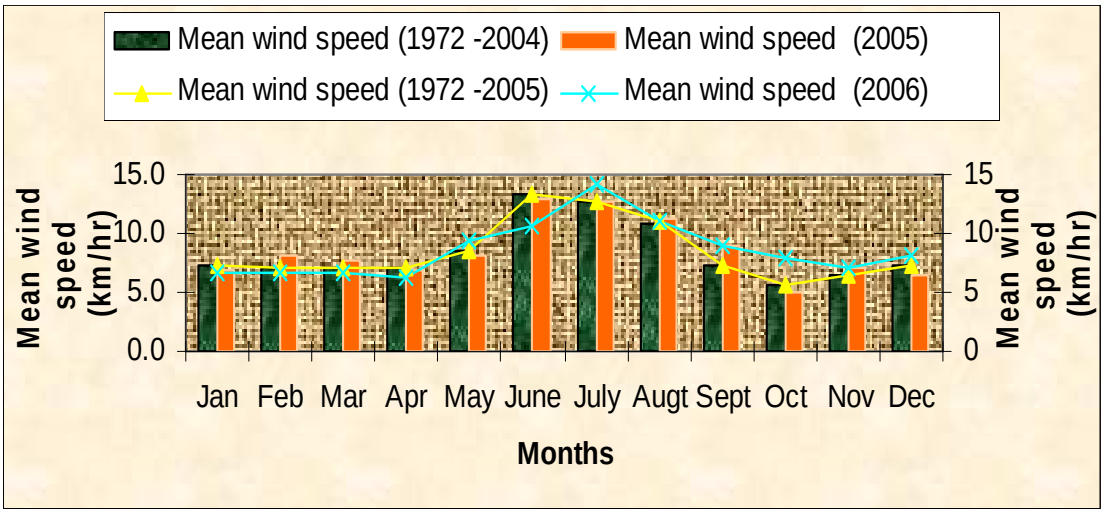


Fig. 3b : Mean wind speed recorded during the years 2005 and 2006 at GKVK, Bangalore

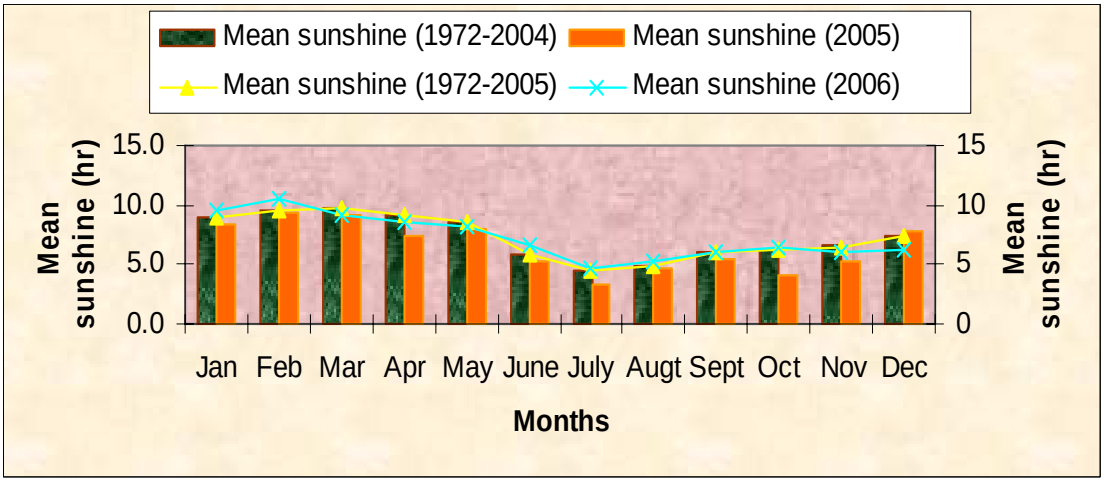


Fig.3c:Mean sunshine hours recorded during the years 2005 and 2006 at GKVK, Bangalore

3.3.2 Actual climatic conditions during the period of experimentation

The total annual rainfall was more during 2005 (1374.40 mm) and less during 2006 (708.80 mm) as compared to normal rainfall. The crop growth period is from August to November in both the years. During the crop growth period, October 2005 and November 2006 months recorded higher rainfall (523.6 and 111.8 mm during 2005 and 2006 respectively) and was more as compared to normal annual rainfall.

The mean maximum air temperature was higher in the month of May (33.9°C) during 2005 and April (33.5°C) during 2006. The mean minimum temperature was more than normal for most of the months. The mean monthly relative humidity ranged from 57 per cent in March to 76 per cent in October during 2005, while it ranged from 61 per cent during February, March and April months to 74 per cent in November during 2006.

The mean pan evaporation ranged from 3.7 mm per day in October to 8.7 mm per day in March during 2005 and 4.4 mm per day in November to 7.9 mm per day in April during 2006. Monthly wind speed during 2005 varied between 5.1 to 12.9 km per hour during October and June months respectively, whereas during 2006, it varied between 6.2 km per hour during April to 14.1 km per hour during July.

The mean bright sunshine hours was highest in February month (9.4 hr and 10.6 hr, respectively) during both the years. The lowest hour of sunshine was noticed in July (3.4 hr) during 2005 and in July (4.6 hr) during 2006.

3.4 PREVIOUS CROP IN THE EXPERIMENTAL AREA

During the *kharif* season of 2004, the experimental area was sown with finger millet and left fallow during *rabi* and summer.

3.5 EXPERIMENTAL DETAILS

Field investigation was carried out during *kharif* 2005 and *kharif* 2006 with two separate experiments as follows.

3.5.1 Experiment I

The study entitled **"Response of finger millet-soybean rotation to zinc and boron nutrition"** was conducted with the following details.

The experiment was conducted with nine treatments during *kharif* 2005 as finger millet-soybean rotation and repeated during *kharif* 2006 as soybean-finger millet rotation in randomized complete block design with three replications. The treatment details are as follows.

Treatment details

T_1: Control (No FYM + No NPK)
T_2 : NPK only
T_3 : NPK + FYM
T_4 : NPK + $ZnSO_4$ @ 12.50 kg/ha
T_5 : NPK + Borax @ 10 kg/ha
T_6 : NPK + $ZnSO_4$ @ 12.50 kg/ha + Borax @ 10 kg/ha
T_7 : NPK + FYM + $ZnSO_4$ @ 12.50 kg/ha
T_8 : NPK + FYM + Borax @ 10 kg/ha
T_9 : NPK + FYM + $ZnSO_4$ @ 12.50 kg/ha + Borax @ 10 kg/ha

Note: The recommended dose of fertilizers 50:40:25 kg NPK per ha; FYM @ 7.5t per ha for finger millet. Similarly, 25:60:25 kg NPK per ha and FYM @ 6.25 t per ha for soybean were applied as per the treatment.

Experiment II

The study entitled **"Response of finger millet-soybean sequence to conjunctive use of zinc, boron and microbial inoculants"** was conducted with the following details.

The experiment was conducted with 10 treatments during *kharif* 2005 as finger millet-soybean rotation and repeated during *kharif* 2006 as soybean-finger millet rotation in randomized complete block design with three replications. The treatment details are as follows.

Treatment details

T_1 : Control (NPK + FYM only)

T_2 : NPK + FYM+ $ZnSO_4$ @ 12.50 kg/ha

T_3 : NPK + FYM + Borax @ 10.00 kg/ha

T_4 : NPK + FYM + *Bradyrhizobium japonicum* /*Azospirillum brasilense*

T_5 : NPK + FYM + VAM (Vesicular arbuscular mycorrhiza)

T_6 : NPK + FYM + $ZnSO_4$ @ 12.50 kg/ha + *Bradyrhizobium japonicum* /*A. brasilense*

T_7 : NPK + FYM + Borax @ 10 kg/ha + *Bradyrhizobium japonicum* / *A. brasilense*

T_8 : NPK + FYM + $ZnSO_4$ @ 12.50 kg/ha + VAM

T_9 : NPK + FYM + Borax @ 10 kg/ha + VAM

T_{10} : NPK + FYM + $ZnSO_4$ @ 12.50 kg/ha + Borax @ 10 kg/ha + *Bradyrhizobium japonicum* / *A. brasilense* + VAM

Note: The seeds of soybean were treated with *Bradyrhizobium japonicum* @ 375 g per ha and the seedlings of finger millet were treated with *Azospirillum brasilense* @ 1 kg in 10 litre of water per ha. FYM @7.5 t per ha for finger millet and 6.25 t per ha for soybean was applied to all the treatments.

3.5.2 Design and layout

The experiments were laid out in randomized complete block design (RCBD). The treatments were replicated thrice. The plan of layout of experiments is depicted in Fig. 4 and 5 and general view of the experimental sites are presented in plate 1.

3.5.3 Plot size, spacing, manure and fertilizers

Sl. No.	Specification	Crops	
		Finger millet	**Soybean**
1	Gross plot	4 m x 3 m = 12 m^2	4 m x 3 m=12m^2
2	Net plot	3.4 m x 1.8m=6.12 m^2	3.4 mx1.8m=6.12m^2
3	Spacing	30 cm x 10 cm	30 cm x 10 cm
4	FYM (t/ha)	7.5	6.25
5	N, P_2O_5, K_2O (kg/ha)	50:40:25	25:60:25

3.6 CULTURAL OPERATIONS

3.6.1 Land preparation

The land was prepared by disc ploughing once and later by passing cultivator twice followed by final harrowing to bring the soil to fine tilth. The land was laid out into required plot size for both soybean and finger millet. Small bunds were formed around each plot and replication to avoid movement of water and nutrients from one plot to another.

3.6.2 Fertilizer application

The recommended dose of fertilizer for finger millet (40:25 P_2O_5, K_2O kg/ha) and for soybean (25:60:25 N, P_2O_5, K_2O kg/ha) was applied

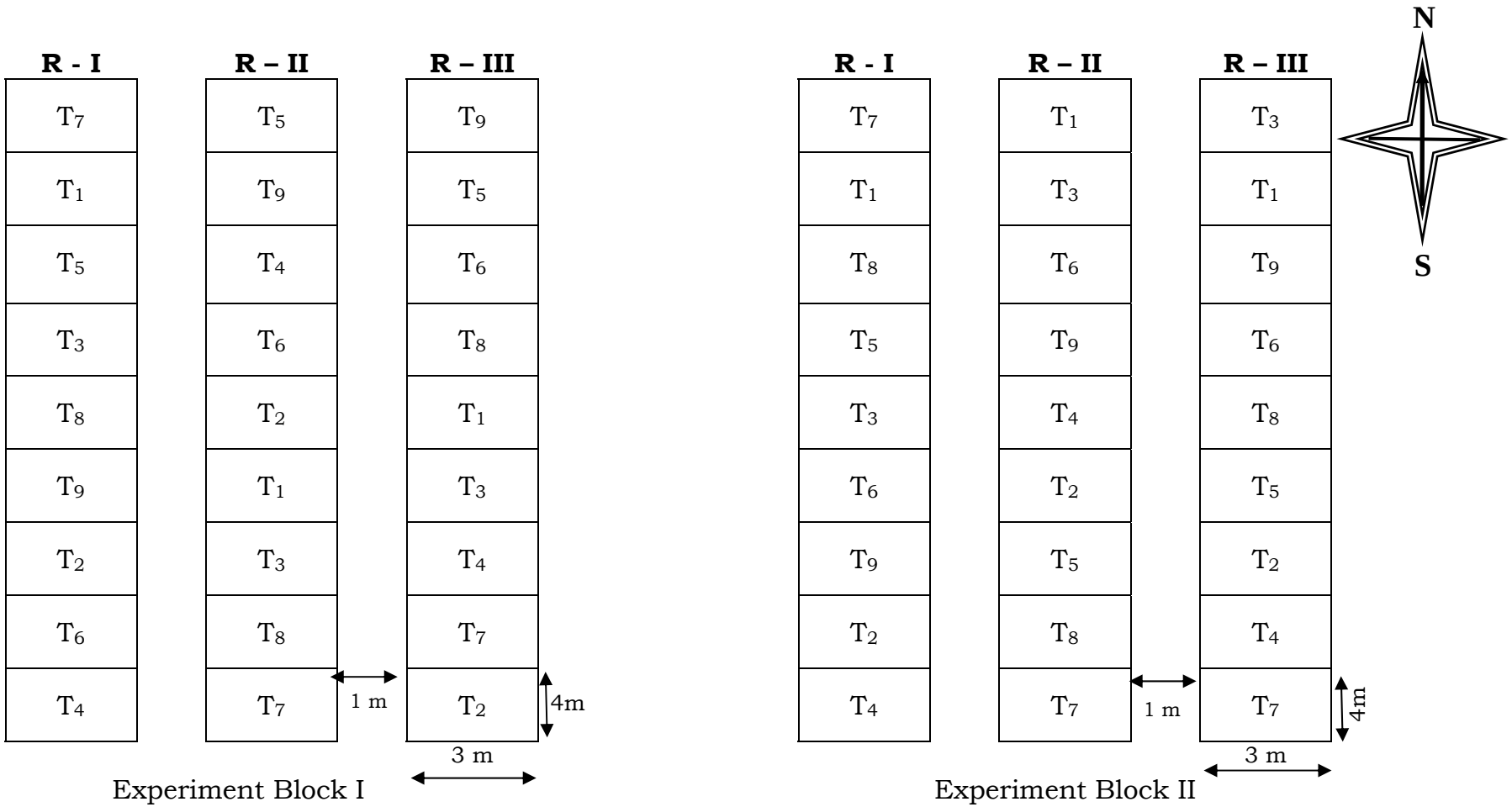


Fig. 4: Plan of layout of experiment I

	Experiment block I		Experiment block II
First year: *Kharif* 2005:	Finger millet	-	Soybean rotation
Second year: *Kharif* 2006:	Soybean	-	Finger millet rotation

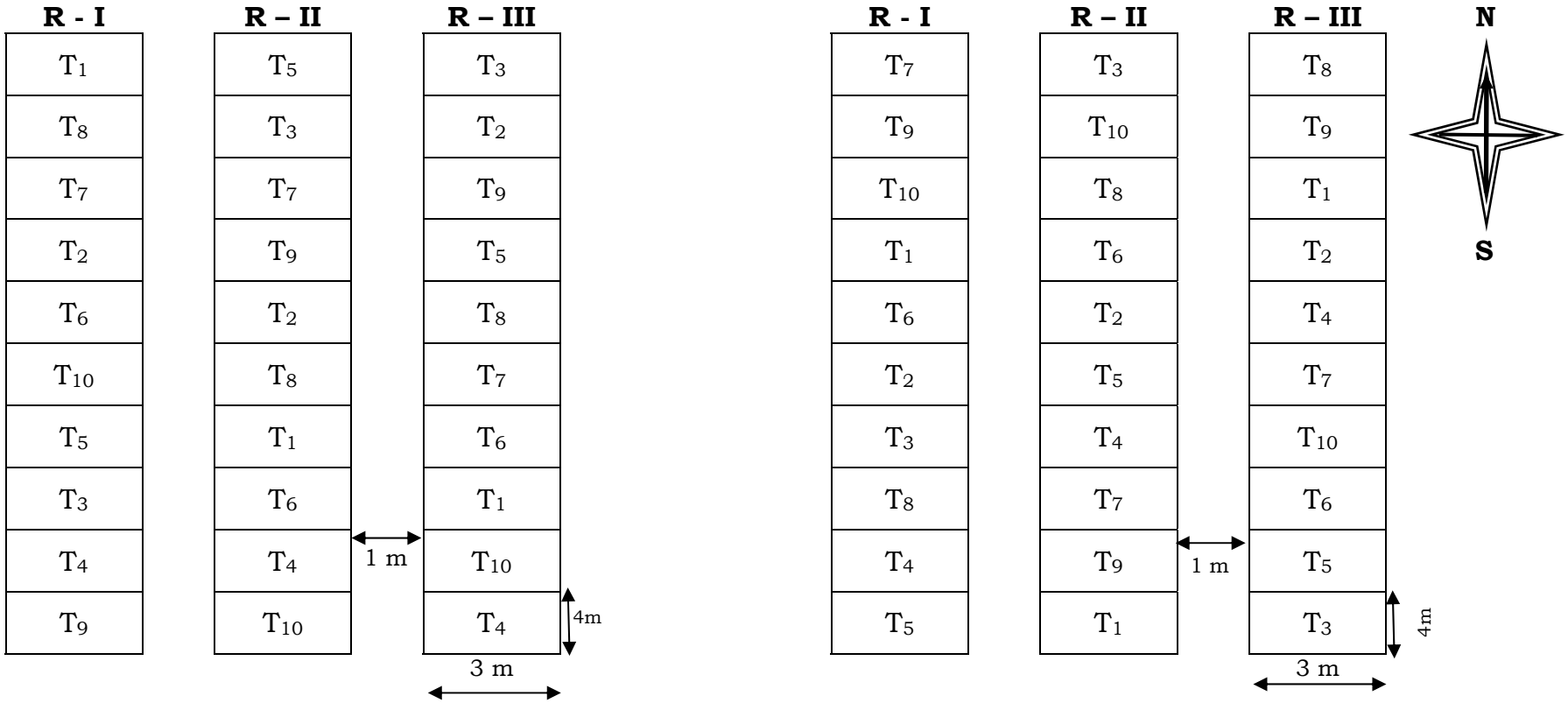


Fig. 5: Plan of layout of experiment II

	Experiment block I	Experiment block II
First year: *Kharif* 2005: Finger millet	-	Soybean rotation
Second year: *Kharif* 2006: Soybean	-	Finger millet rotation

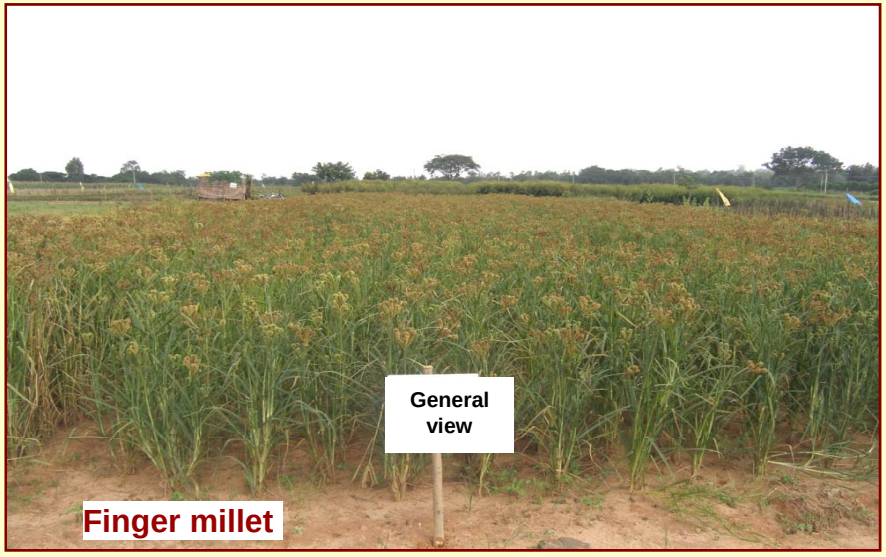


Plate 1: General view of the experimental sites

at the time of sowing. The recommended dose of nitrogen (50 kg N/ha) was applied in two splits doses as basal dose and at 45 days after transplanting (DAT) in case of finger millet. Well decomposed farmyard manure @ 7.5 t per ha (finger millet) and 6.25 t per ha (soybean) was applied as per the treatment specifications two weeks before transplanting/sowing of the crops and mixed thoroughly with soil. The nutrients were applied in the form of urea, diammonium phosphate and muriate of potash. Zinc as $ZnSO_4$ @ 12.50 kg per ha and boron as borax @ 10 kg per ha were applied for both crops as per the treatment at the time of sowing. The fertilizer was band placed at 5 cm away from the seed line and mixed thoroughly in soil. The VAM (*Glomus fasciculatum*) was applied as soil application at the rate of 10 kg per ha. Finger millet seedlings were root dipped in the slurry of *Azospirillum brasilense* @ 1 kg per ha in 10 litres of water before transplanting. Soybean seeds were inoculated with *Bradyrhizobium japonicum* @ 375 g per ha.

3.6.3 Crop variety

3.6.3.1 Finger millet

GPU-28 is a finger millet variety released from Project Co-ordination Cell, All India Co-ordinated Small Millets Improvement Project, UAS, Bangalore during 1998. It posses high degree of resistance to finger and neck blast diseases. It is a cross between Indaf 5 and IE 1012 and developed by pedigree method. It is a medium duration variety of 110 to 115 days and is being preferred over other varieties because of high yield potential with acceptable harvest index.

3.6.3.2 Soybean

Soybean variety KB-79 was used for experimentation. It is determinate type of variety with pink flowers; lusterous light yellow seeds and matures in 90 to 95 days. It yields nearly 30 per cent higher than

short duration variety; Monetta (producing average seed yield of 1500 kg/ha). It is also recommended for intercropping with sugarcane. The variety is resistant to alternaria, yellow mosaic vein, soybean mosaic, and has moderate tolerance to *Cercospora* and bud blight.

3.6.4 Sowing

GPU-28 seeds of finger millet were used for sowing with recommended seed rate of 5 kg per ha. The seeds were raised in nursery and transplanted after 22 DAS.

The seedlings were inoculated with *Azospirillum brasilense* slurry (1 kg/ha in 10 litres of water) through dipping of roots before transplanting. Two seedlings per plant were transplanted at a row spacing of 30 cm and were planted at 10 cm distance within the rows. The transplanting was done on 12th August 2005 and 14th August 2006.

Soybean KB-79 seeds were used for sowing with recommended seed rate of 62.5 kg per ha. The seeds were treated with *Rhizobium* (*Bradyrhizobium japonicum*) @ 375 g per ha. The furrows were opened at a row spacing of 30 cm and seeds were placed at 10 cm distance within the rows to a depth of 5 cm and later soil was covered. Sowing was done on 16th August 2005 and 19th August 2006.

3.7 AFTER CARE

3.7.1 Gap filling and thinning

After 15 days of transplanting of finger millet/ sowing of soybean, thinning and gap filling was done manually to maintain optimum plant population.

3.7.2 Intercultivation and weeding

Two hand weedings were done at 20 and 40 DAT/DAS for both the crops. Intercultivation was done once just after top dressing with urea for finger millet and just after second weeding in soybean.

3.7.3 Plant protection measures

Only in soybean plant protection measures were initiated against leaf miner, defoliator and pod borer. A spray of *Monocrotophos* 36 SL (1.35 ml/litre of water) was sprayed at 45 and 65 DAS.

3.7.4 Harvesting and threshing

The finger millet was harvested on 29th November and soybean 15th November of 2005. Similarly finger millet and soybean were harvested on 30th and 20th November respectively during 2006 by cutting the plant to base level leaving 5 cm above ground level. The plants from the net plots were harvested and after complete drying, the weight of the total dry matter from each net plot was recorded. After threshing, the produce was cleaned and the weight of grains per net plot was computed on hectare basis and expressed in kg per ha.

3.8 BIOMETRIC OBSERVATIONS

3.8.1 Growth parameters of finger millet

3.8.1.1 Plant height (cm)

The plant height of five randomly selected plants were measured. The measurement was made from base of the plant to base of the fully emerged leaf at 30 and 60 DAT. After emergence of panicle, the height was measured from base of the plant to tip of the panicle at 90 DAT and at harvest and expressed in centimeter.

3.8.1.2 Number of leaves per hill

Number of fully opened green leaves were counted from the five randomly selected hills, in each plot at 30, 60, 90 DAT and at harvest.

3.8.1.3 Number of tillers per hill

From the randomly selected five hills, number of tillers per hill was recorded at 30, 60, 90 DAT and at harvest and pooled and average number of tillers per hill was determined.

3.8.1.4 Leaf area (cm^2/plant)

The green leaves collected from five plants were passed through a leaf area meter (Model LI-3100 from LI COR Co., Nebraska) in order to measure the leaf area plot wise and results were recorded at all the four stages (30, 60, 90 DAT and at harvest) and expressed as cm^2/plant.

3.8.1.5 Leaf area index (LAI)

LAI was worked out by dividing the leaf area per plant by land area covered by the plant as per the formula given by Watson (1952).

$$LAI = \frac{\text{Leaf area } (cm^2)}{\text{Land area covered by the plant } (cm^2)}$$

3.8.1.6 Leaf area duration (LAD)

It is an integral of leaf area index over time and was worked out as per the formulae given by Power *et al.* (1967).

$$LAD = \frac{Li + (Li + 1)}{2} X\ t_2\text{-}t_1$$

Where,

LAD = Leaf area duration in days

Li = Leaf area index at i^{th} stage

Li + 1 = Leaf area index at i^{th} + 1 stage

$t_2 - t_1$ = Time interval between $(i+1)^{th}$ and i^{th} stages

3.8.1.7 Dry matter accumulation and its partitioning into different parts

Five plants were randomly selected and uprooted at different stages (30, 60, 90 DAT and at harvest) in each treatment. The leaves stem and ear heads were separated and oven dried at 65 to 70°C to attain constant weight. Total dry matter was worked out by adding the dry weight of all the component parts and expressed as g per plant.

3.8.2 Yield and yield components of finger millet

3.8.2.1 Number of productive tillers per hill

The total number of productive tillers from five hills were counted and averaged to get the number of productive tillers per hill.

3.8.2.2 Finger number per ear

Number of finger per ear was counted for five randomly selected plants and averaged.

3.8.2.3 Ear head length (cm)

Ten ear heads were taken at random and length of each ear head was recorded in centimeter and averaged.

3.8.2.4 Finger length (cm)

Five ear heads were selected at random and the length of finger was measured from the base to the tip of the finger and the average finger length was calculated in centimeter.

3.8.2.5 Weight of grains per earhead (g)

Earheads from five randomly selected hills were separated, dried and hand threshed. The threshed seeds were used to record grain weight per ear head in g.

3.8.2.6 1000-grain weight (g)

Grain samples were drawn from net plot produce for recording 1000-grain weight. Using seed counter, only 1000-grains were sorted out (NUMIGRAL, Type-GTFP No. series – 1367) and weight of these grains were recorded as 1000- grain weight and expressed in g.

3.8.2.7 Grain yield (kg/ha)

The net plot was marked, harvested separately and total dried biomass yield from each net plot was recorded. After threshing, grains were separated, cleaned and weighed. Later the grain yield per net plot was computed to hectare basis and expressed in kg per ha.

3.8.2.8 Straw yield (kg/ha)

Straw yield per net plot was worked out by subtracting respective total grain weight from the total biomass. Later the straw yields per net plot was computed to hectare basis and expressed in kg per ha.

3.8.2.9 Threshing percentage

It was computed as the ratio of grain weight per hill to the ear weight per hill and expressed as per cent.

$$\text{Threshing per cent} = \frac{\text{Grain weight}}{\text{Ear weight}} \text{ X } 100$$

3.8.2.10 Harvest index (HI)

From the yield of grain and biomass, the harvest index was calculated by using the formula of Donald (1962) which is as follows

$$HI = \frac{\text{Grain yield (kg/ha)}}{\text{Total biomass yield (kg/ha)}} \quad OR \quad \frac{\text{Economical yield}}{\text{Biological yield}}$$

3.8.3 Growth parameters of soybean

Biometric observations were recorded on five randomly selected plants from each net plot at 30, 60 DAS and at harvest.

3.8.3.1 Plant height (cm)

The procedure was mentioned under finger millet (3.8.1.1)

3.8.3.2 Number of branches per plant

The number of branches per plant was counted and the mean values were calculated and recorded in each plot at 30, 60 DAS and at harvest.

3.8.3.3 Number of leaves per plant

The procedure was mentioned under finger millet (3.8.1.3)

3.8.3.4 Leaf area per plant (cm^2/plant)

The procedure was mentioned under finger millet (3.8.1.5)

3.8.3.5 Leaf area index (LAI)

The procedure was mentioned under finger millet (3.8.1.6)

3.8.3.6 Leaf area duration (LAD)

The procedure was mentioned under finger millet (3.8.1.7)

3.8.3.7 Dry matter accumulation and its distribution into different plant parts

The pattern of dry matter and its distribution into leaves, stem and pods was studied at 30, 60 DAS and at harvest. To study the dry matter accumulation and its distribution, five plants were randomly selected and the leaves stem and pods were separated. Dry weight was recorded by air drying and later oven dried at 65 to 75°C to constant weight. The mean values for each plant for individual parts were calculated.

3.8.3.8 Number of nodules and nodule dry weight (g/plant)

Peak nodulation take place between 45-60 days after sowing in soybean. The nodule count and nodule dry weight was taken on five randomly selected plants during this stage. Plants were removed from the soil without disturbing the roots and then roots were put in a bucket containing water to remove the adhered soil. The nodules were then detached from the root and total numbers of nodules were recorded. Mean values per plant was worked out. Nodule dry weight per plant was determined after drying the nodules at 60°C to a constant weight.

3.8.4 Yield and yield parameters of soybean

Randomly selected five plants were used for recording the observations on the yield components.

3.8.4.1 Number of pods per plant

The pods from the five randomly selected plants were counted. Mean of five plants gave the number of pods per plant.

3.8.4.2 Pod length

Each pod was measured individually by using a centimeter scale and the mean length was recorded in cm.

3.8.4.3 Number of seeds per pod

The seeds from five representative matured pods were separated and counted. The mean number of seeds per pod was calculated by dividing the number of seeds by number of pods.

3.8.4.4 Pod yield per plant

All pods from five plants were separated and pod yield was recorded. The mean of five plants gave the pod yield per plant.

3.8.4.5 Seed yield per plant

All pods from five plants were threshed cleaned and seed weight was recorded, mean of the five plants gave the seed yield per plant.

3.8.4.6 Hundred seed weight (g)

From each treatment one hundred seeds were selected at randomly and their weight was recorded in g.

3.8.4.7 Seed yield (kg/ha)

Seed yield was recorded after threshing and winnowing the pods from the net plot area. Seed yield per net plot was converted to kg per hectare.

3.8.4.8 Haulm yield (kg/ha)

Shoot portion of the plant was harvested and recorded after complete sun drying. From the net plot values the haulm yield per net plot was converted to kg per ha.

3.8.4.9 Harvest index (HI)

The procedure was mentioned under finger millet (3.8.2.10)

3.9 QUALITY PARAMETERS OF SOYBEAN AND FINGER MILLET SEEDS

3.9.1 Protein content (%)

Nitrogen content in the seeds of soybean was estimated by Kjeldhal's method (Jackson, 1973). The protein per cent in the seeds was calculated by multiplying the nitrogen content by a factor of 6.25.

3.9.2 Protein yield (kg/ha)

Protein yield per hectare was worked out on the basis of seed protein content and seed yield of soybean.

$$\text{Protein yield (kg/ha)} = \frac{\text{Seed protein content}}{100} \text{ X seed yield (kg/ha)}$$

3.9.3 Oil content (%)

The oil content was estimated by nuclear magnetic resonance (NMR) spectrometer by using a standard reference sample.

3.9.4 Oil yield (kg/ha)

Oil yield per hectare was worked out on the basis of seed oil content and seed yield of soybean.

$$\text{Oil yield (kg/ha)} = \frac{\text{Seed oil content}}{100} \text{ X Seed yield (kg/ha)}$$

3.9.5 Germination per cent

From each treatment, the seeds were selected after 35 days after harvest at randomly and were used for germination test.

The germination test was conducted in four replications by using Wet Paper Towel method as per ISTA rules (Anon., 1996b). The rolled towels were incubated in a germinator at 25 ±1°C at 90 per cent relative humidity. The germination counts were taken on 8th day (final count) and the per cent germination was expressed based on normal seedlings in both crops.

3.9.6 Dry weight of shoot and root (mg)

Ten seedlings were randomly selected during final count of the germination test and they were kept for drying at 70 ±1°C for 24 hrs. Dried seedlings were kept in desicator for cooling about 30 min and average weight was recorded in an electronic balance and expressed in milligrams.

3.9.7 Seed vigour index

Seed vigour index was computed by adopting the formula as suggested by Abdul-Baki and Anderson (1973) and expressed in number.

Seed vigour index= Germination (%) x mean seedling dry weight

3.10 CHEMICAL ANALYSIS OF PLANT SAMPLE

The plant samples used for recording dry matter production at harvest were used for analyzing nutrients present in the plant. After recording the dry weight from each treatment the samples were powdered in a micro Willey mill. The samples were analyzed for concentration (%) of different nutrients (N, P, K and Zn and B) present in finger millet and soybean plant parts.

3.10.1 Nitrogen uptake by crop

Nitrogen content of straw and grains was estimated by modified micro-kjeldhal's method as outlined by Jackson (1967) and expressed in

percentage. Nitrogen uptake (kg/ha) by crop was calculated for each treatment separately using the following formula.

$$\text{Nitrogen uptake (kg/ha)} = \frac{\text{Nitrogen concentration(\%)}}{100} \text{ X Biomass (kg/ha)}$$

The sum of uptake of grain and straw was considered as the total uptake by the crop.

3.10.2 Phosphorus uptake by crop

The phosphorus content of grains and straw was determined by Vanadomolybodo phosphoric acid yellow colour method and absorbance of the solution was recorded at 430 nm using spectrophotometer (Jackson, 1967) and then computed to total uptake by crop as same as that of N uptake 3.10.1.

3.10.3 Potassium uptake by crop

Potassium content in plant sample (grain and straw separately) was determined by flame photometer method (Jackson, 1967) and expressed in kg per ha as explained in nitrogen estimation 3.10.1.

3.10.4 Zinc and boron uptake by crop

Zinc content was determined in an aliquot of the digested plant sample (grain and straw separately) using atomic absorption spectrophotometer (AAS) as per the method described by Follett and Lindsay (1969). The sum of uptake by grain and straw was considered as total uptake by the crop.

Boron content in a suitable aliquot was determined by carmine red method as indicated by Hatcher and Wilcox (1950). The sum of uptake by grain and straw was considered as the total uptake by the crops.

3.11 MICROBIOLOGICAL ANALYSIS OF SOIL

The soil samples were collected from the rhizosphere of the plants at 50% flowering and at harvest. The soil samples collected were placed in a polyethylene bag and brought to laboratory and stored in refrigerator at 5^0 C until used for analysis.

3.11.1 ENUMERATION OF SOIL MICROORGANISMS

The rhizosphere soil samples collected from experimental soil were analyzed for different soil microorganisms *viz.*, total bacteria, total fungi and total actinomycetes, using standard dilution plate count technique and plating on specific nutrient media.

Specific media used for enumeration of soil microorganisms.

Group of microorganism	Media used
Bacteria	Nutrient agar
Fungi	Martin's Rose Bengal agar
Actinomycetes	Kuster's agar

3.11.2 ESTIMATION OF SOIL ENZYMES

The rhizosphere soil samples collected at 50% flowering of crops in different experiments were also analyzed for activity of soil enzymes *viz.,* Dehydrogenase, Urease and Phosphatase (acid and alkaline). The procedure followed for the estimation of soil enzymes is described below.

3.11.2.1 Estimation of Dehydrogenase activity

The Dehydrogenase activity was determined by the procedure given by Casida *et al.* (1964). Five grams of air-dried soil (< 2 mm) was taken in screw cap tubes and mixed with 0.2 g of $CaCO_3$. To each sample tube 1 ml of 2 per cent aqueous solution of 2, 3, 5- Triphenyl Tetrazolium

Chloride (TTC) and 2.5 ml of distilled water were added. Content of each tube were mixed and incubated at 37^{o} C for 24 hour. After incubation period 10 ml of methanol was added to each tube and shaken well. The suspension was filtered through a glass funnel plugged with cotton into a 50 ml volumetric flask. Each tube was washed with methanol and the soil was quantitatively transferred to the funnel, additional methanol was added to the funnel till the red colour disappeared from the cotton in the funnel. The volume was made up to 50 ml by adding methanol. The intensity of red colour was read at 485 nm using spectrophotometer and the activity was expressed as µg TPF/g soil/24hr.

3.11.2.2 Estimation of phosphatase activity

Acid and alkaline phosphatase activities were estimated as per the procedure given by Eiavazi and Tabatabai (1977). One gram of soil was taken in screw cap tubes to that 0.2 ml of toluene and 4 ml of modified universal buffer (MUB) solution (MUB of pH 6.5 for acid phosphatase and pH 11.0 for alkaline phosphatase) were added and the contents were mixed and 1ml of paranitrophenol was added and tubes were closed with screw cap. In the next step tubes were kept for incubation at 37^{0} C for overnight. After incubation period of one day, the caps were removed and 1ml of 0.5M calcium chloride was added, to this 4ml of 0.5M NaOH was added, kept on a mechanical shaker for one hour. Subsequently the solution was filtered using filter paper. The resulting filtrates were measured for absorbance at 420 nm using spectrophotometer. The intensity of the colour was estimated by using the standard graph values of standard paranitrophenol and concentration was expressed as µg PNP/g/hr.

3.11.2.3 Estimation of urease activity

The urease activity was determined by following the methods outlined by Eiavazi and Tabatabai (1977). Five grams of moist soil was

taken in screw cap tubes to each 0.2ml of toluene, 9ml of tris buffer and 1ml of urea was added and the mouth of the tube was covered with caps and incubated at 37^0 C for 2hr. After two hours 35ml of KCl-Ag_2SO_4 solution was added, volume was made up to 50 ml and the solution was filtered using filter paper. One ml of the filtrate was taken in 25 ml volumetric flasks and to each flasks 5ml of nesslers reagent, 1ml of 1 per cent gum acacia and 2 ml of 10 per cent sodium potassium tartarate were added. The volume was made up to 25 ml using distilled water. The intensity of the solution was read at 410 nm using spectrophotometer and the Urease activity was expressed as µg NH_4-N/g/2hr.

3.12 CHEMICAL ANALYSIS OF SOIL

Representative soil samples from the experimental plot were drawn from the top 20 cm depth before sowing of the crop. Similarly, the surface soil samples from 0 to 20 cm depth were also collected from each experimental plot at harvest. Soil samples thus collected were air dried in shade, powdered with wooden mallet and passed through 2 mm sieve and chemically analyzed for nitrogen, phosphorus, potassium, zinc and boron content.

3.12.1 Available nitrogen (kg/ha)

Available nitrogen was determined by alkaline permanganate method as outlined by Subbaiah and Asija (1959).

3.12.2 Available phosphorus (kg/ha)

Available phosphorus was determined by Olsen's method as outlined by Jackson (1967).

3.12.3 Available potassium (kg/ha)

Available potassium was determined by neutral normal ammonium acetate solution using flame photometer as outlined by Jackson (1967).

3.12.4 Zinc and boron content

Zinc content in the soil was determined by DTPA (Diethylene triamine penta acetate) method as proposed by Lindsay and Norwell (1978). The boron content in the soil sample was determined by Azomethine – H reagent method as outlined by Hatcher and Wilcox (1950).

3.12.5 Micronutrient use efficiency (MUE)

Micronutrient use efficiency was determined by using the following formula

$$MUE = \frac{\text{Per unit of additional yield produced}}{\text{Per unit of micronutrient applied}}$$

3.12.6 Balance of nitrogen, phosphorus, potassium, zinc and boron status in soil

In both the years, balance of nitrogen, phosphorus, potassium, zinc and boron was worked out by considering the initial soil available N, P_2O_5, K_2O, Zn and B status. To this amount, nutrients supplied through fertilizers and manures were added. Subtracting the crop uptake from this sum, the expected balance of nutrients was arrived. Net gain or loss of nutrients was worked by subtracting expected balance from initial balance (Mongia and Gangwar, 1991; Prasad and Kerketta, 1991).

3.13 ECONOMIC ANALYSIS

The price of inputs that were prevailing at the time of their use were considered for working out the cost of cultivation. The details considered to workout the economics are given in Appendix – I. A net return per hectare was calculated by deducting the cost of cultivation per

hectare from gross income per hectare. Benefit-cost ratio was worked as shown below.

$$\text{Benefit : cost ratio} = \frac{\text{Net returns (Rs./ha)}}{\text{Cost of cultivation (Rs./ha)}}$$

3.14 STATISTICAL ANALYSIS OF DATA

The experimental data collected were subjected to statistical analysis using Fisher's method of analysis of variance as outlined by Gomez and Gomez (1984). The level of significance used in 'F' and 't' tests was P=0.05. Critical difference values were calculated, wherever F test was found significant. Results have been interpreted and discussed based on the pooled data of two years (2005 and 2006).

3.15 CORRELATION COEFFICIENT STUDIES

Correlation analysis was carried out to study the nature and degree of relationship between yield and various growth, yield components and quality parameters.

Correlation coefficient values (r) were calculated and test of significance were applied as per the procedure outlined by Panse and Sukhatme (1967).

3.16 REGRESSION ANALYSIS STUDIES

Multiple regression equation was fitted between the yield and the most important growth, yield parameters and total nutrients uptake dictating the yield as per procedure outlined by Panse and Sukhatme (1967).

EXPERIMENTAL RESULTS

IV. EXPERIMENTAL RESULTS

The results of the experiment conducted to study the **"Relative response of Finger millet- Soybean rotation to application of zinc, boron and microbial inoculants"** at All India Co-ordinated Research Project for Dry land Agriculture Centre, UAS, GKVK, Bangalore during *Kharif* seasons of 2005 and 2006, which comprised of two field experiments are presented in this chapter. In both the field experiments involving finger millet-soybean and soybean - finger millet cropping systems, the crop yields, growth and yield parameters of both crops differed slightly during first (2005) and second (2006) year of experiments, but the pattern of response to zinc, boron and microbial inoculants application was similar in both the years. Therefore, only pooled data of the two years are presented in this chapter.

4.1 EXPERIMENT I (a)

RESPONSE OF FINGER MILLET – SOYBEAN ROTATION TO ZINC AND BORON NUTRITION

Crop: Finger millet

4.1.1 GROWTH PARAMETERS OF FINGER MILLET AS INFLUENCED BY ZINC AND BORON NUTRITION

The growth parameters of finger millet *viz.,* plant height, number of tillers per hill, number of green leaves per plant, leaf area (LA), leaf area index (LAI), leaf area duration (LAD) and dry matter accumulation in leaf, stem, ear head and total dry matter accumulation (TDMA), as influenced by zinc and boron nutrition at different growth stages are presented in Table 4.1.1 to 4.1.10.

4.1.1.1 Plant height (cm)

Presentation of data is based on pooled over two years. The data on plant height of finger millet at different growth stages of crop growth was significantly influenced by zinc and boron nutrition and are presented in Table 4.1.1 and Fig. 6.

At 30 days after transplanting (DAT), application of NPK + FYM + $ZnSO_4$ +borax (T_9) registered significantly higher plant height (9.44 cm) over rest of treatments. However, it was found on par with application of NPK + FYM + $ZnSO_4$ (T_7: 9.07 cm) and NPK + FYM + borax (T_8: 8.62cm)

Significantly higher plant height was recorded with application of NPK + FYM + $ZnSO_4$ + borax (T_9) at 60, 90 DAT and at harvest (41.76, 96.94 and 98.57 cm, respectively) as compared to other treatments. However, it was found on par with application of NPK + FYM + $ZnSO_4$ (T_7:39.14, 93.17 and 94.66 cm at 60, 90 DAT and at harvest, respectively) and NPK + FYM + borax (T_8) at harvest (92.54 cm).

4.1.1.2 Number of tillers per hill

Application of NPK + FYM + $ZnSO_4$ + borax (T_9) recorded significantly higher number of tillers per hill (1.58 and 5.11 tillers per hill at 30 and 60 DAT, respectively) as compared to other treatments. However, it was found on par with that of application of NPK + FYM + $ZnSO_4$ (T_7: 1.47 and 4.82 tillers per hill, respectively) (Table 4.1.2).

At 90 DAT and at harvest, significantly higher number of tillers were recorded with application of NPK + FYM + $ZnSO_4$ + borax (T_9: 6.63 and 6.80 tillers per hill, respectively) as compared to other treatments.

Table 4.1.1: Plant height of finger millet as influenced by zinc and boron application in finger millet-soybean based cropping system

Treatment	Plant height (cm)											
	30 DAT			60 DAT			90 DAT			At harvest		
	2005	2006	Pooled	2005	2006	Pooled	2005	2006	Pooled	2005	2006	Pooled
T_1: Control	4.12	3.90	4.01	18.57	15.98	17.28	52.23	50.35	51.29	52.62	51.65	52.13
T_2:NPK only	5.70	5.50	5.60	25.57	22.98	24.28	65.23	64.85	65.04	67.62	65.32	66.47
T_3:NPK + FYM	7.87	7.01	7.44	32.12	29.89	31.00	77.23	78.00	77.62	80.62	78.56	79.59
T_4:NPK+ $ZnSO_4$	6.98	6.78	6.88	32.18	27.05	29.61	72.71	73.81	73.26	76.20	74.65	75.43
T_5:NPK + Borax	6.81	6.60	6.71	30.62	25.42	28.02	69.61	70.65	70.13	73.30	71.35	72.33
T_6:NPK+ $ZnSO_4$ + Borax	8.32	7.85	8.09	37.23	34.95	36.09	85.32	86.53	85.93	86.23	87.35	86.79
T_7:NPK + FYM + $ZnSO_4$	9.12	9.02	9.07	40.25	38.03	39.14	92.62	93.72	93.17	94.82	94.50	94.66
T_8:NPK + FYM + Borax	8.72	8.52	8.62	38.62	36.38	37.50	88.23	89.35	88.79	93.52	91.56	92.54
T_9:NPK+FYM+$ZnSO_4$ + Borax	9.59	9.29	9.44	42.52	41.00	41.76	96.38	97.50	96.94	98.89	98.25	98.57
F test	*	*	*	*	*	*	*	*	*	*	*	*
S.Em ±	**0.41**	**0.44**	**0.29**	**2.08**	**1.91**	**1.41**	**3.59**	**3.39**	**2.64**	**4.06**	**4.00**	**2.83**
CD at 5 %	**1.22**	**1.31**	**0.84**	**6.23**	**5.72**	**4.04**	**10.75**	**10.18**	**7.60**	**12.17**	**12.00**	**8.12**
CV (%)	**9.44**	**10.56**	**9.79**	**10.88**	**10.94**	**10.88**	**7.99**	**7.51**	**8.30**	**8.74**	**8.75**	**8.67**

DAT: Days after transplanting, NPK @ 50:40:25 kg/ha, FYM @ 7.5 T/ha, $ZnSO_4$ @ 12.50 kg/ha, Borax @ 10 kg/ha
Crop rotation: Finger millet (2005) - Soybean (2006), Soybean (2005) - Finger millet (2006)

Table 4.1.2: Number of tillers per hill of finger millet at different growth stages as influenced by zinc and boron application in finger millet- soybean based cropping system

Treatment	Number of tillers per hill											
	30DAT			60DAT			90DAT			At harvest		
	2005	2006	Pooled	2005	2006	Pooled	2005	2006	Pooled	2005	2006	Pooled
T_1: Control	0.43	0.33	0.38	2.01	2.03	2.02	3.50	3.03	3.27	3.53	3.25	3.39
T_2: NPK only	0.90	0.80	0.85	2.60	2.63	2.62	4.50	4.05	4.28	4.43	4.25	4.34
T_3:NPK + FYM	1.15	1.05	1.10	3.80	3.91	3.86	5.50	4.95	5.23	5.44	5.15	5.30
T_4:NPK+ $ZnSO_4$	1.10	0.95	1.03	3.65	3.78	3.72	5.20	4.63	4.92	5.25	4.82	5.04
T_5:NPK + Borax	1.06	0.90	0.98	3.55	3.64	3.60	4.85	4.28	4.57	4.88	4.47	4.67
T_6:NPK+ $ZnSO_4$ + Borax	1.35	1.25	1.30	4.45	4.56	4.51	5.85	5.75	5.80	6.05	5.95	6.00
T_7:NPK + FYM + $ZnSO_4$	1.50	1.43	1.47	4.76	4.87	4.82	6.15	5.95	6.05	6.18	6.11	6.15
T_8:NPK + FYM + Borax	1.40	1.30	1.35	4.56	4.66	4.61	6.03	5.80	5.92	6.45	6.01	6.23
T_9:NPK+FYM+$ZnSO_4$ + Borax	1.60	1.55	1.58	5.06	5.16	5.11	6.73	6.52	6.63	6.90	6.70	6.80
F test	*	*	*	*	*	*	*	*	*	*	*	*
S.Em ±	**0.07**	**0.07**	**0.05**	**0.17**	**0.16**	**0.11**	**0.26**	**0.24**	**0.18**	**0.18**	**0.27**	**0.16**
CD at 5 %	**0.22**	**0.20**	**0.14**	**0.50**	**0.49**	**0.33**	**0.78**	**0.71**	**0.51**	**0.54**	**0.81**	**0.46**
CV (%)	**10.98**	**11.13**	**10.82**	**7.50**	**7.28**	**7.17**	**8.39**	**8.22**	**8.41**	**5.75**	**9.07**	**7.37**

DAT: Days after transplanting, NPK @ 50:40:25 kg/ha, FYM @ 7.5 T/ha, $ZnSO_4$ @ 12.50 kg/ha, Borax @ 10 kg/ha
Crop rotation: Finger millet (2005) - Soybean (2006), Soybean (2005) - Finger millet (2006)

4.1.1.3 Number of green leaves per hill

At 30 and 60 DAT, significantly higher number of green leaves per hill (22.86 and 36.25 per hill, respectively) was recorded with the application of NPK + FYM + $ZnSO_4$ + borax (T_9) as compared to other treatment combinations. However, it was found at par with application of NPK + FYM + $ZnSO_4$ (T_7 :20.66 and 34.55 per hill, respectively) (Table 4.1.3).

At 90 DAT and at harvest, application of NPK + FYM + $ZnSO_4$ + borax (T_9) accounted for significantly higher number of green leaves per hill (25.60 and 22.25, respectively) than other treatments. Nevertheless, it was on par with application of NPK + FYM + $ZnSO_4$ (T_7: 23.24 and 21.58, respectively).

4.1.1.4 Leaf area (cm^2 / plant)

At 30 DAT, application of NPK + FYM + $ZnSO_4$ + borax (T_9) recorded significantly higher leaf area (17.74 cm^2 / plant) as compared to other treatments. However, it was found on par with application of NPK + FYM + $ZnSO_4$ (T_7: 16.54 cm^2 / plant). Significantly lower leaf area (7.97 cm^2 / plant) was recorded in control (T_1) (Table 4.1.4).

At 60, 90 DAT and at harvest leaf area was significantly higher with application of NPK + FYM + $ZnSO_4$ + borax (T_9: 785.15, 488.15 and 472.63 cm^2 / plant, respectively) which was on par with that of NPK + FYM + $ZnSO_4$ (T_7 :776.78 cm^2 / plant) and NPK + FYM + borax (T_8:746.90 cm^2 / plant) at 60 DAT. Significantly lower leaf area per plant was recorded in the plot which did not receive any fertilizer and manure (Control, T_1 : 418. 94, 240.56 and 193.44 cm^2 /plant, respectively). On the contrary the rest of the treatments were found to be intermediate.

Table 4.1.3: Number of green leaves per hill of finger millet at different growth stages as influenced by zinc and boron application in finger millet- soybean based cropping system

Treatment	Number of green leaves per hill											
	30DAT			60DAT			90DAT			At harvest		
	2005	2006	Pooled	2005	2006	Pooled	2005	2006	Pooled	2005	2006	Pooled
T_1: Control	5.50	4.40	4.95	20.20	18.70	19.45	11.20	9.05	10.13	10.02	7.85	8.94
T_2: NPK only	10.00	9.47	9.74	26.20	24.70	25.45	15.20	13.15	14.18	13.13	11.07	12.10
T_3:NPK + FYM	14.75	14.24	14.50	30.30	28.90	29.60	19.20	17.19	18.20	17.26	15.20	16.23
T_4:NPK+ $ZnSO_4$	13.30	12.30	12.80	29.80	28.35	29.08	18.60	16.55	17.58	16.24	14.15	15.20
T_5:NPK + Borax	12.56	11.56	12.06	27.60	26.20	26.90	16.40	14.35	15.38	14.23	12.14	13.19
T_6:NPK+ $ZnSO_4$ + Borax	19.57	18.50	19.04	33.02	31.72	32.37	22.12	20.09	21.11	21.31	18.55	19.93
T_7:NPK + FYM + $ZnSO_4$	21.18	20.14	20.66	35.20	33.90	34.55	24.24	22.23	23.24	22.62	20.53	21.58
T_8:NPK + FYM + Borax	19.75	18.70	19.23	34.30	33.00	33.65	23.10	21.09	22.10	20.92	18.83	19.88
T_9:NPK+FYM+$ZnSO_4$ + Borax	23.37	22.35	22.86	36.90	35.60	36.25	26.60	24.59	25.60	23.29	21.20	22.25
F test	*	*	*	*	*	*	*	*	*	*	*	*
S.Em +	**1.38**	**1.47**	**1.08**	**1.17**	**1.27**	**0.85**	**1.16**	**1.22**	**0.90**	**1.02**	**0.99**	**0.69**
CD at 5 %	**4.14**	**4.40**	**3.10**	**3.50**	**3.82**	**2.43**	**3.48**	**3.65**	**2.59**	**3.04**	**2.96**	**2.00**
CV (%)	**15.36**	**17.38**	**17.51**	**6.66**	**7.61**	**6.99**	**10.23**	**12.00**	**11.87**	**9.95**	**11.02**	**10.25**

DAT: Days after transplanting, NPK @ 50:40:25 kg/ha, FYM @ 7.5 T/ha, $ZnSO_4$ @ 12.50 kg/ha, Borax @ 10 kg/ha
Crop rotation: Finger millet (2005) - Soybean (2006), Soybean (2005) - Finger millet (2006)

Table 4.1.4: Leaf area of Finger millet at different growth stages as influenced by zinc and boron application in finger millet- soybean based cropping system

Treatment	Leaf area (cm^2/plant)											
	30DAT			60DAT			90DAT			At harvest		
	2005	2006	Pooled	2005	2006	Pooled	2005	2006	Pooled	2005	2006	Pooled
T_1: Control	8.89	7.04	7.97	425.98	411.89	418.94	255.68	225.43	240.56	206.37	180.51	193.44
T_2: NPK only	11.49	9.74	10.62	530.60	516.40	523.50	330.65	301.00	315.83	293.23	268.87	281.05
T_3:NPK + FYM	13.90	12.35	13.13	664.15	651.15	657.65	405.12	376.77	390.95	383.32	348.52	365.92
T_4:NPK+ $ZnSO_4$	13.57	12.15	12.86	611.36	599.63	605.50	395.87	368.62	382.25	353.36	330.49	341.93
T_5:NPK + Borax	12.79	11.04	11.92	546.89	536.65	541.77	365.27	339.12	352.20	306.31	282.63	294.47
T_6:NPK+ $ZnSO_4$ + Borax	15.64	13.90	14.77	743.62	731.65	737.64	445.63	420.38	433.01	420.62	397.07	408.84
T_7:NPK + FYM + $ZnSO_4$	17.56	15.51	16.54	782.32	771.23	776.78	480.52	454.02	467.27	445.62	419.94	432.78
T_8:NPK + FYM + Borax	16.50	14.75	15.63	751.95	741.84	746.90	463.12	436.47	449.80	432.32	409.54	420.93
T_9:NPK+FYM+$ZnSO_4$ + Borax	18.62	16.85	17.74	790.10	780.20	785.15	500.65	475.65	488.15	482.63	462.63	472.63
F test	*	*	*	*	*	*	*	*	*	*	*	*
S.Em +	**0.79**	**0.71**	**0.59**	**27.27**	**28.20**	**19.05**	**17.60**	**15.82**	**12.54**	**15.98**	**19.21**	**12.37**
CD at 5 %	**2.37**	**2.14**	**1.69**	**81.77**	**84.54**	**54.74**	**52.77**	**47.43**	**36.03**	**47.92**	**57.60**	**35.54**
CV (%)	**9.57**	**9.82**	**10.67**	**7.27**	**7.66**	**7.25**	**7.53**	**7.26**	**7.85**	**7.50**	**9.66**	**8.49**

DAT: Days after transplanting, NPK @ 50:40:25 kg/ha, FYM @ 7.5 T/ha, $ZnSO_4$ @ 12.50 kg/ha, Borax @ 10 kg/ha
Crop rotation: Finger millet (2005) - Soybean (2006), Soybean (2005) - Finger millet (2006)

4.1.1.5 Leaf area index (LAI)

The LAI differed significantly at all the growth stages with different treatments. At 30 DAT, application of NPK + FYM + $ZnSO_4$ + borax (T_9: 0.059) recorded significantly higher LAI as compared to other treatments. However, it was found on par with application of NPK + FYM + $ZnSO_4$ (T_7: 0.055). Significantly lower LAI was observed in control (T_1: 0.027) (Table 4.1.5 and Fig. 6).

Application of NPK + FYM + $ZnSO_4$ + borax (T_9) recorded significantly higher LAI at 60, 90 DAT and at harvest with values 2.617, 1.627 and 1.575, respectively. This was followed by application of NPK + FYM + $ZnSO_4$ (T_7) with values 2.589, 1.558 and 1.443, respectively. Application of NPK + FYM + borax (T_8) and NPK + $ZnSO_4$ + borax (T_6) were found to be next best treatments, whereas, significantly lower LAI was recorded in control (T_1).

4.1.1.6 Leaf area duration (LAD)(Days)

The longer leaf area duration was noticed with application of NPK + FYM + $ZnSO_4$ + borax (T_9) at (30-60) DAT (60-90) DAT and 90 DAT – harvest (40.14, 63.67 and 48.04 days, respectively). However, it was found on par with application of NPK + FYM + $ZnSO_4$ (T_7: 39.67 and 62.20 days at ((30-60) and (60-90) DAT, respectively) and NPK + FYM + borax (T_8 :38.13 and 59.83, days at (30-60) and (60-90) DAT, respectively) (Table 4.1.6 and Fig. 6).

At 90 DAT – harvest, significantly longer LAD was observed with the application of NPK + FYM + $ZnSO_4$ + borax (T_9: 48.04 days) as compared to all other treatments. Significantly shorter leaf area duration was observed in control plot at all the growth stages (21.35, 32.97 and 21.70 days, at (30-60) DAT, (60-90) DAT and 90 DAT- harvest,

Table 4.1.5: Leaf area index of finger millet at different growth stages as influenced by zinc and boron application in finger millet- soybean based cropping system

Treatment	Leaf area index											
	30DAT			60DAT			90DAT			At harvest		
	2005	2006	Pooled	2005	2006	Pooled	2005	2006	Pooled	2005	2006	Pooled
T_1: Control	0.030	0.023	0.027	1.420	1.373	1.396	0.852	0.751	0.802	0.688	0.602	0.645
T_2: NPK only	0.038	0.032	0.035	1.769	1.721	1.745	1.102	1.003	1.053	0.977	0.896	0.937
T_3:NPK + FYM	0.046	0.041	0.044	2.214	2.171	2.192	1.350	1.256	1.303	1.278	1.162	1.220
T_4:NPK+ $ZnSO_4$	0.045	0.041	0.043	2.038	1.999	2.018	1.320	1.229	1.274	1.178	1.102	1.140
T_5:NPK + Borax	0.043	0.037	0.040	1.823	1.789	1.806	1.218	1.130	1.174	1.021	0.942	0.982
T_6:NPK+ $ZnSO_4$ + Borax	0.052	0.046	0.049	2.479	2.439	2.459	1.485	1.401	1.443	1.402	1.324	1.363
T_7:NPK + FYM + $ZnSO_4$	0.059	0.052	0.055	2.608	2.571	2.589	1.602	1.513	1.558	1.485	1.400	1.443
T_8:NPK + FYM + Borax	0.055	0.049	0.052	2.507	2.473	2.490	1.544	1.455	1.499	1.441	1.365	1.403
T_9:NPK+FYM+$ZnSO_4$ + Borax	0.062	0.056	0.059	2.634	2.601	2.617	1.669	1.586	1.627	1.609	1.542	1.575
F test	*	*	*	*	*	*	*	*	*	*	*	*
S.Em ±	**0.003**	**0.002**	**0.002**	**0.091**	**0.094**	**0.064**	**0.059**	**0.053**	**0.042**	**0.053**	**0.064**	**0.041**
CD at 5 %	**0.008**	**0.007**	**0.006**	**0.273**	**0.282**	**0.182**	**0.176**	**0.158**	**0.120**	**0.160**	**0.192**	**0.118**
CV (%)	**9.569**	**9.821**	**10.671**	**7.271**	**7.657**	**7.249**	**7.532**	**7.259**	**7.851**	**7.496**	**9.661**	**8.488**

DAT: Days after transplanting, NPK @ 50:40:25 kg/ha, FYM @ 7.5 T/ha, $ZnSO_4$ @ 12.50 kg/ha, Borax @ 10 kg/ha
Crop rotation: Finger millet (2005) - Soybean (2006), Soybean (2005) - Finger millet (2006)

Table 4.1.6: Leaf area duration of finger millet at different growth stages as influenced by zinc and boron application in finger millet- soybean based cropping system

Treatment	Leaf area duration (Days)								
	(30- 60)DAT			(60-90)DAT			90 DAT- harvest		
	2005	2006	Pooled	2005	2006	Pooled	2005	2006	Pooled
T_1: Control	21.74	20.95	21.35	34.08	31.87	32.97	23.10	20.30	21.70
T_2: NPK only	27.10	26.31	26.71	43.06	40.87	41.97	31.19	28.49	29.84
T_3:NPK + FYM	33.90	33.18	33.54	53.46	51.40	52.43	39.42	36.26	37.84
T_4:NPK+ $ZnSO_4$	31.25	30.59	30.92	50.36	48.41	49.39	37.46	34.96	36.21
T_5:NPK + Borax	27.98	27.38	27.68	45.61	43.79	44.70	33.58	31.09	32.33
T_6:NPK + $ZnSO_4$ + Borax	37.96	37.28	37.62	59.46	57.60	58.53	43.31	40.87	42.09
T_7:NPK+FYM + $ZnSO_4$	39.99	39.34	39.67	63.14	61.26	62.20	46.31	43.70	45.00
T_8:NPK + FYM + Borax	38.42	37.83	38.13	60.75	58.92	59.83	44.77	42.30	43.54
T_9:NPK + FYM + $ZnSO_4$ + Borax	40.44	39.85	40.14	64.54	62.79	63.67	49.16	46.91	48.04
F test	*	*	*	*	*	*	*	*	*
S.Em ±	**1.36**	**1.42**	**0.95**	**1.73**	**1.57**	**1.17**	**1.26**	**1.34**	**0.94**
CD at 5 %	**4.07**	**4.27**	**2.74**	**5.19**	**4.70**	**3.36**	**3.78**	**4.01**	**2.69**
CV (%)	**7.08**	**7.58**	**7.11**	**5.68**	**5.34**	**5.54**	**5.64**	**6.42**	**6.14**

DAT: Days after transplanting, NPK @ 50:40:25 kg/ha, FYM @ 7.5 T/ha, $ZnSO_4$ @ 12.50 kg/ha, Borax @ 10 kg/ha
Crop rotation: Finger millet (2005) - Soybean (2006), Soybean (2005) - Finger millet (2006)

respectively). In general, LAD decreased with the advance in age of crop from (60-90) DAT till harvest.

4.1.1.7 Dry matter accumulation (DMA) and its distribution (g/ plant)

4.1.1.7.1 Dry matter accumulation in leaf, stem and total dry matter accumulation (TDMA) at 30 DAT (g/plant)

At 30 DAT, application of NPK + FYM + $ZnSO_4$ + borax (T_9) registered significantly higher leaf dry matter (1.41 g/plant), stem dry mater (1.14 g/plant) which was closely followed by application of NPK + FYM + $ZnSO_4$ (T_7 : 1.32 and 1.04 g/ plant of leaf and stem dry matter, respectively). Significantly lower leaf and stem dry matter was recorded in control (T_1: 0.38 and 0.26 g/plant, respectively) while the rest of the treatments were found intermediate (Table 4.1.7).

Significantly higher total dry matter accumulation was recorded with application of NPK + FYM + $ZnSO_4$ + borax (T_9:2.55 g/ plant) as compared to all other treatments. However, application of NPK + FYM + $ZnSO_4$ (T_7:2.35 g/plant) was on par with application of NPK + FYM + borax (T_8: 2.24 g/plant) while the rest of the treatments were found intermediate except control plot (T_1: 0.63 g/plant) which recorded significantly lower TDMA as compared to other treatments.

4.1.1.7.2 Dry matter accumulation in leaf, stem and total dry matter accumulation (TDMA) at 60 DAT (g/plant)

Application of NPK + FYM + $ZnSO_4$ + borax (T_9) recorded significantly higher leaf (4.48 g/plant) and stem dry matter (5.98 g/plant) as compared to other treatments, but it was found on par with application of NPK + FYM + $ZnSO_4$ (T_7 :4.28 g/plant) and NPK + FYM + borax (T_8 : 4.18 g/ plant) with respect to leaf dry matter, while it was found on par with application of NPK + FYM + $ZnSO_4$ (T_7 : 5.53

Table 4.1.7: Dry matter accumulation in leaf, stem and total dry matter accumulation (TDMA) of finger millet at 30 DAT as influenced by zinc and boron application in finger millet-soybean based cropping system

Treatment	Leaf dry matter (g/plant)			Stem dry matter (g/plant)			TDMA (g/plant)		
	2005	2006	Pooled	2005	2006	Pooled	2005	2006	Pooled
T_1: Control	0.40	0.35	0.38	0.31	0.20	0.26	0.71	0.55	0.63
T_2: NPK only	0.85	0.80	0.83	0.55	0.45	0.50	1.40	1.25	1.33
T_3:NPK + FYM	1.15	1.00	1.08	0.80	0.69	0.75	1.95	1.69	1.82
T_4:NPK+ $ZnSO_4$	1.10	0.93	1.01	0.77	0.65	0.71	1.87	1.58	1.72
T_5:NPK + Borax	1.05	0.90	0.98	0.72	0.51	0.61	1.77	1.41	1.59
T_6:NPK + $ZnSO_4$ + Borax	1.30	1.15	1.23	1.00	0.92	0.96	2.30	2.07	2.19
T_7:NPK+FYM + $ZnSO_4$	1.39	1.24	1.32	1.08	0.99	1.04	2.47	2.23	2.35
T_8:NPK + FYM + Borax	1.32	1.17	1.25	1.05	0.93	0.99	2.37	2.10	2.24
T_9:NPK + FYM + $ZnSO_4$ + Borax	1.48	1.33	1.41	1.25	1.03	1.14	2.73	2.36	2.55
F test	*	*	*	*	*	*	*	*	*
S.Em +	0.05	0.05	0.04	0.06	0.07	0.05	0.08	0.10	0.06
CD at 5 %	0.16	0.15	0.10	0.19	0.22	0.13	0.23	0.29	0.17
CV (%)	8.11	8.77	8.21	12.84	17.76	14.76	6.66	9.93	8.01

DAT: Days after transplanting, NPK @ 50:40:25 kg/ha, FYM @ 7.5 T/ha, ZnSO4 @ 12.50 kg/ha, Borax @ 10 kg/ha
Crop rotation: Finger millet (2005) - Soybean (2006), Soybean (2005) - Finger millet (2006)

g/plant) with respect to stem dry matter. Significantly lower leaf and stem dry matter was recorded in control plot (T_1: 1.49 and 2.43 g/plant, respectively) (Table 4.1.8).

The total dry matter accumulation was significantly higher with application of NPK + FYM + $ZnSO_4$ + borax (T_9:10.45 g/ plant) as compared to all other treatments, while significantly lower TDMA was recorded in control plot (T_1: 3.92 g/ plant).

4.1.1.7.3 Dry matter accumulation in leaf, stem, ear head and total dry matter accumulation (TDMA) at 90 DAT (g/plant)

At 90 DAT, significantly higher leaf, ear head and total dry matter accumulation (6.98, 10.43 and 31.33 g/ plant, respectively) was recorded with application of NPK + FYM + $ZnSO_4$ + borax (T_9) as compared to other treatments. However, it was found on par with application of NPK + FYM + $ZnSO_4$ (T_7 : 6.62, 9.99 and 29.93 g/ plant, respectively) (Table 4.1.9).

Significantly higher stem dry matter accumulation (13.92 g/ plant) was recorded with application of NPK + FYM + $ZnSO_4$ + borax (T_9) as compared to other treatments except in NPK + FYM + $ZnSO_4$ (T_7 : 13.33 g/ plant) and NPK + FYM + borax (T_8:13.34 g/ plant). Significantly lower leaf, stem, ear head dry matter and TDMA were recorded in control plot (2.74, 5.76, 3.25 and 11.74 g/plant, respectively).

4.1.1.7.4 Dry matter accumulation in leaf, stem ear head and total dry matter accumulation (TDMA) at harvest (g/plant)

Significant differences were noticed among treatments with respect to DMA in leaf, stem ear head and TDMA at harvest. Application of NPK + FYM + $ZnSO_4$ + borax (T_9) accumulated higher dry matter in leaves, stem, ear head and total dry matter in finger millet (6.21, 13.06, 13.47 and 32.73 g/ plant, respectively) as compared to other treatments, but it

Table 4.1.8: Dry matter accumulation in leaf, stem and total dry matter accumulation (TDMA) of finger millet at 60 DAT as influenced by zinc and boron application in finger millet-soybean based cropping system

Treatment	Leaf dry matter (g/plant)			Stem dry matter (g/plant)			TDMA (g/plant)		
	2005	2006	pooled	2005	2006	pooled	2005	2006	pooled
T_1: Control	1.80	1.18	1.49	2.83	2.03	2.43	4.63	3.21	3.92
T_2: NPK only	3.15	2.50	2.83	4.13	3.33	3.73	7.28	5.83	6.56
T_3:NPK + FYM	3.93	3.28	3.61	4.95	4.23	4.59	8.88	7.51	8.20
T_4:NPK+ $ZnSO_4$	3.77	3.02	3.40	4.87	4.21	4.54	8.64	7.23	7.94
T_5:NPK + Borax	3.67	2.92	3.30	4.76	4.10	4.43	8.43	7.02	7.73
T_6:NPK + $ZnSO_4$ + Borax	4.39	3.66	4.03	5.66	5.23	5.45	10.05	8.89	9.47
T_7:NPK+FYM + $ZnSO_4$	4.64	3.91	4.28	5.86	5.20	5.53	10.50	9.11	9.81
T_8:NPK + FYM + Borax	4.54	3.81	4.18	5.75	5.10	5.43	10.29	8.91	9.60
T_9:NPK + FYM + $ZnSO_4$ + Borax	4.84	4.11	4.48	6.29	5.66	5.98	11.13	9.77	10.45
F test	*	*	*	*	*	*	*	*	*
S.Em ±	**0.15**	**0.16**	**0.12**	**0.26**	**0.23**	**0.17**	**0.28**	**0.30**	**0.21**
CD at 5 %	**0.45**	**0.48**	**0.33**	**0.77**	**0.70**	**0.50**	**0.83**	**0.89**	**0.61**
CV (%)	**6.79**	**8.85**	**8.11**	**8.89**	**9.25**	**9.07**	**5.42**	**6.84**	**6.31**

DAT: Days after transplanting, NPK @ 50:40:25 kg/ha, FYM @ 7.5 T/ha, ZnSO4 @ 12.50 kg/ha, Borax @ 10 kg/ha
Crop rotation: Finger millet (2005) - Soybean (2006), Soybean (2005) - Finger millet (2006)

Table 4.1.9: Dry matter accumulation in leaf, stem, ear head and total dry matter accumulation (TDMA) of finger millet at 90 DAT as influenced by zinc and boron application in finger millet- soybean based cropping system

Treatment	Leaf dry matter (g/plant)			Stem dry matter (g/plant)			Ear head dry matter(g/plant)			TDMA (g/plant)		
	2005	2006	Pooled	2005	2006	Pooled	2005	2006	Pooled	2005	2006	Pooled
T_1: Control	3.09	2.38	2.74	5.33	6.18	5.76	4.15	2.35	3.25	12.57	10.91	11.74
T_2: NPK only	4.38	3.66	4.02	7.65	9.50	8.57	6.55	4.85	5.70	18.58	18.00	18.29
T_3:NPK + FYM	5.58	4.83	5.21	9.97	11.52	10.75	8.45	6.75	7.60	24.00	23.10	23.55
T_4:NPK+ $ZnSO_4$	5.48	4.72	5.10	9.18	10.72	9.95	8.00	6.24	7.12	22.66	21.68	22.17
T_5:NPK + Borax	5.32	4.56	4.94	9.68	10.10	9.89	7.49	5.73	6.61	22.49	20.39	21.44
T_6:NPK+ $ZnSO_4$ + Borax	6.56	5.80	6.18	11.62	13.02	12.32	9.95	8.15	9.05	28.13	26.97	27.55
T_7:NPK + FYM + $ZnSO_4$	6.98	6.25	6.62	12.62	14.03	13.33	10.87	9.10	9.99	30.47	29.38	29.93
T_8:NPK + FYM + Borax	6.78	6.03	6.41	13.15	13.53	13.34	10.15	8.40	9.28	30.08	27.96	29.02
T_9:NPK+FYM+$ZnSO_4$+ Borax	7.40	6.56	6.98	13.23	14.61	13.92	11.27	9.58	10.43	31.90	30.75	31.33
F test	*	*	*	*	*	*	*	*	*	*	*	*
S.Em +	**0.32**	**0.24**	**0.20**	**0.60**	**0.64**	**0.43**	**0.52**	**0.52**	**0.36**	**0.84**	**0.92**	**0.61**
CD at 5 %	**0.94**	**0.71**	**0.57**	**1.80**	**1.91**	**1.24**	**1.57**	**1.56**	**1.03**	**2.51**	**2.74**	**1.75**
CV (%)	**9.52**	**8.27**	**9.01**	**10.11**	**9.60**	**9.74**	**10.61**	**13.24**	**11.50**	**5.91**	**6.82**	**6.25**

DAT: Days after transplanting, NPK @ 50:40:25 kg/ha, FYM @ 7.5 T/ha, $ZnSO_4$ @ 12.50 kg/ha, Borax @ 10 kg/ha
Crop rotation: Finger millet (2005) - Soybean (2006), Soybean (2005) - Finger millet (2006)

was found on par with application of NPK + FYM + $ZnSO_4$ (T_7 : 6.09, 12.26, 13.42 and 31.77 g/plant, respectively) and NPK + FYM + borax (T_8: 6.0,12.34, 13.28 and 31.61 g/plant, respectively). Application of NPK + $ZnSO_4$ + borax (T_6: 13.16 g/ plant) recorded significantly higher ear head dry matter as compared to other treatments, but it was found on par with application of NPK + FYM + $ZnSO_4$ (T_7),NPK + FYM + borax (T_8) and NPK + FYM + $ZnSO_4$ + borax (T_9). On the contrary, the absolute control recorded significantly lower leaf, stem, ear head and total dry matter accumulation (2.45, 4.95, 6.20 and 13.59 g/plant, respectively) (Table 4.1.10 and Fig. 7).

4.1.2 YIELD ATTRIBUTES OF FINGER MILLET AS INFLUENCED BY ZINC AND BORON NUTRITION

The data on effect of zinc and boron on various yield components are presented in Table 4.1.11 to 4.1.12.

4.1.2.1 Number of productive tillers per hill

Number of productive tillers per hill increased significantly due to application of NPK + FYM + $ZnSO_4$ + borax (T_9:5.13) as compared to other treatments except in T_7 (NPK + FYM + $ZnSO_4$; 4.98). However, significantly lower number of productive tillers was noticed in control (1.90), while rests of the treatments were intermediate. In general there was an increase in number of productive tillers per hill was observed with application of NPK + FYM + $ZnSO_4$ + borax (T_9), NPK + FYM + $ZnSO_4$ (T_7), NPK + FYM + borax (T_8), NPK+ $ZnSO_4$ + borax (T_6) was 170, 162, 150, and 150.05 per cent respectively over control(Table 4.1.11 and Fig. 8).

Table 4.1.10: Dry matter accumulation in leaf, stem, ear head and total dry matter accumulation (TDMA) of finger millet at harvest as influenced by zinc and boron application in finger millet- soybean based cropping system

Treatment	Leaf dry matter (g/plant)			Stem dry matter (g/plant)			Ear head dry matter(g/plant)			TDMA (g/plant)		
	2005	2006	Pooled	2005	2006	Pooled	2005	2006	Pooled	2005	2006	Pooled
T_1: Control	2.73	2.16	2.45	5.70	4.20	4.95	6.67	5.72	6.20	15.10	12.08	13.59
T_2: NPK only	4.27	3.52	3.90	7.37	8.87	8.12	9.87	9.98	9.93	21.51	22.37	21.94
T_3:NPK + FYM	5.13	4.75	4.94	9.34	10.72	10.03	11.69	11.47	11.58	26.16	26.94	26.55
T_4:NPK+ $ZnSO_4$	4.87	4.49	4.68	9.16	10.55	9.86	11.55	11.43	11.49	25.58	26.47	26.03
T_5:NPK + Borax	4.62	4.23	4.43	9.62	10.02	9.82	11.41	11.35	11.38	25.65	25.60	25.62
T_6:NPK+ $ZnSO_4$ + Borax	6.12	5.12	5.62	11.26	11.70	11.48	13.37	12.94	13.16	30.75	29.09	29.92
T_7:NPK + FYM + $ZnSO_4$	6.43	5.75	6.09	11.52	13.00	12.26	13.66	13.18	13.42	31.61	31.93	31.77
T_8:NPK + FYM + Borax	6.34	5.65	6.00	12.10	12.57	12.34	13.47	13.09	13.28	31.91	31.31	31.61
T_9:NPK+FYM+$ZnSO_4$ + Borax	6.54	5.88	6.21	12.32	13.79	13.06	13.73	13.21	13.47	32.59	32.88	32.73
F test	*	*	*	*	*	*	*	*	*	*	*	*
S.Em +	**0.28**	**0.26**	**0.19**	**0.55**	**0.57**	**0.39**	**0.52**	**0.44**	**0.34**	**0.91**	**0.95**	**0.65**
CD at 5 %	**0.84**	**0.78**	**0.55**	**1.65**	**1.70**	**1.12**	**1.55**	**1.33**	**0.98**	**2.73**	**2.86**	**1.86**
CV (%)	**9.27**	**9.79**	**9.49**	**9.68**	**9.25**	**9.38**	**7.62**	**6.77**	**7.20**	**5.89**	**6.23**	**5.95**

NPK @ 50:40:25 kg/ha, FYM @ 7.5 T/ha, $ZnSO_4$ @ 12.50 kg/ha, Borax @ 10 kg/ha
Crop rotation: Finger millet (2005) - Soybean (2006), Soybean (2005) - Finger millet (2006)

Table 4.1.11: Number of productive tillers per hill, number of fingers per ear head, ear head length, finger length of finger millet as influenced by zinc and boron application in finger millet-soybean based cropping system

Treatment	Number of productive tillers per hill			Number of fingers per ear head			Ear head length (cm)			Finger length (cm)		
	2005	2006	Pooled	2005	2006	Pooled	2005	2006	Pooled	2005	2006	Pooled
T_1: Control	1.95	1.85	1.90	4.95	3.77	4.36	6.12	5.98	6.05	3.91	3.16	3.54
T_2: NPK only	3.61	3.50	3.56	5.60	4.62	5.11	6.87	6.70	6.79	4.90	4.15	4.53
T_3:NPK + FYM	4.23	4.10	4.17	6.07	5.42	5.75	7.92	7.40	7.66	5.90	5.30	5.60
T_4:NPK+ $ZnSO_4$	4.33	4.32	4.33	5.83	5.13	5.48	7.58	7.06	7.32	5.60	4.95	5.28
T_5:NPK + Borax	3.87	3.87	3.87	5.72	4.97	5.35	7.48	6.95	7.22	5.41	4.70	5.06
T_6:NPK+ $ZnSO_4$ + Borax	4.79	4.73	4.76	6.67	6.02	6.35	8.23	7.71	7.97	6.22	5.45	5.84
T_7:NPK + FYM + $ZnSO_4$	5.06	4.90	4.98	7.10	6.55	6.83	8.69	8.16	8.42	6.75	5.76	6.26
T_8:NPK + FYM + Borax	4.80	4.71	4.75	6.87	6.27	6.57	8.63	8.10	8.37	6.54	5.90	6.22
T_9:NPK+FYM+$ZnSO_4$ + Borax	5.26	5.00	5.13	7.20	6.70	6.95	9.02	8.50	8.76	7.06	6.35	6.71
F test	*	*	*	*	*	*	*	*	*	*	*	*
S.Em +	**0.17**	**0.18**	**0.12**	**0.24**	**0.25**	**0.17**	**0.23**	**0.23**	**0.16**	**0.19**	**0.18**	**0.13**
CD at 5 %	**0.52**	**0.54**	**0.36**	**0.72**	**0.74**	**0.50**	**0.69**	**0.69**	**0.45**	**0.56**	**0.53**	**0.36**
CV (%)	**7.16**	**7.60**	**7.36**	**6.67**	**7.81**	**7.30**	**5.06**	**5.38**	**5.06**	**5.53**	**6.00**	**5.63**

NPK @ 50:40:25 kg/ha, FYM @ 7.5 T/ha, $ZnSO_4$ @ 12.50 kg/ha, Borax @ 10 kg/ha
Crop rotation: Finger millet (2005) - Soybean (2006), Soybean (2005) - Finger millet (2006)

4.1.2.2 Number of finger per ear head

Application of NPK + FYM + $ZnSO_4$ + borax (T_9) recorded significantly higher number of fingers per ear head (6.95) followed by NPK + FYM + $ZnSO_4$ (T_7:6.83) and NPK + FYM + borax (T_8:6.57) as compared to control. However, all these treatments were found to be on par with each other. Control treatment recorded significantly lower number of fingers per ear head (T_1:4.36) (Table 4.1.11 and Fig. 8).

4.1.2.3 Ear head length (cm)

Significantly longer ear head length was registered with application of NPK + FYM + $ZnSO_4$ + borax (T_9: 8.76cm) followed by NPK + FYM + $ZnSO_4$ (T_7:8.42 cm) and NPK + FYM + borax (T_8: 8.37 cm). However, all these treatments were found to be on par with each other. Significantly shorter ear length (6.05cm) was recorded in control (Table 4.1.11 and Fig. 8).

4.1.2.4 Finger length (cm)

Application of NPK + FYM + $ZnSO_4$ + borax (T_9) registered significantly longer finger length(6.71cm) as compared to all other treatments, while application of NPK + FYM + $ZnSO_4$ (T_7) recorded significantly longer finger length (6.26cm) as compared to other treatments but it was found on par with application of NPK + FYM + borax (T_8:6.22cm). Control treatment recorded significantly shorter finger length (3.54cm) (Table 4.1.11 and Fig. 8).

4.1.2.5 Grain yield per plant (g/plant)

Data on grain yield per plant differed significantly due to zinc and boron application (Table 4.1.12 and Fig. 9). Application of NPK + FYM + $ZnSO_4$ + borax (T_9: 10.84 g), NPK + FYM + $ZnSO_4$ (T_7:10.69 g/plant), NPK + FYM + borax (T_8: 10.52g/plant) and NPK + $ZnSO_4$ + borax (T_6:10.26

Table 4.1.12: Grain yield per plant, test weight (1000-grain weight) and threshing per cent of finger millet as influenced by zinc and boron application in finger millet- soybean based cropping system

Treatment	Grain yield per plant (g)			1000-grain weight (g)			Threshing per cent (%)		
	2005	2006	Pooled	2005	2006	Pooled	2005	2006	Pooled
T_1: Control	2.89	2.50	2.70	2.59	2.27	2.43	44.21	47.25	45.73
T_2: NPK only	7.44	7.72	7.58	3.00	2.63	2.82	76.70	77.19	76.94
T_3:NPK + FYM	9.10	8.65	8.88	3.36	3.01	3.19	77.88	75.70	76.79
T_4:NPK+ $ZnSO_4$	8.79	8.51	8.65	3.31	2.96	3.14	78.05	74.91	76.48
T_5:NPK + Borax	8.63	8.35	8.49	3.27	2.90	3.09	76.16	73.88	75.02
T_6:NPK + $ZnSO_4$ + Borax	10.67	9.85	10.26	3.68	3.45	3.57	80.01	77.09	78.55
T_7:NPK+FYM + $ZnSO_4$	11.02	10.35	10.69	3.77	3.54	3.65	80.55	79.15	79.85
T_8:NPK + FYM + Borax	10.83	10.20	10.52	3.73	3.50	3.62	80.76	80.41	80.59
T_9:NPK + FYM + $ZnSO_4$ + Borax	11.16	10.52	10.84	3.83	3.60	3.72	81.98	80.09	81.04
F test	*	*	*	*	*	*	*	*	*
S.Em ±	**0.39**	**0.28**	**0.25**	**0.11**	**0.10**	**0.07**	**5.38**	**6.32**	**4.17**
CD at 5 %	**1.18**	**0.84**	**0.71**	**0.33**	**0.30**	**0.21**	**16.14**	**18.95**	**11.97**
CV (%)	**7.64**	**5.68**	**6.92**	**5.69**	**5.64**	**5.57**	**12.41**	**14.80**	**13.69**

NPK @ 50:40:25 kg/ha, FYM @ 7.5 T/ha, $ZnSO_4$ @ 12.50 kg/ha, Borax @ 10 kg/ha
Crop rotation: Finger millet (2005) - Soybean (2006), Soybean (2005) - Finger millet (2006)

g/plant) recorded significantly higher grain yield per plant over other treatments. However, all these treatments were found to be on par with each other. Significantly lower grain yield per plant (2.70 g/plant) was recorded in plots which did not receive any fertilizer or manure (control).

4.1.2.6 1000-grain weight (g)

Application of NPK + FYM + $ZnSO_4$ + borax (T_9) recorded significantly higher 1000- grain weight (3.72g) over other treatments. However, it was found on par with application of NPK + FYM + $ZnSO_4$ (T_7:3.65g), NPK + FYM + borax (T_8: 3.62g) and NPK + FYM + borax (T_6:3.57 g). 1000-grain weight due NPK + FYM + $ZnSO_4$ + borax (T_9) application was higher by 53.09 per cent over control (Table 4.1.12 and Fig. 9).

4.1.2.7 Threshing per cent (%)

Significant variation in threshing percentage was noticed due to treatment effects (Table 4.1.12 and Fig. 9). Higher threshing percentage was obtained with application of NPK + FYM + $ZnSO_4$ + borax (T_9:81.04%) followed by NPK + FYM + borax (T_8:80.59%). However, these treatments were on par with each other and with remaining treatments except control (45.73%) which recorded significantly lower threshing percentage.

4.1.3 GRAIN YIELD, STRAW YIELD (kg/ha) AND HARVEST INDEX OF FINGER MILLET AS INFLUNCED BY ZINC AND BORON NUTRITION

4.1.3.1 Grain yield (kg/ha)

Application of NPK + FYM + $ZnSO_4$ + borax (T_9) recorded significantly higher grain yield (3613 kg/ha) over other treatments. However, it was found on par with application of NPK + FYM + $ZnSO_4$

(T_7:3564 kg /ha), NPK + FYM + borax (T_8: 3506 kg/ha) and NPK + $ZnSO_4$ + borax (T_6: 3424 kg/ha), whereas, significantly lower grain yield (871 kg/ha) was recorded in control. In general there was an increase in the yield due to application of NPK + FYM + $ZnSO_4$ + borax (T_9), NPK + FYM + $ZnSO_4$ (T_7), NPK + FYM +borax (T_8) and NPK + $ZnSO_4$ + borax (T_6) was 314.80, 309.18, 302.52 and 293.11 per cent over control, respectively which was highly conspicuous (Table 4.1.13 and Fig. 10).

4.1.3.2 Straw yield (kg/ha)

Data on straw yield differed due to zinc and boron and application. Significantly higher straw yield (5566 kg/ha) was registered with application of NPK + FYM + $ZnSO_4$ + borax (T_9) which was found to be on par with application of NPK + FYM + $ZnSO_4$ (T_7 :5516 kg/ha), NPK + FYM +borax (T_8:5468 kg/ha) and NPK +$ZnSO_4$ + borax (T_6: 5401 kg/ha). However, significantly lower straw yield (1755 kg/ha) was recorded in plots which did not receive any manure or fertilizers (T_1: Control) over all other treatments. Nevertheless, application of NPK + $ZnSO_4$ + borax (T_6) recorded significantly higher straw yield as compared to application of NPK + $ZnSO_4$ (T_4 :4442 kg/ha), NPK +borax (T_5: 4394 kg/ha) NPK + FYM (T_3 : 4599 kg/ha) (Table 4.1.13 and Fig. 10).

4.1.3.3 Harvest index

Data on harvest index of finger millet did not differ significantly due to zinc and boron application (Table 4.1.13 and Fig. 10)

4.1.4 SEED QUALITY PARAMETERS

4.1.4.1 Germination (%)

The results indicated that, application of NPK + FYM + $ZnSO_4$ + borax (T_9), NPK + FYM + $ZnSO_4$ (T_7), NPK + FYM + borax (T_8) and NPK + $ZnSO_4$ + borax (T_6) registered significantly higher germination per cent

Table 4.1.13: Grain yield, straw yield and harvest index of Finger millet as influenced by zinc and boron application in finger millet- soybean based cropping system

Treatment	Grain yield (kg/ha)			Straw yield (kg/ha)			Harvest index		
	2005	2006	Pooled	2005	2006	Pooled	2005	2006	Pooled
T_1: Control	913	828	871	1417	2093	1755	0.39	0.28	0.34
T_2: NPK only	2512	2341	2427	3815	3728	3772	0.40	0.38	0.39
T_3:NPK + FYM	3067	2910	2989	4669	4528	4599	0.40	0.39	0.39
T_4:NPK+ $ZnSO_4$	2913	2833	2873	4432	4452	4442	0.40	0.40	0.40
T_5:NPK + Borax	2860	2777	2818	4349	4438	4394	0.40	0.38	0.39
T_6:NPK + $ZnSO_4$ + Borax	3563	3284	3424	5424	5377	5401	0.40	0.38	0.39
T_7:NPK+FYM + $ZnSO_4$	3680	3448	3564	5572	5460	5516	0.40	0.39	0.39
T_8:NPK + FYM + Borax	3616	3395	3506	5520	5415	5468	0.40	0.39	0.39
T_9:NPK + FYM + $ZnSO_4$ + Borax	3726	3500	3613	5590	5541	5566	0.40	0.39	0.40
F test	*	*	*	*	*	*	-	-	-
S.Em ±	**181.83**	**155.41**	**119.19**	**283.26**	**264.63**	**197.73**	**0.02**	**0.02**	**0.02**
CD at 5 %	**545.14**	**465.94**	**342.52**	**849.25**	**793.40**	**568.21**	**NS**	**NS**	**NS**
CV (%)	**10.56**	**9.57**	**10.07**	**10.83**	**10.05**	**10.66**	**9.98**	**9.99**	**10.00**

NPK @ 50:40:25 kg/ha, FYM @ 7.5 T/ha, $ZnSO_4$@ 12.50 kg/ha, Borax @ 10 kg/ha, NS: Non significant
Crop rotation: Finger millet (2005) - Soybean (2006), Soybean (2005) - Finger millet (2006)

(98, 97, 96 and 95 %, respectively) over other treatments. However, all these treatments were found to be on par with each other. Significantly lower germination per cent (80%) was recorded in plots which did not receive any manure or fertilizers (T_1: Control) while the rest of the treatments were intermediate (Table 4.1.14 and Fig. 11).

4.1.4.2 Dry weight of root and shoot (mg)

Application of NPK + FYM + $ZnSO_4$ + borax (T_9) recorded significantly higher shoot and root dry weight (4.9 mg) as compared to other treatments but it was found on par with application of NPK + FYM + $ZnSO_4$ (T_7 : 4.75 mg) and NPK + FYM + borax (T_8: 4.65 mg). Significantly lower shoot and root dry weight (1.50 mg) was recorded in control.

4.1.4.3 Seed vigour index

Significantly higher seed vigour index was recorded with conjunctive use of zinc sulphate and boron along with recommended NPK and FYM (T_9:478) as compared to other treatments. However, it was found on par with application of NPK + FYM + $ZnSO_4$ (T_7:461), NPK + FYM + borax (T_8 :446) and NPK + $ZnSO_4$ + borax (T_6:421) (Table 4.1.14 and Fig. 11).

4.1.5 NUTRIENTS UPTAKE STUDIES

4.1.5.1 Nitrogen uptake by finger millet grain, straw and total plant uptake (kg/ha)

Application of NPK + FYM + $ZnSO_4$ + borax (T_9) resulted in significantly higher uptake of nitrogen by finger millet grain (48.34 kg/ha) which was closely followed by application of NPK + FYM + $ZnSO_4$ (T_7:47.96 kg/ha). Significantly lower uptake of nitrogen was recorded in control (T_1:10.62 kg/ha) (Table 4.1.15).

Table 4.1.14: Germination, Dry weight of shoot and root and seed vigour index of finger millet as influenced by zinc and boron application in finger millet- soybean based cropping system

Treatment	Germination (%)			Dry weight of root and shoot (mg)			Seed vigour index		
	2005	2006	Pooled	2005	2006	Pooled	2005	2006	Pooled
T_1: Control	81	78	80	1.40	1.60	1.50	113	125	119
T_2: NPK only	86	84	85	2.80	2.70	2.75	242	227	235
T_3:NPK + FYM	92	90	91	4.00	3.90	3.95	368	351	360
T_4:NPK+ $ZnSO_4$	91	89	90	3.80	3.70	3.75	346	329	338
T_5:NPK + Borax	90	88	89	3.60	3.50	3.55	324	308	316
T_6:NPK + $ZnSO_4$ + Borax	96	93	95	4.50	4.40	4.45	432	409	421
T_7:NPK+FYM + $ZnSO_4$	98	96	97	4.80	4.70	4.75	470	452	461
T_8:NPK + FYM + Borax	97	95	96	4.70	4.60	4.65	456	437	446
T_9:NPK + FYM + $ZnSO_4$ + Borax	98	97	98	5.00	4.80	4.90	490	466	478
F test	*	*	*	*	*	*	*	*	*
S.Em ±	**1.62**	**1.65**	**1.14**	**0.17**	**0.16**	**0.12**	**17.47**	**17.72**	**12.69**
CD at 5 %	**4.85**	**4.96**	**3.28**	**0.52**	**0.48**	**0.35**	**52.37**	**53.11**	**36.46**
CV (%)	**3.04**	**3.18**	**3.07**	**7.85**	**7.40**	**7.79**	**8.40**	**8.89**	**8.81**

NPK @ 50:40:25 kg/ha, FYM @ 7.5 T/ha, $ZnSO_4$@ 12.50 kg/ha, Borax @ 10 kg/ha
Crop rotation: Finger millet (2005) - Soybean (2006), Soybean (2005) - Finger millet (2006)

Significantly higher uptake of nitrogen by finger millet straw (41.19 kg/ha) was recorded due to application of NPK + FYM + $ZnSO_4$ + borax (T_9) and was found at par with application of NPK + FYM + $ZnSO_4$ (T_7:38.62 kg/ha).

Total nitrogen uptake varied from 20.06 to 90.70 kg per ha due to various treatments tested. Significantly higher total uptake of nitrogen was observed with application of NPK + FYM + $ZnSO_4$ + borax (T_9 : 90.70 kg/ha) which was found on par with application of NPK + FYM + $ZnSO_4$ (T_7:86.57 kg/ha). Significantly lower uptake of total nitrogen was recorded in control (T_1 :20.06 kg/ha (Table 4.1.15 and Fig. 12))

4.1.5.2 Phosphorus uptake by finger millet grain, straw and total plant uptake (kg/ha)

The uptake of phosphorus by finger millet grain was higher (9.36 kg/ha) with application of NPK + FYM + $ZnSO_4$ + borax (T_9) as compared to all other treatments, while application of NPK + FYM + $ZnSO_4$ (T_7 : 8.61 kg/ha) and NPK + FYM + borax (T_8: 8.14 kg/ha) recorded significantly higher phosphorus uptake by finger millet grain as compared to other treatments. These treatments were statistically on par with each other.

Application of NPK + FYM + $ZnSO_4$ + borax (T_9:8.04 kg/ha), NPK + FYM + $ZnSO_4$ (T_7:7.72 kg/ha) and NPK + FYM + borax (T_8 :7.55 kg/ha) recorded significantly higher uptake of phosphorus by finger millet straw as compared to other treatments. However, they were found on par with each other. Rest of the treatments were intermediate.

Indeed, there was marked improvement in total phosphorus uptake by finger millet plant as a result of application of NPK + FYM + $ZnSO_4$ + borax (T_9:17.40 kg/ha), NPK + FYM + $ZnSO_4$ (T_7: 16.33 kg/ha) and NPK + FYM + borax (T_8: 15.68 kg/ha). However, all these treatments

Table 4.1.15: Nitrogen uptake by grains, straw and total nitrogen uptake of finger millet as influenced by zinc and boron application in finger millet- soybean based cropping system

Treatment	Nitrogen uptake (kg/ha)								
	Grains (kg/ha)			Straw (kg/ha)			Total uptake (kg/ha)		
	2005	2006	Pooled	2005	2006	Pooled	2005	2006	Pooled
T_1: Control	11.22 (1.23)	10.02 (1.21)	10.62 (1.22)	7.79 (0.55)	11.09 (0.53)	9.44 (0.54)	19.01 (1.78)	21.11 (1.74)	20.06 (1.76)
T_2: NPK only	30.39 (1.21)	27.62 (1.18)	29.01 (1.20)	21.36 (0.56)	18.64 (0.50)	20.00 (0.53)	51.75 (1.77)	46.26 (1.68)	49.01 (1.73)
T_3:NPK + FYM	38.03 (1.24)	35.21 (1.21)	36.62 (1.23)	28.48 (0.61)	26.26 (0.58)	27.37 (0.60)	66.51 (1.85)	61.47 (1.79)	63.99 (1.82)
T_4:NPK+ $ZnSO_4$	35.83 (1.23)	34.00 (1.20)	34.92 (1.22)	25.70 (0.58)	24.93 (0.56)	25.32 (0.57)	61.53 (1.81)	58.93 (1.76)	60.23 (1.79)
T_5:NPK + Borax	34.89 (1.22)	33.05 (1.19)	33.97 (1.21)	24.79 (0.57)	23.52 (0.53)	24.16 (0.55)	59.68 (1.79)	56.57 (1.72)	58.13 (1.76)
T_6:NPK + $ZnSO_4$ + Borax	45.61 (1.28)	41.05 (1.25)	43.33 (1.27)	34.17 (0.63)	33.34 (0.62)	33.76 (0.63)	79.78 (1.91)	74.39 (1.87)	77.09 (1.89)
T_7:NPK+FYM + $ZnSO_4$	50.05 (1.36)	45.86 (1.33)	47.96 (1.35)	39.56 (0.71)	37.67 (0.69)	38.62 (0.70)	89.61 (2.07)	83.53 (2.02)	86.57 (2.05)
T_8:NPK + FYM + Borax	47.37 (1.31)	43.12 (1.27)	45.25 (1.29)	36.43 (0.66)	35.20 (0.65)	35.82 (0.66)	83.80 (1.97)	78.32 (1.92)	81.06 (1.95)
T_9:NPK + FYM + $ZnSO_4$ + Borax	51.42 (1.38)	47.60 (1.36)	48.34 (1.37)	41.92 (0.75)	40.45 (0.73)	41.19 (0.74)	93.34 (2.13)	88.05 (2.09)	90.70 (2.11)
F test	*	*	*	*	*	*	*	*	*
S.Em ±	**1.58**	**1.24**	**0.96**	**1.85**	**1.38**	**1.12**	**2.08**	**2.14**	**1.46**
CD at 5 %	**4.73**	**3.72**	**2.75**	**5.54**	**4.14**	**3.23**	**6.24**	**6.41**	**4.18**
CV (%)	**7.14**	**6.10**	**6.40**	**11.07**	**8.57**	**9.69**	**5.36**	**5.86**	**5.47**

NPK @ 50:40:25 kg/ha, FYM @ 7.5 T/ha, $ZnSO_4$@ 12.50 kg/ha, Borax @ 10 kg/ha,
Figures in parenthesis indicate actual concentration of nitrogen in per cent
Crop rotation: Finger millet (2005) - Soybean (2006), Soybean (2005) - Finger millet (2006)

Table 4.1.16: Phosphorus uptake by grain, straw and total phosphorus uptake finger millet as influenced by zinc and boron application in finger millet- soybean based cropping system

Treatment	Phosphorus uptake (kg/ha)								
	Grain (kg/ha)			Straw (kg/ha)			Total uptake (kg/ha)		
	2005	2006	Pooled	2005	2006	Pooled	2005	2006	Pooled
T_1: Control	1.92 (0.210)	1.53 (0.185)	1.73 (0.198)	1.91 (0.135)	2.89 (0.138)	2.40 (0.137)	3.83 (0.34 5)	4.42 (0.323)	4.13 (0.334)
T_2: NPK only	5.15 (0.205)	4.61 (0.197)	4.88 (0.201)	5.03 (0.132)	4.96 (0.133)	5.00 (0.133)	10.18 (0.337)	9.57 (0.330)	9.88 (0.334)
T_3:NPK + FYM	6.96 (0.227)	6.37 (0.219)	6.67 (0.223)	6.54 (0.14 0)	5.89 (0.130)	6.22 (0.135)	13.50 (0.367)	12.26 (0.34 9)	12.88 (0.358)
T_4:NPK+ $ZnSO_4$	6.55 (0.225)	6.09 (0.215)	6.32 (0.220)	6.03 (0.136)	5.96 (0.134)	6.00 (0.135)	12.58 (0.361)	12.05 (0.34 9)	12.32 (0.355)
T_5:NPK + Borax	6.12 (0.214)	5.83 (0.210)	5.98 (0.212)	5.83 (0.134)	5.89 (0.132)	5.86 (0.133)	11.95 (0.348)	11.72 (0.342)	11.84 (0.345
T_6:NPK + $ZnSO_4$ + Borax	8.27 (0.232)	7.39 (0.225)	7.83 (0.229)	7.48 (0.138)	7.20 (0.134)	7.34 (0.136)	15.75 (0.370)	14.59 (0.359)	15.17 (0.365)
T_7:NPK+FYM + $ZnSO_4$	8.94 (0.243)	8.27 (0.24 0)	8.61 (0.242)	7.91 (0.142)	7.53 (0.138)	7.72 (0.14 0)	16.85 (0.385)	15.80 (0.378)	16.33 (0.382)
T_8:NPK + FYM + Borax	8.46 (0.234)	7.81 (0.230)	8.14 (0.232)	7.73 (0.14 0)	7.36 (0.136)	7.55 (0.138)	16.19 (0.374)	15.17 (0.36 6)	15.68 (0.370)
T_9:NPK + FYM + $ZnSO_4$ + Borax	9.69 (0.260)	9.03 (0.258)	9.36 (0.259)	8.10 (0.14 5)	7.98 (0.144)	8.04 (0.14 5)	17.79 (0.405)	17.01 (0.402)	17.40 (0.404)
F test	*	*	*	*	*	*	*	*	*
S.Em ±	**0.31**	**0.36**	**0.23**	**0.26**	**0.25**	**0.19**	**0.50**	**0.55**	**0.38**
CD at 5 %	**0.92**	**1.07**	**0.68**	**0.79**	**0.76**	**0.53**	**1.51**	**1.66**	**1.08**
CV (%)	**7.68**	**9.81**	**8.70**	**7.24**	**7.07**	**7.30**	**6.62**	**7.65**	**7.19**

NPK @ 50:40:25 kg/ha, FYM @ 7.5 T/ha, $ZnSO_4$@ 12.50 kg/ha, Borax @ 10 kg/ha,
Figures in parenthesis indicate actual concentration of phosphorus in per cent
Crop rotation: Finger millet (2005) - Soybean (2006), Soybean (2005) - Finger millet (2006)

were found to be on par with each other, while significantly lower total phosphorus uptake was recorded in control plots (T_1 :4.13 kg/ha) and the rest of the treatments were found to be intermediate (Table 4.1.16 and Fig. 12).

4.1.5.3 Potassium uptake by finger millet grain, straw and total plant uptake (kg/ha)

Potassium uptake by finger millet grain differed significantly due to micronutrients application (zinc and boron). Application of NPK + FYM + $ZnSO_4$ + borax (T_9:16.55 kg/ha), NPK + FYM + borax (T_8:15.95 kg/ha), NPK + FYM + $ZnSO_4$ (T_7:16.27 kg/ha) and NPK + ZnSO4 + borax (T_6:15.50 kg/ha) recorded significantly higher potassium uptake by finger millet grain, respectively as compared to other treatments. However, all these treatments were found to be on par with each other (Table 4.1.17 and Fig. 12)

In straw, significantly lower uptake of potassium was recorded in control plot (16.74 kg/ha) than the rest of the treatments. Potassium uptake by finger millet straw was significantly higher with application of NPK + FYM + $ZnSO_4$ + borax (T_9: 56.08 kg/ha) which was found to be on par with application of NPK + FYM + $ZnSO_4$ (T_7:55.30 kg/ha), NPK + FYM + borax (T_8: 53.35 kg/ha) and NPK + $ZnSO_4$ + borax (T_6:53.71 kg/ha). Significantly higher total potassium uptake by finger millet plant was recorded with application of NPK + FYM + $ZnSO_4$ + borax (T_9:72.63 kg/ha) closely followed by NPK + FYM + $ZnSO_4$ (T_7: 71.57 kg/ha), NPK + FYM + borax (T_8: 69.30 kg/ha) and NPK + $ZnSO_4$ + borax (T_6: 69.21 kg/ha). These treatments were significantly superior to rest of the treatments but all these treatments were found on par with each other (Table 4.1.17 and Fig. 12).

Table 4.1.17: Potassium uptake by grain, straw and total potassium uptake of Finger millet as influenced by zinc and boron application in finger millet- soybean based cropping system

Treatment	Potassium uptake (kg/ha)								
	Grain (kg/ha)			Straw (kg/ha)			Total uptake (kg/ha)		
	2005	2006	Pooled	2005	2006	Pooled	2005	2006	Pooled
T_1: Control	4.11 (0.450)	3.64 (0.440)	3.88 (0.445)	13.60 (0.960)	19.88 (0.950)	16.74 (0.955)	17.71 (1.410)	23.52 (1.390)	20.62 (1.400)
T_2: NPK only	10.80 (0.430)	9.95 (0.425)	10.38 (0.428)	34.33 (0.900)	33.37 (0.895)	33.85 (0.898)	45.13 (1.330)	43.32 (1.320)	44.23 (1.325)
T_3:NPK + FYM	13.92 (0.454)	13.04 (0.448)	13.48 (0.451)	46.22 (0.990)	44.37 (0.980)	45.30 (0.985)	60.14 (1.444)	57.41 (1.428)	58.78 (1.436)
T_4:NPK+ $ZnSO_4$	13.28 (0.456)	12.64 (0.446)	12.96 (0.451)	44.72 (1.009)	44.61 (1.002)	44.67 (1.006)	58.00 (1.465)	57.25 (1.448)	57.63 (1.457)
T_5:NPK + Borax	12.75 (0.446)	12.27 (0.442)	12.51 (0.444)	41.75 (0.960)	42.38 (0.955)	42.07 (0.958)	54.50 (1.406)	54.65 (1.397)	54.58 (1.402)
T_6:NPK + $ZnSO_4$ + Borax	16.21 (0.455)	14.79 (0.450)	15.50 (0.453)	54.08 (0.997)	53.34 (0.992)	53.71 (0.995)	70.29 (1.452)	68.13 (1.442)	69.21 (1.447)
T_7:NPK+FYM + $ZnSO_4$	16.85 (0.458)	15.69 (0.455)	16.27 (0.457)	56.00 (1.005)	54.60 (1.000)	55.30 (1.003)	72.85 (1.463)	70.29 (1.455)	71.57 (1.459)
T_8:NPK + FYM + Borax	16.52 (0.457)	15.38 (0.453)	15.95 (0.455)	55.26 (1.001)	51.44 (0.950)	53.35 (0.976)	71.78 (1.458)	66.82 (1.403)	69.30 (1.431)
T_9:NPK + FYM + $ZnSO_4$ + Borax	17.14 (0.460)	15.96 (0.456)	16.55 (0.458)	56.57 (1.012)	55.58 (1.003)	56.08 (1.008)	73.71 (1.472)	71.54 (1.459)	72.63 (1.466)
F test	*	*	*	*	*	*	*	*	*
S.Em ±	**0.60**	**0.55**	**0.44**	**1.84**	**2.15**	**1.38**	**1.84**	**2.27**	**1.43**
CD at 5 %	**1.80**	**1.64**	**1.25**	**5.51**	**6.44**	**3.95**	**5.52**	**6.80**	**4.12**
CV (%)	**7.68**	**7.53**	**8.19**	**7.11**	**8.39**	**7.56**	**5.47**	**6.90**	**6.10**

NPK @ 50:40:25 kg/ha, FYM @ 7.5 T/ha, $ZnSO_4$@ 12.50 kg/ha, Borax @ 10 kg/ha,
Figures in parenthesis indicate actual concentration of potassium in per cent
Crop rotation: Finger millet (2005) - Soybean (2006), Soybean (2005) - Finger millet (2006)

4.1.5.4 Zinc uptake by finger millet grain, straw and total plant uptake (g/ha)

Significant differences were observed in zinc uptake by finger millet grain due to micronutrients (Zinc and boron) application. Application of NPK + FYM + $ZnSO_4$ + borax (T_9:88.54 g/ha) recorded significantly higher zinc uptake by finger millet grain as compared to rest of the treatments, while, application of NPK + FYM + $ZnSO_4$ (T_7: 83.05 g/ha) recorded significantly higher zinc uptake by finger millet grain than other treatments.

The zinc uptake by straw differed significantly due to application of zinc and boron. Application of NPK + $ZnSO_4$ + borax (T_6: 52.53 g/ha) recorded significantly higher uptake of zinc as compared to other treatments. Application of NPK + FYM + $ZnSO_4$ + borax (T_9:48.84 g/ha) recorded significantly higher uptake of zinc as compared to other treatments except T_6 (NPK + $ZnSO_4$ + borax) whereas, significantly lower uptake of zinc uptake (10.39 g/ha) by finger millet straw was recorded in control.

Significantly higher total zinc uptake by finger millet plant was recorded with the application of NPK + FYM + $ZnSO_4$ + borax (T_9:137.38 g/ha) as compared to rest of the treatments. While application of NPK + FYM + $ZnSO_4$ (T_7: 128.84 g/ha) and NPK + $ZnSO_4$ + borax (T_6: 128.56 g/ha) were found at par with each other but recorded significantly higher total uptake of zinc than rest of the treatments (Table 4.1.18 and Fig. 13).

4.1.5.5 Boron uptake by finger millet grain, straw and total plant uptake (g/ha)

Significant differences were observed in boron uptake by finger millet grain, straw and total uptake due to zinc and boron application.

Table 4.1.18: Zinc uptake by grain, straw and total zinc uptake of finger millet as influenced by zinc and boron application in finger millet- soybean based cropping system

Treatment	Zinc uptake (g/ha)								
	Grain (g/ha)			Straw (g/ha)			Total uptake (g/ha)		
	2005	2006	Pooled	2005	2006	Pooled	2005	2006	Pooled
T_1: Control	18.44 (20.20)	16.56 (20.00)	17.50 (20.10)	8.64 (6.10)	12.14 (5.80)	10.39 (5.95)	27.08 (26.30)	28.70 (25.80)	27.89 (26.05)
T_2: NPK only	52.00 (20.70)	45.65 (19.50)	48.83 (20.10)	25.14 (6.59)	23.90 (6.41)	24.52 (6.50)	77.14 (27.29)	69.55 (25.91)	73.35 (26.60)
T_3:NPK + FYM	65.94 (21.50)	61.98 (21.30)	63.96 (21.40)	29.41 (6.30)	26.26 (5.80)	27.84 (6.05)	95.35 (27.80)	88.24 (27.10)	91.80 (27.45)
T_4:NPK+ $ZnSO_4$	64.09 (22.00)	60.91 (21.50)	62.50 (21.75)	30.54 (6.89)	30.05 (6.75)	30.30 (6.82)	94.63 (28.89)	90.96 (28.25)	92.80 (28.57)
T_5:NPK + Borax	60.92 (21.30)	55.54 (20.00)	58.23 (20.65)	27.83 (6.40)	26.63 (6.00)	27.23 (6.20)	88.75 (27.70)	82.17 (26.00)	85.46 (26.85)
T_6:NPK + $ZnSO_4$ + Borax	79.81 (22.40)	72.25 (22.00)	76.03 (22.20)	53.43 (9.85)	51.62 (9.60)	52.53 (9.73)	133.24 (32.25)	123.87 (31.60)	128.56 (31.93)
T_7:NPK+FYM + $ZnSO_4$	86.11 (23.40)	79.99 (23.20)	83.05 (23.30)	46.80 (8.40)	44.77 (8.20)	45.79 (8.30)	132.91 (31.80)	124.76 (31.40)	128.84 (31.60)
T_8:NPK + FYM + Borax	78.47 (21.70)	72.65 (21.40)	75.56 (21.55)	36.43 (6.60)	34.39 (6.35)	35.41 (6.48)	114.90 (28.30)	107.04 (27.75)	110.97 (28.03)
T_9:NPK + FYM + $ZnSO_4$ + Borax	92.03 (24.70)	85.05 (24.30)	88.54 (24.50)	49.47 (8.85)	48.21 (8.70)	48.84 (8.78)	141.50 (33.55)	133.26 (33.00)	137.38 (33.28)
F test	*	*	*	*	*	*	*	*	*
S.Em ±	**2.85**	**2.62**	**1.88**	**1.37**	**0.75**	**0.94**	**3.79**	**2.92**	**2.38**
CD at 5 %	**8.54**	**7.84**	**5.39**	**4.11**	**2.26**	**2.71**	**11.35**	**8.75**	**6.85**
CV (%)	**7.42**	**7.41**	**7.20**	**6.94**	**3.94**	**6.87**	**6.52**	**5.36**	**5.99**

NPK @ 50:40:25 kg/ha, FYM @ 7.5 T/ha, $ZnSO_4$@ 12.50 kg/ha, Borax @ 10 kg/ha,
Figures in parenthesis indicate actual concentration of zinc in ppm
Crop rotation: Finger millet (2005) - Soybean (2006), Soybean (2005) - Finger millet (2006)

Application of NPK + FYM + $ZnSO_4$ + borax (T_9) recorded significantly higher boron uptake by finger millet grain (19.49 g/ha) and straw (54.41 g/ha) as compared to other treatments. However, it was found on par with application of NPK + FYM + borax (T_8:18.59 and 53.70 g/ha, respectively) and NPK + $ZnSO_4$ + borax (T_6:17.95 and 51.86 g/ha, respectively). Significantly lower boron uptake by grain and straw was registered in control (3.37 and 13.23 g/ha, respectively).

With regard to total uptake of boron by finger millet plant, application of NPK + FYM + $ZnSO_4$ + borax (T_9), NPK + FYM + borax (T_8) and NPK +$ZnSO_4$ + borax (T_6) recorded significantly higher total boron uptake (73.89, 72.28 and 69.81 g/ha, respectively) as compared to rest of the treatments. However, all these treatments were found on par with each other (Table 4.1.19 and Fig. 13).

4.1.6 CORRELATION AND REGRESSION ANALYSIS FOR GROWTH, YIELD COMPONENTS AND TOTAL UPTAKE OF NUTRIENTS BY FINGER MILLET

The correlation studies between yield and growth, yield components and total nutrient uptake revealed that, grain yield had a positive and significant association with TDM at harvest (r = 0.920), leaf area at harvest (r = 0.857), number of tillers at harvest (r = 0.842), number of productive tillers at harvest (r = 0.901), number of fingers per earhead (r = 0.789), earhead length (r = 0.820), finger length (r = 0.845), grain yield per plant (r = 0.925), test weight (r = 0.870), threshing per cent (r = 0.668) and total uptake of N, P_2O_5, K_2O, Zn and B nutrients (r = 0.930, 0.919, 0.933, 0.913 and 0.893, respectively) (Table 4.1.20).

Further, the variation in the grain yield due to growth, yield parameters and total nutrients uptake was about 93 per cent as explained by the multiple linear regression equation.

Table 4.1.19: Boron uptake by grain, straw and total boron uptake of finger millet as influenced by zinc and boron application in finger millet- soybean based cropping system

Treatment	Boron uptake (g/ha)								
	Grain (g/ha)			Straw (g/ha)			Total uptake (g/ha)		
	2005	2006	Pooled	2005	2006	Pooled	2005	2006	Pooled
T_1: Control	3.55 (3.89)	3.19 (3.85)	3.37 (3.87)	10.71 (7.56)	15.74 (7.52)	13.23 (7.54)	14.26 (11.45)	18.93 (11.37)	16.60 (11.41)
T_2: NPK only	10.05 (4.00)	9.33 (3.99)	9.69 (3.99)	29.13 (7.64)	28.40 (7.62)	28.77 (7.63)	39.18 (11.64)	37.73 (11.60)	38.46 (11.62)
T_3:NPK + FYM	13.81 (4.50)	12.91 (4.44)	13.36 (4.47)	45.67 (9.78)	43.64 (9.64)	44.66 (9.71)	59.48 (14.28)	56.55 (14.08)	58.02 {14.18)
T_4:NPK+ $ZnSO_4$	12.41 (4.26)	11.93 (4.21)	12.17 (4.24)	34.98 (7.89)	34.91 (7.84)	34.95 (7.87)	47.39 (12.15)	46.84 (12.05)	47.12 (12.10)
T_5:NPK + Borax	15.10 (5.28)	14.61 (5.26)	14.86 (5.27)	47.53 (10.93)	48.77 (10.99)	48.15 (10.96)	62.63 (16.21)	63.38 (16.25)	63.01 (16.23)
T_6:NPK + $ZnSO_4$ + Borax	18.89 (5.30)	17.01 (5.18)	17.95 (5.24)	51.77 (9.55)	51.94 (9.66)	51.86 (9.60)	70.66 (14.85)	68.95 (14.84)	69.81 (14.84)
T_7:NPK+FYM + $ZnSO_4$	17.11 (4.65)	15.62 (4.53)	16.37 (4.59)	48.42 (8.69)	47.67 (8.73)	48.05 (8.71)	65.53 (13.34)	63.29 (13.26)	64.41 (13.30)
T_8:NPK + FYM + Borax	19.47 (5.39)	17.70 (5.22)	18.59 (5.30)	54.40 (9.86)	52.99 (9.79)	53.70 (9.82)	73.87 15.24)	70.69 (15.00)	72.28 (15.12)
T_9:NPK + FYM + $ZnSO_4$ + Borax	20.12 (5.40)	18.85 (5.39)	19.49 (5.39)	55.34 (9.90)	53.47 (9.65)	54.41 (9.78)	75.46 (15.30)	72.32 (15.04)	73.89 (15.17)
F test	*	*	*	*	*	*	*	*	*
S.Em ±	**0.92**	**0.70**	**0.57**	**2.17**	**2.01**	**1.44**	**1.90**	**2.45**	**1.52**
CD at 5 %	**2.75**	**2.11**	**1.63**	**6.49**	**6.02**	**4.13**	**5.71**	**7.35**	**4.37**
CV (%)	**10.95**	**9.06**	**9.95**	**8.93**	**8.29**	**8.39**	**5.84**	**7.66**	**6.65**

NPK @ 50:40:25 kg/ha, FYM @ 7.5 T/ha, $ZnSO_4$@ 12.50 kg/ha, Borax @ 10 kg/ha,
Figures in parenthesis indicate actual concentration of boron in ppm
Crop rotation: Finger millet (2005) - Soybean (2006), Soybean (2005) - Finger millet (2006)

Table 4.1.20: Correlation and regression equation for pooled data of finger millet as influenced by zinc and boron application in finger millet- soybean based cropping system

Sl. No.	Parameters (X)	Regression equation Y{Grain yield(kg/ha))}	Correlation coefficient (r)	R^2
1	TDM at harvest (g/plant)	Y= -663.528+138.694 X	0.920**	0.846
2	Leaf area (cm^2) at harvest	Y= -75.670+8.332 X	0.857**	0.735
3	No. of tillers at harvest	Y= 658.597+668.178 X	0.842**	0.710
4	No. of productive tillers at harvest	Y= -375.944+787.028 X	0.901**	0.812
5	No. of fingers per ear head	Y= -1154.774+691.769 X	0.789**	0.623
6	Ear head length (cm)	Y= -2979.320+771.668 X	0.820**	0.672
7	Finger length (cm)	Y= -908.097+699.001 X	0.845**	0.714
8	Grain yield per plant (g)	Y=99.824+320.460 X	0.925**	0.856
9	Test weight (g)	Y= -2328.246+1610.950 X	0.870**	0.758
10	Threshing (%)	Y= -159.129+41.006 X	0.668**	0.446
11	Total N uptake(kg/ha)	Y= 445.990+37.608 X	0.930**	0.865
12	Total P_2O_5 uptake (kg/ha)	Y =334.308+199.597 X	0.919**	0.845
13	Total K_2O uptake (kg/ha)	Y=54.159 +49.362 X	0.933**	0.870
14	Total Zn uptake (g/ha)	Y=575.917 +23.830 X	0.913**	0.834
15	Total B uptake (g/ha)	Y=534.360 +42.246 X	0.893**	0.798
$Y= -1250.84+79.034X_1-0.495X_2+256.85X_3-45.988X_4-65.149X_5\ 73.239X_6+123.763X_7-3.776X_8+682.545X_9+9.332X_{10}+12.927X_{11}-59.582X_{12}+20.806X_{13}-0.256X_{14}-1.506X_{15}$			0.962	0.927

** Correlation is significant at the 0.01 level (2-tailed)

Note: The dependent variables X_1, X_2, X_3….. X_{15} refers to the parameters listed in serial number 1, 2, 3 .....15, respectively

4.2 EXPERIMENT-I(b) : RESPONSE OF FINGER MILLET – SOYBEAN ROTATION TO ZINC AND BORON NUTRITION

Crop: Soybean

4.2.1 GROWTH PARAMETERS OF SOYBEAN AS INFLUENCED BY ZINC AND BORON NUTRITION

The growth parameters of soybean as influenced by zinc and boron nutrition at different growth stages are presented in Table 4.2.1 to 4.2.10. The presentation of data is based on pooled over two years.

4.2.1.1 Plant height (cm)

Data on plant height of soybean differed significantly at different growth stages due to micronutrients (zinc and boron) application. At 30 DAS, among different treatments, application of NPK + FYM + $ZnSO_4$ + borax (T_9 : 16.90 cm), NPK + FYM + $ZnSO_4$ (T_7 : 16.45 cm) and NPK + FYM + borax (T_8 : 15.52 cm) were found on par with each other and had significantly higher plant height than control (Table 4.2.1 and Fig. 14).

Significantly higher plant height was recorded with application of NPK + FYM + $ZnSO_4$ + borax (T_9) at 60 DAS and at harvest (31.85 and 36.75 cm, respectively). However, it was found on par with application of NPK + FYM + $ZnSO_4$ (T_7) and NPK + FYM + borax (T_8) at 60 DAS (29.55 and 28.95 cm, respectively) and at harvest (34.35 and 33.10 cm, respectively). Significantly lower plant height was recorded in control (9.35 and 11.55 cm at 60 DAS and at harvest, respectively).

4.2.1.2 Number of green leaves per plant

At 30 and 60 DAS, significantly higher number of green leaves per plant were recorded with application of NPK + FYM + $ZnSO_4$ + borax (T_9 : 5.42 and 19.26 cm, respectively) as compared to rest of the treatments. However, it was found on par with the application of NPK + FYM + $ZnSO_4$

Table 4.2.1: Plant height of soybean at different growth stages as influenced by zinc and boron application in finger millet - soybean based cropping system

Treatment	Plant height (cm)								
	30 DAS			60 DAS			At harvest		
	2005	2006	Pooled	2005	2006	Pooled	2005	2006	Pooled
T_1: Control	5.80	4.95	5.38	10.10	8.60	9.35	12.30	10.80	11.55
T_2: NPK only	9.50	8.60	9.05	17.00	15.70	16.35	19.80	18.25	19.03
T_3:NPK + FYM	12.80	11.98	12.39	23.30	21.98	22.64	26.90	25.40	26.15
T_4:NPK+ $ZnSO_4$	11.67	10.80	11.24	25.25	23.85	24.55	28.50	27.00	27.75
T_5:NPK + Borax	10.32	9.50	9.91	24.30	22.80	23.55	26.10	24.60	25.35
T_6:NPK + $ZnSO_4$ + Borax	14.67	13.80	14.24	28.50	27.20	27.85	32.15	30.65	31.40
T_7:NPK+FYM + $ZnSO_4$	16.85	16.05	16.45	30.20	28.90	29.55	35.25	33.45	34.35
T_8:NPK + FYM + Borax	15.92	15.12	15.52	29.60	28.30	28.95	34.00	32.20	33.10
T_9:NPK + FYM + $ZnSO_4$ + Borax	17.30	16.50	16.90	32.50	31.20	31.85	37.50	36.00	36.75
F test	*	*****	*****	*	*****	*****	*	*****	*****
S.Em ±	**1.02**	**0.76**	**0.64**	**1.95**	**1.74**	**1.34**	**2.32**	**2.13**	**1.54**
CD at 5 %	**3.06**	**2.29**	**1.85**	**5.85**	**5.23**	**3.86**	**6.97**	**6.40**	**4.43**
CV (%)	**13.84**	**11.07**	**12.79**	**13.79**	**13.04**	**13.79**	**14.34**	**13.96**	**13.84**

DAS: Days after sowing, NPK @ 25:60:25 kg/ha, FYM @ 6.25 t/ha, $ZnSO_4$ @ 12.50 kg/ha, Borax @ 10 kg/ha
Crop rotation: Finger millet (2005)- Soybean (2006), Soybean(2005)- Finger millet (2006)

(T_7 : 18.28 cm) at 60 DAS. Significantly lower number of green leaves were registered in control (1.25 and 6.15, at 30 and 60 DAS, respectively) (Table 4.2.2).

At harvest, application of NPK + FYM + $ZnSO_4$ + borax (T_9 : 1.85), NPK + FYM + $ZnSO_4$ (T_7 : 1.75) and NPK + FYM + borax (T_8 : 1.65) recorded significantly higher number of green leaves as compared to control. However, all these treatments were found on par with each other. Application of NPK + $ZnSO_4$ + borax (T_6 : 1.55) and NPK + FYM (T_3 : 1.25) were found to be the next best treatments.

4.2.1.3 Leaf area (cm^2/plant)

Significantly higher leaf area per plant was observed at 30 DAS with application of NPK + FYM + $ZnSO_4$ + borax (T_9 : 459.75 cm^2/plant), NPK + FYM + $ZnSO_4$ (T_7 : 449.38 cm^2/plant) and NPK + FYM + borax (T_8 : 438.70 cm^2/plant) as compared to rest of the treatments except with application of NPK + $ZnSO_4$ + borax (T_6 : 413.25 cm^2/plant) which was found on par with NPK + FYM + borax (T_8) application.

At 60 DAS and at harvest, application of NPK + FYM + $ZnSO_4$ + borax recorded significantly higher leaf area per plant (T_9 : 1104.75 and 87.83 cm^2/plant, respectively) as compared to rest of the treatments. However, it was found on par with application of NPK + FYM + $ZnSO_4$ (T_7 : 1079.10 and 82.40 cm^2/plant, respectively) and NPK + FYM + borax (T_8 : 1066.75 and 76.95 cm^2/plant, respectively). Significantly lower leaf area was recorded in control plots (T_1 : 186.80, 411.80 and 13.65 cm^2/plant, respectively) at all the growth stages over the rest of the treatments.

Table 4.2.2: Number of green leaves per plant of soybean at different growth stages as influenced by zinc and boron application in finger millet- soybean based cropping system

Treatment	Number of green leaves per plant								
	30DAS			60DAS			At harvest		
	2005	2006	Pooled	2005	2006	Pooled	2005	2006	Pooled
T_1: Control	2.20	1.65	1.25	6.70	5.60	6.15	0.20	0.08	0.14
T_2: NPK only	4.15	3.65	2.35	11.00	10.00	10.50	0.70	0.58	0.64
T_3:NPK + FYM	4.80	4.29	3.00	15.20	14.70	14.95	1.30	1.19	1.25
T_4:NPK+ $ZnSO_4$	4.50	4.00	2.73	14.30	13.75	14.03	1.20	1.09	1.15
T_5:NPK + Borax	4.43	3.78	2.38	12.50	11.90	12.20	1.10	1.00	1.05
T_6:NPK + $ZnSO_4$ + Borax	6.50	5.98	3.91	16.50	15.95	16.23	1.60	1.50	1.55
T_7:NPK+FYM + $ZnSO_4$	7.30	6.79	4.66	18.50	18.05	18.28	1.80	1.70	1.75
T_8:NPK + FYM + Borax	6.90	6.38	4.36	17.00	16.50	16.75	1.70	1.60	1.65
T_9:NPK + FYM + $ZnSO_4$ + Borax	8.50	8.17	5.42	19.50	19.02	19.26	1.90	1.80	1.85
F test	*	*	*	*	*	*	*	*	*
S.Em ±	**0.21**	**0.18**	**0.12**	**0.54**	**0.55**	**0.39**	**0.11**	**0.12**	**0.08**
CD at 5 %	**0.63**	**0.53**	**0.33**	**1.62**	**1.64**	**1.12**	**0.34**	**0.36**	**0.24**
CV (%)	**6.63**	**6.15**	**8.44**	**6.43**	**6.78**	**6.70**	**15.46**	**17.71**	**16.75**

DAS: Days after sowing, NPK @ 25:60:25 kg/ha, FYM @ 6.25 t/ha, $ZnSO_4$@12.50 kg/ha, Borax@10 kg/ha
Crop rotation: Finger millet (2005)- Soybean (2006), Soybean(2005)- Finger millet (2006)

Table 4.2.3: Leaf area of soybean at different growth stages as influenced by zinc and boron application in finger millet- soybean based cropping system

Treatment	Leaf area (cm^2/ plant)								
	30DAS			60DAS			At harvest		
	2005	2006	Pooled	2005	2006	Pooled	2005	2006	Pooled
T_1: Control	202.40	171.20	186.80	432.40	391.20	411.80	17.20	10.10	13.65
T_2: NPK only	287.40	259.30	273.35	663.00	622.00	642.50	37.50	30.20	33.85
T_3:NPK + FYM	366.50	340.80	353.65	850.30	815.00	832.65	56.30	49.50	52.90
T_4:NPK+ $ZnSO_4$	350.65	324.10	337.38	750.20	714.00	732.10	48.60	41.90	45.25
T_5:NPK + Borax	325.60	298.00	311.80	700.80	663.30	682.05	43.20	36.40	39.80
T_6:NPK + $ZnSO_4$ + Borax	425.50	401.00	413.25	995.50	961.00	978.25	76.50	69.60	73.05
T_7:NPK+FYM + $ZnSO_4$	460.75	438.00	449.38	1095.20	1063.00	1079.10	85.80	79.00	82.40
T_8:NPK + FYM + Borax	450.40	427.00	438.70	1083.50	1050.00	1066.75	80.20	73.70	76.95
T_9:NPK + FYM + $ZnSO_4$ + Borax	470.50	449.00	459.75	1120.50	1089.00	1104.75	90.50	85.15	87.83
F test	*	*****	*****	*	*****	*****	*	*****	*****
S.Em ±	**22.22**	**22.01**	**15.34**	**59.20**	**54.74**	**40.18**	**4.67**	**4.80**	**3.26**
CD at 5 %	**66.63**	**65.99**	**44.09**	**177.49**	**164.12**	**115.47**	**14.01**	**14.41**	**9.37**
CV (%)	**10.37**	**11.04**	**10.49**	**12.00**	**11.58**	**11.76**	**13.60**	**15.75**	**14.21**

DAS: Days after sowing, NPK @ 25:60:25 kg/ha, FYM @ 6.25 t/ha, $ZnSO_4$@12.50 kg/ha, Borax @ 10 kg/ha
Crop rotation: Finger millet (2005)- Soybean (2006), Soybean(2005)- Finger millet (2006)

4.2.1.4 Leaf area index (LAI)

At 30 and 60 DAS, application of NPK + FYM + $ZnSO_4$ + borax (T_9 : 1.53 and 3.68) recorded significantly higher LAI as compared to control (T_1 :0.62 and 1.37, respectively), while it was found on par with application of NPK + FYM + $ZnSO_4$ (T_7 : 1.50 and 3.60) and NPK + FYM + borax (T_8 : 1.46 and 3.56, respectively).

Application of NPK + FYM + $ZnSO_4$ + borax (T_9 : 0.29) recorded significantly higher LAI at harvest as compared to rest of the treatments, but it was found on par with application of NPK + FYM + $ZnSO_4$ (T_7 : 0.27). Significantly the lower LAI at all the growth stages was recorded in control (0.62, 1.37 and 0.05, respectively) over the rest of the treatments (Table 4.2.4 and Fig. 14).

4.2.1.5 Leaf area duration (LAD) (days) and number of branches

4.2.1.5.1 Leaf area duration (days)

The longer leaf area duration was noticed with application of NPK + FYM + $ZnSO_4$ + borax (T_9 : 78.06 and 59.63 days at 30-60 DAS and 60 DAS to harvest, respectively). However, it was found on par with application of NPK + FYM + $ZnSO_4$ (T_7 : 76.42 and 58.08 days) and NPK + FYM + borax (T_8 : 75.27 and 57.19 days, at (30-60) DAS and 60 DAS – harvest, respectively). Significantly shorter LAD was observed in control at (30-60 DAS) (29.93 days) and 60 DAS – harvest (21.27 days) over rest of the treatments (Table 4.2.5 and Fig. 14).

4.2.1.5.2 Number of branches

At 60 DAS, application of NPK + FYM + $ZnSO_4$ + borax (T_9 : 4.77), NPK + FYM + $ZnSO_4$ (T_7 :4.66) and NPK + FYM + borax (T_8 : 4.36) recorded significantly higher number of branches as compared to control

Table 4.2.4: Leaf area index of soybean at different growth stages as influenced by zinc and boron application in finger millet- soybean based cropping system

Treatment	Leaf area index								
	30 DAS			60 DAS			At harvest		
	2005	2006	Pooled	2005	2006	Pooled	2005	2006	Pooled
T_1: Control	0.67	0.57	0.62	1.44	1.30	1.37	0.06	0.03	0.05
T_2: NPK only	0.96	0.86	0.91	2.21	2.07	2.14	0.13	0.10	0.11
T_3:NPK + FYM	1.22	1.14	1.18	2.83	2.72	2.78	0.19	0.17	0.18
T_4:NPK+ $ZnSO_4$	1.17	1.08	1.12	2.50	2.38	2.44	0.16	0.14	0.15
T_5:NPK + Borax	1.09	0.99	1.04	2.34	2.21	2.27	0.14	0.12	0.13
T_6:NPK + $ZnSO_4$ + Borax	1.42	1.34	1.38	3.32	3.20	3.26	0.26	0.23	0.24
T_7:NPK+FYM + $ZnSO_4$	1.54	1.46	1.50	3.65	3.54	3.60	0.29	0.26	0.27
T_8:NPK + FYM + Borax	1.50	1.42	1.46	3.61	3.50	3.56	0.27	0.25	0.26
T_9:NPK + FYM + $ZnSO_4$ + Borax	1.57	1.50	1.53	3.74	3.63	3.68	0.30	0.28	0.29
F test	*	*****	*****	*	*****	*****	*	*****	*****
S.Em ±	**0.07**	**0.07**	**0.06**	**0.20**	**0.18**	**0.13**	**0.02**	**0.02**	**0.01**
CD at 5 %	**0.22**	**0.22**	**0.16**	**0.59**	**0.55**	**0.38**	**0.05**	**0.05**	**0.03**
CV (%)	**10.37**	**10.85**	**11.45**	**12.00**	**11.58**	**11.76**	**13.60**	**17.40**	**15.10**

DAS: Days after sowing, NPK @ 25:60:25 kg/ha, FYM @ 6.25 t/ha, $ZnSO_4$@ 12.50 kg/ha, Borax@10 kg/ha
Crop rotation: Finger millet (2005)- Soybean (2006), Soybean(2005)- Finger millet (2006)

Table 4.2.5: Leaf area duration and number of branches per plant of soybean at different growth stages as influenced zinc and boron application in finger millet- soybean based cropping system

Treatment	Leaf area duration (days)						Number of branches					
	30-60 DAS			60 DAS-harvest			60 DAS			At harvest		
	2005	2006	Pooled	2005	2006	Pooled	2005	2006	Pooled	2005	2006	Pooled
T_1: Control	31.74	28.12	29.93	22.48	20.07	21.27	0.90	0.50	0.70	1.30	0.95	1.13
T_2: NPK only	47.52	44.07	45.79	35.03	32.61	33.82	2.00	1.66	1.83	2.80	2.46	2.63
T_3:NPK + FYM	60.84	57.79	59.32	45.33	43.23	44.28	3.30	2.99	3.15	4.10	3.79	3.95
T_4:NPK+ $ZnSO_4$	55.04	51.91	53.47	39.94	37.80	38.87	3.10	2.78	2.94	3.90	3.58	3.74
T_5:NPK + Borax	51.32	48.07	49.69	37.20	34.99	36.09	2.80	2.47	2.64	3.70	3.37	3.54
T_6:NPK+ $ZnSO_4$ + Borax	71.05	68.10	69.58	53.60	51.53	52.57	4.10	3.80	3.95	4.80	4.50	4.65
T_7:NPK + FYM + $ZnSO_4$	77.80	75.05	76.42	59.05	57.10	58.08	4.80	4.52	4.66	5.70	5.42	5.56
T_8:NPK + FYM + Borax	76.70	73.85	75.27	58.19	56.19	57.19	4.50	4.21	4.36	5.20	4.91	5.06
T_9:NPK+FYM+$ZnSO_4$+ Borax	79.55	76.57	78.06	60.55	58.71	59.63	4.90	4.63	4.77	5.90	5.63	5.77
F test	*	*****	*****	*	*****	*****	*	*****	*****	*	*****	*****
S.Em ±	**3.12**	**3.25**	**2.28**	**2.98**	**2.70**	**2.00**	**0.36**	**0.26**	**0.26**	**0.34**	**0.25**	**0.22**
CD at 5 %	**9.37**	**9.73**	**6.57**	**8.93**	**8.09**	**5.76**	**1.09**	**0.78**	**0.75**	**1.03**	**0.73**	**0.62**
CV (%)	**8.83**	**9.67**	**9.37**	**11.29**	**10.72**	**10.99**	**18.56**	**14.65**	**19.75**	**14.30**	**11.04**	**13.29**

DAS: Days after sowing, NPK @ 25:60:25 kg/ha, FYM @ 6.25 t/ha, $ZnSO_4$ @ 12.50 kg/ha, Borax @ 10 kg/ha
Crop rotation: Finger millet (2005)- Soybean (2006), Soybean(2005)- Finger millet (2006)

(T_1 :0.70). However, all these treatments were found on par with each other (Table 4.2.5 and Fig. 14).

Significantly higher number of branches was recorded with application of NPK + FYM + $ZnSO_4$ + borax (T_9) at harvest (5.77) as compared to rest of the treatments. Application of NPK + FYM + $ZnSO_4$ (T_7) was found significantly on par with former treatment (5.56) and application of NPK + FYM + borax (T_8 : 5.06) at harvest. Significantly lower number of branches was recorded in control at 60 DAS (0.70) and at harvest (1.13).

4.2.1.6 Dry matter accumulation and its distribution (g/plant)

The data on dry matter accumulation in leaf, stem and total at 30 DAS and leaf, stem, pods and total at 60 DAS and at harvest of soybean plant are presented in Table 4.2.6 to 4.2.8.

4.2.1.6.1 Dry matter accumulation in leaf, stem and total dry matter accumulation (TDMA) at 30 DAS (g/plant)

Application of NPK + FYM + $ZnSO_4$ + borax (T_9) recorded significantly higher leaf dry matter (2.37 g/plant) as compared to rest of the treatments. Significantly higher leaf dry matter accumulation was noticed by application of NPK + FYM + $ZnSO_4$ (T_7 :2.06 g/plant) and NPK + FYM + borax (T_8 : 1.86 g/plant) which were found to be at par with each other (Table 4.2.6).

Significantly higher stem dry matter accumulation (1.98 g/plant) was recorded with application of NPK + FYM + $ZnSO_4$ + borax (T_9) which was found to be on par with application of NPK + FYM + $ZnSO_4$ (T_7 : 1.78 g/plant) and NPK + FYM + borax (T_8 : 1.73 g/plant).

Significantly lower TDMA was recorded in control (T_1 :0.47 g/plant), while application of NPK + FYM + $ZnSO_4$ + borax (T_9 :4.34

Table 4.2.6: Dry matter accumulation in leaf, stem and total dry matter accumulation (TDMA) of soybean at 30 DAS as influenced by zinc and boron application in finger millet- soybean based cropping system

Treatment	Leaf dry matter (g/plant)			Stem dry matter (g/plant)			TDMA(g/plant)		
	2005	2006	Pooled	2005	2006	Pooled	2005	2006	Pooled
T_1: Control	0.37	0.30	0.34	0.17	0.10	0.14	0.54	0.40	0.47
T_2: NPK only	0.62	0.55	0.59	0.40	0.35	0.38	1.02	0.90	0.96
T_3:NPK + FYM	1.27	1.20	1.24	1.05	1.00	1.03	2.32	2.20	2.26
T_4:NPK+ $ZnSO_4$	1.05	0.95	1.00	0.85	0.80	0.83	1.90	1.75	1.83
T_5:NPK + Borax	0.85	0.32	0.59	0.65	0.60	0.63	1.50	0.92	1.21
T_6:NPK + $ZnSO_4$ + Borax	1.70	1.32	1.51	1.55	1.50	1.53	3.25	2.82	3.04
T_7:NPK+FYM + $ZnSO_4$	2.10	2.02	2.06	1.80	1.75	1.78	3.90	3.77	3.84
T_8:NPK + FYM + Borax	1.90	1.82	1.86	1.75	1.70	1.73	3.65	3.52	3.59
T_9:NPK + FYM + $ZnSO_4$ + Borax	2.40	2.33	2.37	2.00	1.95	1.98	4.40	4.28	4.34
F test	*	*****	*****	*	*****	*****	*	*****	*****
S.Em ±	**0.15**	**0.10**	**0.09**	**0.09**	**0.08**	**0.06**	**0.23**	**0.18**	**0.14**
CD at 5 %	**0.46**	**0.30**	**0.26**	**0.28**	**0.24**	**0.18**	**0.68**	**0.54**	**0.41**
CV (%)	**19.60**	**14.30**	**17.22**	**14.37**	**12.72**	**13.54**	**15.79**	**13.60**	**14.76**

DAS: Days after sowing, NPK @ 25:60:25 kg/ha, FYM @ 6.25 t/ha, $ZnSO_4$ @ 12.50 kg/ha, Borax @ 10 kg/ha
Crop rotation: Finger millet (2005)- Soybean (2006), Soybean(2005)- Finger millet (2006)

g/plant) recorded significantly higher TDMA as compared to rest of the treatments and were found intermediate.

4.2.1.6.2 Dry matter accumulation in leaf, stem, pods and TDMA (g/plant) at 60 DAS

At 60 DAS, application of NPK + FYM + $ZnSO_4$ + borax (T_9 : 5.30 and 4.73 g/plant), NPK + FYM + $ZnSO_4$ (T_7 : 5.09 and 4.68 g/plant) and NPK + FYM + borax (T_8 : 4.89 and 4.52 g/plant) recorded significantly higher leaf and stem dry matter as compared to rest of the treatments except in NPK + $ZnSO_4$ + borax (T_6 : 4.37 g/plant) which was on par with application of NPK + FYM + borax (T_8) with respect to stem dry matter accumulation (Table 4.2.7).

Significantly higher pod dry matter (5.10 g/plant) and TDMA (15.13 g/plant) was recorded with application of NPK + FYM + $ZnSO_4$ + borax (T_9) over rest of the treatments. However, it was found on par with application of NPK + FYM + $ZnSO_4$ (T_7 : 4.99 and 14.76 g/plant in pods and TDMA, respectively) and NPK + FYM + borax (T_8 : 4.79 and 14.20 g per plant in pods and TDMA, respectively).

The control treatment recorded significantly lower dry matter in leaves, stem, pods and TDMA (T_1 : 1.28, 1.10, 1.38 and 3.75 g/plant, respectively) as compared to rest of the treatments.

4.2.1.6.3 Dry matter accumulation in leaf, stem, pods and TDMA (g/plant) at harvest

Application of NPK + FYM + $ZnSO_4$ + borax (T_9) recorded significantly higher dry matter in leaves and stem (2.03 and 4.55 g/plant) as compared to rest of the treatments. However, application of NPK + FYM + $ZnSO_4$ (T_7 :4.35 g/plant) was found on par with application

Table 4.2.7: Dry matter accumulation in leaf, stem, pod and total dry matter accumulation (TDMA) of soybean at 60 DAS as influenced zinc and boron application in finger millet- soybean based cropping system

Treatment	Leaf dry matter (g/plant)			Stem dry matter (g/plant)			Pod dry matter (g/plant)			TDMA (g/plant)		
	2005	2006	Pooled	2005	2006	Pooled	2005	2006	Pooled	2005	2006	Pooled
T_1: Control	1.40	1.15	1.28	1.20	1.00	1.10	1.50	1.25	1.38	4.10	3.40	3.75
T_2: NPK only	2.65	2.42	2.54	2.50	2.30	2.40	2.70	2.45	2.58	7.85	7.17	7.51
T_3:NPK + FYM	3.80	3.58	3.69	3.50	3.35	3.43	3.80	3.58	3.69	11.10	10.51	10.81
T_4:NPK+ $ZnSO_4$	3.60	3.38	3.49	3.00	2.84	2.92	3.70	3.50	3.60	10.30	9.72	10.01
T_5:NPK + Borax	3.40	3.19	3.30	2.80	2.64	2.72	3.55	3.32	3.44	9.75	9.15	9.45
T_6:NPK+ $ZnSO_4$ + Borax	4.75	4.53	4.64	4.45	4.29	4.37	4.20	3.98	4.09	13.40	12.80	13.10
T_7:NPK + FYM + $ZnSO_4$	5.20	4.98	5.09	4.75	4.60	4.68	5.10	4.88	4.99	15.05	14.46	14.76
T_8:NPK + FYM + Borax	5.00	4.78	4.89	4.60	4.44	4.52	4.90	4.68	4.79	14.50	13.90	14.20
T_9:NPK+FYM+$ZnSO_4$+ Borax	5.40	5.20	5.30	4.80	4.65	4.73	5.20	5.00	5.10	15.40	14.85	15.13
F test	*	*	*	*	*	*	*	*	*	*	*	*
S.Em ±	**0.30**	**0.26**	**0.20**	**0.25**	**0.15**	**0.14**	**0.24**	**0.20**	**0.15**	**0.85**	**0.95**	**0.63**
CD at 5 %	**0.90**	**0.77**	**0.58**	**0.75**	**0.43**	**0.42**	**0.72**	**0.60**	**0.44**	**2.54**	**2.86**	**1.81**
CV (%)	**13.28**	**12.11**	**12.95**	**12.34**	**7.51**	**10.34**	**10.86**	**9.48**	**10.05**	**13.04**	**15.51**	**14.09**

DAS: Days after sowing, NPK @ 25:60:25 kg/ha, FYM @ 6.25 t/ha, $ZnSO_4$ @ 12.50 kg/ha, Borax @ 10 kg/ha
Crop rotation: Finger millet (2005)- Soybean (2006), Soybean(2005)- Finger millet (2006)

of NPK + FYM + $ZnSO_4$ + borax (T_9) with respect to DMA in stem (Table 4.2.8).

Significantly higher pod dry matter and TDMA was registered with application of NPK + FYM + $ZnSO_4$ + borax (T_9: 10.83 and 17.40 g/plant, respectively), NPK + FYM + $ZnSO_4$ (T_7: 10.12 and 16.24 g/plant, respectively) and NPK + FYM + borax (T_8: 9.97 and 15.83 g/plant, respectively). However, all these treatments were found to be on par with each other and even with application of NPK + $ZnSO_4$ + borax(T_6) also (Table 4.2.8 and Fig. 15).

Significantly lower DMA in leaf, stem, pods and TDMA was noticed in control (T_1 : 0.50, 1.30, 3.40 and 5.20 g/plant, respectively) as compared to other treatments.

4.2.1.7 Nodule number per plant and nodule dry weight (g/plant)

The data pertaining to nodule number per plant and nodule dry weight are presented in Table 4.2.9 and 4.2.10.

4.2.1.7.1 Nodule number per plant

At 45 DAS, application of NPK + FYM + $ZnSO_4$ + borax (T_9) recorded significantly higher number of nodules per plant (42.97) followed by NPK + FYM + $ZnSO_4$ (T_7 : 40.51) and NPK + FYM + borax (T_8 : 38.61) which were found on par with each other (Table 4.2.9).

Application of NPK + FYM + $ZnSO_4$ + borax (T_9), NPK + FYM + $ZnSO_4$ (T_7), NPK + FYM + borax (T_8) and NPK + $ZnSO_4$ + borax (T_6) recorded significantly higher nodule number at 60 (65.62, 63.86, 61.36 and 59.35, respectively) and 75 DAS (55.02, 52.66, 50.01 and 48.55, respectively). However, they were found on par with each other. Significantly lower number of nodules were recorded in control (T_1 : 9.58, 23.43 and 12.48 at 45, 60 and 75 DAS, respectively).

Table 4.2.8: Dry matter accumulation in leaf, stem, pod and total dry matter accumulation (TDMA) of soybean at harvest as influenced zinc and boron application in finger millet- soybean based cropping system

Treatment	Leaf dry matter (g/plant)			Stem dry matter (g/plant)			Pod dry matter (g/plant)			TDMA (g/plant)		
	2005	2006	Pooled	2005	2006	Pooled	2005	2006	Pooled	2005	2006	Pooled
T_1: Control	0.60	0.40	0.50	1.50	1.10	1.30	3.50	3.30	3.40	5.60	4.80	5.20
T_2: NPK only	1.05	0.89	0.97	2.47	2.13	2.30	5.65	5.48	5.57	9.17	8.50	8.83
T_3:NPK + FYM	1.42	1.25	1.34	3.35	3.03	3.19	7.80	7.80	7.80	12.57	12.08	12.33
T_4:NPK+ $ZnSO_4$	1.30	1.00	1.15	3.20	2.90	3.05	7.50	7.34	7.42	12.00	11.24	11.62
T_5:NPK + Borax	1.20	0.98	1.09	3.10	2.78	2.94	7.30	7.13	7.22	11.60	10.89	11.25
T_6:NPK+ $ZnSO_4$ + Borax	1.70	1.49	1.60	3.95	3.63	3.79	9.85	9.68	9.77	15.50	14.80	15.15
T_7:NPK + FYM + $ZnSO_4$	1.90	1.64	1.77	4.50	4.20	4.35	10.20	10.03	10.12	16.60	15.87	16.24
T_8:NPK + FYM + Borax	1.84	1.70	1.77	4.25	3.94	4.10	10.05	9.88	9.97	16.14	15.52	15.83
T_9:NPK+FYM+$ZnSO_4$+ Borax	2.10	1.95	2.03	4.80	4.30	4.55	10.90	10.75	10.83	17.80	17.00	17.40
F test	*	*	*	*	*	*	*	*	*	*	*	*
S.Em ±	**0.11**	**0.11**	**0.08**	**0.26**	**0.24**	**0.17**	**0.63**	**0.58**	**0.43**	**1.03**	**0.93**	**0.69**
CD at 5 %	**0.33**	**0.33**	**0.23**	**0.77**	**0.70**	**0.49**	**1.88**	**1.74**	**1.25**	**3.08**	**2.79**	**1.98**
CV (%)	**13.00**	**15.04**	**14.20**	**12.86**	**13.09**	**12.83**	**13.42**	**12.68**	**13.28**	**13.69**	**13.12**	**13.33**

DAS: Days after sowing, NPK @ 25:60:25 kg/ha, FYM @ 6.25 t/ha, $ZnSO_4$ @ 12.50 kg/ha, Borax @ 10 kg/ha
Crop rotation: Finger millet (2005)- Soybean (2006), Soybean(2005)- Finger millet (2006)

Table 4.2.9: Nodule number in soybean at 45, 60 and 75 DAS as influenced by zinc and boron application in finger millet- soybean based cropping system

Treatment	Nodule number								
	45 DAS			60 DAS			75 DAS		
	2005	2006	Pooled	2005	2006	Pooled	2005	2006	Pooled
T_1: Control	10.30	8.85	9.58	24.60	22.25	23.43	14.20	10.75	12.48
T_2: NPK only	19.80	18.36	19.08	37.20	34.85	36.03	22.00	18.56	20.28
T_3:NPK + FYM	29.30	27.89	28.60	49.50	47.19	48.35	37.00	33.59	35.30
T_4:NPK+ $ZnSO_4$	26.20	24.78	25.49	45.25	42.93	44.09	35.00	34.58	34.79
T_5:NPK + Borax	24.30	22.87	23.59	40.00	37.67	38.84	30.20	26.87	28.54
T_6:NPK + $ZnSO_4$ + Borax	37.80	36.40	37.10	60.50	58.20	59.35	50.20	46.90	48.55
T_7:NPK + FYM + $ZnSO_4$	41.20	39.82	40.51	65.00	62.72	63.86	54.30	51.02	52.66
T_8:NPK + FYM + Borax	39.30	37.91	38.61	62.50	60.21	61.36	51.20	48.81	50.01
T_9:NPK + FYM + $ZnSO_4$ + Borax	43.60	42.33	42.97	66.75	64.48	65.62	56.20	53.83	55.02
F test	*	*	*	*	*	*	*	*	*
S.Em ±	**2.78**	**2.53**	**1.89**	**3.53**	**3.75**	**2.58**	**3.55**	**3.77**	**2.56**
CD at 5 %	**8.34**	**7.60**	**5.44**	**10.57**	**11.26**	**7.42**	**10.65**	**11.29**	**7.34**
CV (%)	**15.96**	**15.24**	**15.71**	**12.18**	**13.59**	**12.91**	**15.81**	**18.06**	**16.69**

DAS-Days after sowing, NPK @ 25:60:25 kg/ha, FYM @ 6.25 t/ha, $ZnSO_4$ @ 12.5 kg/ha, Borax @ 10 kg/ha
Crop rotation: Finger millet (2005)- Soybean (2006), Soybean(2005)- Finger millet (2006)

4.2.1.7.2 Nodule dry weight (g/plant)

Significant increase in nodule dry weight was recoded with application of NPK + FYM + $ZnSO_4$ + borax (T_9 : 0.78 g/plant) which was on par with application of NPK + FYM + $ZnSO_4$ (T_7 : 0.74 g/plant) at 45 DAS and was significantly superior over rest of the treatments. Lower nodule dry weight (0.08 g/plant) was observed in control (T_1) (Table 4.2.10).

At 60 and 75 DAS, application of NPK + FYM + $ZnSO_4$ + borax (T_9), NPK + FYM + $ZnSO_4$ (T_7) and NPK + FYM + borax (T_8) recorded significantly maximum nodule dry weight (1.13, 1.05 and 1.03 g/plant, respectively at 60 DAS) and (0.95, 0.92 and 0.89 g/plant, respectively at 75 DAS) as compared to rest of the treatments. However, lower nodule dry weight was recorded in control at 60 and 75 DAS (0.22 and 0.15 g/plant).

4.2.2 YIELD PARAMETERS OF SOYBEAN AS INFLUENCED BY ZINC AND BORON NUTRITION

The data on yield parameters of soybean are presented in Table 4.2.11 to 4.2.12.

4.2.2.1 Number of pods per plant

The micronutrients (zinc and boron) application caused significant variations in number of pods per plant (Table 4.2.11 and Fig. 16).

Significantly higher number of pods was recorded with application of NPK + FYM + $ZnSO_4$ + borax (T_9 : 23.65), NPK + FYM + $ZnSO_4$ (T_7 : 22.54) and NPK + FYM + borax (T_8 : 21.55). However, all these treatments were found to be on par with each other. Significantly lower number of pods per plant (5.75) was recorded in the control (T_1).

Table 4.2.10: Nodule dry weight in soybean at 45, 60 and 75 DAS as influenced by zinc and boron application in finger millet- soybean based cropping system

Treatment	Nodule dry weight (g/plant)								
	45 DAS			60 DAS			75 DAS		
	2005	2006	Pooled	2005	2006	Pooled	2005	2006	Pooled
T_1: Control	0.10	0.06	0.08	0.25	0.19	0.22	0.20	0.10	0.15
T_2: NPK only	0.40	0.36	0.38	0.60	0.54	0.57	0.50	0.43	0.47
T_3:NPK + FYM	0.45	0.41	0.43	0.70	0.64	0.67	0.62	0.50	0.56
T_4:NPK+ $ZnSO_4$	0.30	0.26	0.28	0.65	0.64	0.65	0.58	0.48	0.53
T_5:NPK + Borax	0.24	0.20	0.22	0.63	0.57	0.60	0.55	0.45	0.50
T_6:NPK + $ZnSO_4$ + Borax	0.70	0.66	0.68	0.85	0.80	0.83	0.90	0.82	0.86
T_7:NPK + FYM + $ZnSO_4$	0.75	0.73	0.74	1.08	1.03	1.05	0.95	0.88	0.92
T_8:NPK + FYM + Borax	0.75	0.72	0.73	1.06	1.01	1.03	0.93	0.84	0.89
T_9:NPK + FYM + $ZnSO_4$ + Borax	0.78	0.77	0.78	1.15	1.10	1.13	1.00	0.90	0.95
F test	*	*	*	*	*	*	*	*	*
S.Em ±	**0.03**	**0.01**	**0.02**	**0.05**	**0.05**	**0.03**	**0.04**	**0.02**	**0.02**
CD at 5 %	**0.09**	**0.04**	**0.05**	**0.15**	**0.14**	**0.10**	**0.11**	**0.06**	**0.06**
CV (%)	**10.10**	**5.13**	**8.14**	**11.53**	**11.54**	**11.23**	**9.49**	**5.43**	**8.53**

DAS-Days after sowing, NPK @ 25:60:25 kg/ha, FYM @ 6.25 t/ha, $ZnSO_4$ @ 12.5 kg/ha, Borax @ 10 kg/ha
Crop rotation: Finger millet (2005)- Soybean (2006), Soybean(2005)- Finger millet (2006)

4.2.2.2 Number of seeds per plant

Application of NPK + FYM + $ZnSO_4$ + borax (T_9) recorded significantly higher number of seeds per plant (2.85) as compared to rest of the treatments, while application of NPK + FYM + $ZnSO_4$ (T_7), NPK + FYM + borax (T_8) and NPK + $ZnSO_4$ + borax (T_6) were on par with each other and recorded significantly higher number of seeds per plant (2.77, 2.75 and 2.65 seeds/plants, respectively) as compared to other treatments. However, lower number of seeds per plant (2) was recorded in the control plot (T_1) (Table 4.2.11 and Fig. 16).

4.2.2.3 Pod length (cm)

Significantly higher pod length (4.75 cm) was obtained with application of NPK + FYM + $ZnSO_4$ + borax (T_9) which was on par with application of NPK + FYM + borax (T_8 : 4.50 cm) and NPK + FYM + $ZnSO_4$ (T_7 : 4.64 cm). Lower pod length was recorded in the control (T_1 :1.50 cm) (Table 4.2.11 and Fig. 16).

4.2.2.4 Pod yield (g/plant)

Data on pod yield differed significantly due to micronutrients application (Table 4.2.12 and Fig. 17).

Application of NPK + FYM + $ZnSO_4$ + borax (T_9 : 10.83 g/plant) recorded significantly higher pod yield as compared to rest of the treatments. However, it was found to be on par with application of NPK + FYM + $ZnSO_4$ (T_7 : 10.12 g/plant), NPK + $ZnSO_4$ + borax (T_6 : 9.77 g/plant). Application NPK + FYM (T_3 : 7.80 g/plant), NPK + $ZnSO_4$ (T_4 : 7.42 g/plant) and NPK + borax (T_5 : 7.22 g/plant) were found on par with each other and recorded significantly higher pod yield as compared to NPK only (T_2 : 5.57 g/plant) and control (T_1 : 3.40 g/plant).

Table 4.2.11: Number of pods per plant, number of seeds per plant and pod length of soybean as influenced by zinc and boron application in finger millet- soybean based cropping system

Treatment	Number of pods per plant			Number of seeds per plant			Pod length (cm)		
	2005	2006	Pooled	2005	2006	Pooled	2005	2006	Pooled
T_1: Control	7.00	4.50	5.75	2.00	2.00	2.00	1.80	1.20	1.50
T_2: NPK only	12.40	10.00	11.20	2.20	2.07	2.13	3.30	2.71	3.01
T_3:NPK + FYM	17.50	15.10	16.30	2.50	2.30	2.40	3.60	3.04	3.32
T_4:NPK+ $ZnSO_4$	16.50	14.18	15.34	2.30	2.20	2.25	3.50	2.93	3.22
T_5:NPK + Borax	16.00	13.68	14.84	2.20	2.10	2.15	3.35	3.27	3.31
T_6:NPK + $ZnSO_4$ + Borax	20.50	18.00	19.25	2.70	2.60	2.65	4.70	4.15	4.43
T_7:NPK + FYM + $ZnSO_4$	23.70	21.38	22.54	2.80	2.73	2.77	4.90	4.37	4.64
T_8:NPK + FYM + Borax	22.80	20.30	21.55	2.80	2.70	2.75	4.73	4.26	4.50
T_9:NPK + FYM + $ZnSO_4$ + Borax	24.80	22.50	23.65	2.90	2.80	2.85	5.00	4.50	4.75
F test	*	*****	*****	*	*****	*****	*	*****	*****
S.Em ±	**1.64**	**1.42**	**1.13**	**0.09**	**0.07**	**0.06**	**0.09**	**0.10**	**0.09**
CD at 5 %	**4.91**	**4.25**	**3.26**	**0.28**	**0.21**	**0.17**	**0.26**	**0.29**	**0.25**
CV (%)	**15.85**	**15.82**	**16.62**	**6.51**	**5.20**	**6.06**	**3.83**	**5.03**	**5.87**

NPK @ 25:60:25 kg/ha, FYM @ 6.25 t/ha, $ZnSO_4$ @ 12.5 kg/ha, Borax @ 10 kg/ha

Crop rotation: Finger millet (2005)- Soybean (2006), Soybean(2005)- Finger millet (2006)

4.2.2.5 Seed yield (g/plant)

Among the various treatments, conjunctive use of zinc sulphate and borax along with recommended NPK and FYM (T_9) recorded significantly higher seed yield (5.22 g/plant), but it was found on par with application of NPK + $ZnSO_4$ + borax (T_6 : 4.72 g/plant), NPK + FYM + $ZnSO_4$ (T_7 : 5.13 g/plant), NPK + FYM + borax (T_8 : 5.02 g/plant), while control plot (T_1) recorded lower seed yield (1.85 g/plant) (Table 4.2.12 and Fig. 17).

4.2.2.6 Test weight (g)

Significantly lower test weight (10.90 g) was recorded in control (T_1) as compared to rest of the treatments, whereas application of NPK + FYM + $ZnSO_4$ + borax (T_9), NPK + FYM + borax (T_8) and NPK + FYM + $ZnSO_4$ (T_7) were found on par with each other, but recorded significantly higher test weight (14.35, 13.60 and 14.05 g, respectively) as compared to control (Table 4.2.12 and Fig. 17).

4.2.3 SEED YIELD, HAULM YIELD AND HARVEST INDEX OF SOYBEAN AS INFLUENCED BY ZINC AND BORON APPLICATION

4.2.3.1 Seed yield (kg/ha)

The micronutrients application caused significant variation in seed yield. Among different treatments, application of NPK + FYM + $ZnSO_4$ + borax (T_9) recorded significantly higher seed yield (1936 kg/ha) as compared to control (T_1 :838 kg/ha). However, it was found on par with application of NPK + FYM + borax (T_8 :1875 kg/ha), NPK + FYM + $ZnSO_4$ (T_7 : 1908 kg/ha) and NPK + $ZnSO_4$ + borax (T_6 :1777 kg/ha). Whereas, application of NPK + FYM (T_3 :1560 kg/ha), NPK + $ZnSO_4$ (T_4 :1517 kg/ha) and NPK + borax (T_5 :1491 kg/ha) were found on par with each other and recorded significantly higher seed yield as compared to control (T_1). The magnitude of increase in the yield due to application of NPK +

Table 4.2.12: Pod yield, seed yield and test weight (100-seed weight) of soybean as influenced by zinc and boron application in finger millet- soybean based cropping system

Treatment	Pod yield (g/plant)			Seed yield (g/ plant)			Test weight (g)		
	2005	2006	Pooled	2005	2006	Pooled	2005	2006	Pooled
T_1: Control	3.50	3.30	3.40	2.03	1.67	1.85	11.00	10.80	10.90
T_2: NPK only	5.65	5.48	5.57	3.51	2.64	3.08	12.80	12.37	12.58
T_3:NPK + FYM	7.80	7.80	7.80	4.45	3.66	4.06	13.30	13.10	13.20
T_4:NPK+ $ZnSO_4$	7.50	7.34	7.42	4.29	3.64	3.97	13.10	12.90	13.00
T_5:NPK + Borax	7.30	7.13	7.22	4.10	3.56	3.83	12.90	12.70	12.80
T_6:NPK + $ZnSO_4$ + Borax	9.85	9.68	9.77	5.04	4.39	4.72	13.50	13.20	13.35
T_7:NPK + FYM + $ZnSO_4$	10.20	10.03	10.12	5.48	4.78	5.13	14.10	14.00	14.05
T_8:NPK + FYM + Borax	10.05	9.88	9.97	5.37	4.67	5.02	13.70	13.50	13.60
T_9:NPK + FYM + $ZnSO_4$ + Borax	10.90	10.75	10.83	5.57	4.87	5.22	14.30	14.40	14.35
F test	*	*****	*****	*	*****	*****	*	*****	*****
S.Em ±	**0.63**	**0.58**	**0.43**	**0.30**	**0.24**	**0.19**	**0.45**	**0.27**	**0.29**
CD at 5 %	**1.88**	**1.74**	**1.25**	**0.90**	**0.73**	**0.54**	**NS**	**NS**	**0.83**
CV (%)	**13.42**	**12.68**	**13.28**	**11.71**	**11.14**	**11.26**	**5.96**	**3.58**	**5.42**

NPK @ 25:60:25 kg/ha, FYM @ 6.25 t/ha, $ZnSO_4$ @12.5 kg/ha, Borax @10 kg/ha, NS: Non significant
Crop rotation: Finger millet (2005)- Soybean (2006), Soybean(2005)- Finger millet (2006)

FYM + $ZnSO_4$ + borax (T_9), NPK + FYM + $ZnSO_4$ (T_7) and NPK + FYM + borax (T_8) was 131.03, 127.68 and 123.75 per cent over control, respectively (Table 4.2.13 and Fig. 18).

4.2.3.2 Haulm yield (kg/ha)

The data on haulm yield of soybean differed significantly due to micronutrients application (Table 4.2.13 and Fig. 18). Application of NPK + FYM + $ZnSO_4$ + borax (T_9), NPK + FYM + $ZnSO_4$ (T_7), NPK + FYM + borax (T_8) and NPK + $ZnSO_4$ + borax (T_6) recorded significantly higher haulm yield (3152, 3107, 3056 and 2956 kg/ha, respectively). However, all these treatments were found on par with each other. Significantly lower haulm yield was registered in control (T_1 :1428 kg/ha) while rest of the treatments were found intermediate.

4.2.3.3 Harvest index (HI)

Data on HI of soybean did not differ significantly due to micronutrients application (Table 4.2.13 and Fig. 18).

4.2.4 SEED QUALITY PARAMETERS OF SOYBEAN

4.2.4.1 Protein content (%) and protein yield (kg/ha)

The data on protein content (%) and protein yield (kg/ha) are presented in Table 4.2.14 and Fig. 20)

The protein content (%) of soybean did not differ significantly due to micronutrients application. However, numerically, higher protein content was recorded with application of NPK + FYM + $ZnSO_4$ + borax (T_9 : 41.19%) followed by NPK + FYM + $ZnSO_4$ (T_7 : 40.84%) and NPK + FYM + borax (T_8 : 40.16%) (Table 4.2.17).

There was significant difference in protein yield due to micronutrients application. Combined application of zinc sulphate and

Table 4.2.13: Seed yield, haulm yield and harvest index of soybean as influenced by zinc and boron application in finger millet- soybean based cropping system

Treatment	Seed yield (kg/ ha)			Haulm yield (kg/ha)			Harvest index		
	2005	2006	Pooled	2005	2006	Pooled	2005	2006	Pooled
T_1: Control	911	764	838	1525	1330	1428	0.37	0.37	0.37
T_2: NPK only	1403	1085	1244	2100	1880	1990	0.40	0.40	0.38
T_3:NPK + FYM	1704	1415	1560	2619	2430	2525	0.39	0.39	0.38
T_4:NPK+ $ZnSO_4$	1623	1410	1517	2613	2395	2504	0.38	0.38	0.37
T_5:NPK + Borax	1594	1387	1491	2563	2355	2459	0.39	0.39	0.38
T_6:NPK + $ZnSO_4$ + Borax	1898	1655	1777	2969	2943	2956	0.39	0.39	0.38
T_7:NPK + FYM + $ZnSO_4$	2038	1778	1908	3187	3027	3107	0.39	0.39	0.38
T_8:NPK + FYM + Borax	2004	1745	1875	3134	2978	3056	0.39	0.39	0.38
T_9:NPK + FYM + $ZnSO_4$ + Borax	2066	1805	1936	3231	3073	3152	0.39	0.39	0.38
F test	*	*	*	*	*	*			*
S.Em ±	**98.36**	**104.29**	**94.72**	**170.97**	**181.58**	**122.74**	**0.02**	**0.02**	**0.02**
CD at 5 %	**294.88**	**312.69**	**272.18**	**512.58**	**544.41**	**352.71**	**NS**	**NS**	**NS**
CV (%)	**10.06**	**12.46**	**14.76**	**11.13**	**12.63**	**11.68**	**8.69**	**10.90**	**10.94**

NPK @ 25:60:25 kg/ha, FYM @ 6.25 t/ha, $ZnSO_4$ @ 12.5 kg/ha, Borax @ 10 kg/ha, NS-Non significant
Crop rotation: Finger millet (2005)- Soybean (2006), Soybean(2005)- Finger millet (2006)

borax along with recommended NPK and FYM (T_9) recorded significantly higher protein yield (792.95 kg/ha) over rest of the treatments. However, application of NPK + FYM + $ZnSO_4$ (T_7 :777.75 kg/ha) and NPK + FYM + borax (T_8 :753.14 kg/ha) were found on par with the former treatments. Significantly lower protein yield (326.54 kg/ha) was recorded in control (T_1) (Table 4.2.14 and Fig. 20).

4.2.4.2 Oil content (%) and oil yield (kg/ha)

Oil content did not differ significantly due to treatment effects. However, numerically higher oil content was obtained with application of NPK + FYM + $ZnSO_4$ + borax (T_9 :18.75%) (Table 4.2.14).

Oil yield differed significantly due to zinc and boron application. Conjunctive application of zinc sulphate and borax along with recommended NPK and FYM recorded significantly higher oil yield (T_9 : 362.04 kg/ha) as compared to rest of the treatments. However, it was found on par with application of NPK + FYM + $ZnSO_4$ (T_7 :354.83 kg/ha) and NPK + FYM + borax (T_8 :350.06 kg/ha). Significantly lower oil yield (146.30 kg/ha) was recorded in control (T_1:146.30 kg/ha) while the rest of the treatments were found intermediate (Table 4.2.14 and Fig. 20).

4.2.4.3 Germination (%), dry weight of root and shoot (mg) and seed vigour index

The data on seed quality parameters of soybean are presented in Table 4.2.15 and Fig. 19.

The results indicated that, application of NPK + FYM + $ZnSO_4$ + borax (T_9) recorded significantly higher germination (97%) and shoot and root dry weight (24.85 mg) when compared to control. This was found to be on par with application of NPK + FYM + $ZnSO_4$ (T_7 : 95% and 23.60 mg, respectively).

Table 4.2.14: Protein content, protein yield, oil content and oil yield of soybean as influenced zinc and boron application in finger millet- soybean based cropping system

Treatment	Protein content (%)			Protein yield (kg/ ha)			Oil content (%)			Oil yield (kg/ ha)		
	2005	2006	Pooled	2005	2006	Pooled	2005	2006	Pooled	2005	2006	Pooled
T_1: Control	39.00	39.06	39.03	354.60	298.49	326.54	17.55	17.40	17.48	159.61	132.98	146.30
T_2: NPK only	39.25	39.13	39.19	547.24	425.47	486.36	18.10	17.98	18.04	253.74	195.14	224.44
T_3:NPK + FYM	39.50	39.38	39.44	674.75	557.57	616.16	18.45	18.39	18.42	314.43	260.18	287.31
T_4:NPK+ $ZnSO_4$	39.38	39.19	39.28	637.71	552.63	595.17	18.13	18.30	18.22	293.37	258.11	275.74
T_5:NPK + Borax	39.25	39.06	39.16	625.53	539.29	582.41	18.42	18.09	18.25	293.66	251.07	272.36
T_6:NPK+$ZnSO_4$+Borax	39.88	40.00	39.94	754.35	661.91	708.13	18.65	18.48	18.57	353.62	305.78	329.70
T_7:NPK+FYM + $ZnSO_4$	40.81	40.88	40.84	827.10	728.40	777.75	18.72	18.66	18.69	381.11	328.54	354.83
T_8:NPK+ FYM + Borax	40.13	40.19	40.16	805.33	700.95	753.14	18.65	18.59	18.62	373.45	326.68	350.06
T_9:NPK+FYM+$ZnSO_4$+ Borax	41.25	41.13	41.19	845.98	739.93	792.95	18.80	18.70	18.75	389.86	334.22	362.04
F test	**-**	**-**	**-**	*****	*****	*****	**-**	**-**	**-**	*****	*****	*****
S.Em ±	**1.39**	**1.45**	**1.01**	**41.62**	**32.79**	**28.02**	**0.65**	**0.65**	**0.47**	**13.84**	**11.63**	**9.03**
CD at 5 %	**NS**	**NS**	**NS**	**124.79**	**98.319**	**80.51**	**NS**	**NS**	**NS**	**41.48**	**34.85**	**25.95**
CV (%)	**6.03**	**6.33**	**6.21**	**10.68**	**9.82**	**10.95**	**6.12**	**6.18**	**6.26**	**7.67**	**7.57**	**7.65**

NS: Non Significant, NPK @ 25:60:25 kg/ha, FYM @ 6.25 t/ha, $ZnSO_4$ @ 12.50 kg/ha, Borax @ 10 kg/ha
Crop rotation: Finger millet (2005)- Soybean (2006), Soybean(2005)- Finger millet (2006)

Significantly higher vigour index was recorded with application of NPK + FYM + $ZnSO_4$ + borax (T_9 :2397)as compared to rest of the treatments. Application of NPK + FYM + $ZnSO_4$ (T_7 :2231) and NPK + FYM + borax (T_8 :2095) were found on par with each other but recorded significantly higher seed vigour index over rest of the treatments except with application of NPK + FYM + $ZnSO_4$ + borax (T_9) (Table 4.2.15 and Fig. 19).

4.2.5 NUTRIENTS UPTAKE STUDIES

4.2.5.1 Nitrogen uptake by soybean seed, haulm and total plant uptake (kg/ha)

The data pertaining to nitrogen uptake by seeds, haulm and total plant uptake at harvest are presented in Table 4.2.16.

Significant differences were observed in nitrogen uptake by seed of soybean due to micronutrients application. Combined application of zinc sulphate and borax along with recommended dose of NPK and FYM (T_9) recorded significantly higher nitrogen uptake by soybean seed (127.57 kg/ha) as compared to rest of the treatments. However, it was found on par with application of NPK + FYM + $ZnSO_4$ (T_7 : 124.68 kg/ha) and NPK + FYM + borax (T_8 : 120.43 kg/ha). Application of NPK + $ZnSO_4$ + borax (T_6 : 113.51 kg/ha) recorded significantly higher nitrogen uptake by soybean seeds as compared to NPK + $ZnSO_4$ (T_4 : 95.33 kg/ha), NPK + borax (T_5 : 93.40 kg/ha), NPK + FYM (T_3 : 98.42 kg/ha) and NPK only (T_2 : 78.02 kg/ha) (Table 4.2.16).

Application of NPK + FYM + $ZnSO_4$ + borax (T_9 : 39.13 kg/ha) recorded significantly higher nitrogen uptake by soybean haulm as compared to rest of the treatments. Application of NPK + FYM + $ZnSO_4$ (T_7 : 34.87 kg/ha), NPK + FYM + borax (T_8 : 33.45 kg/ha) and NPK + $ZnSO_4$ + borax (T_6 : 32.74 kg/ha) registered significantly higher nitrogen

Table 4.2.15: Germination, dry weight of shoot and root and seed vigour index of soybean as influenced by zinc and boron application in finger millet- soybean based cropping system

Treatment	Germination (%)			Dry weight of shoot and root (mg)			Seed vigour index		
	2005	2006	Pooled	2005	2006	Pooled	2005	2006	Pooled
T_1: Control	77	77	77	13.90	13.20	13.55	1070	1015	1043
T_2: NPK only	83	82	83	17.20	17.50	17.35	1427	1437	1432
T_3:NPK + FYM	89	87	88	19.50	19.75	19.63	1735	1718	1726
T_4:NPK+ $ZnSO_4$	88	85	87	18.30	18.20	18.25	1609	1548	1578
T_5:NPK + Borax	87	84	86	18.10	17.80	17.95	1574	1495	1534
T_6:NPK + $ZnSO_4$ + Borax	92	91	92	21.60	20.00	20.80	1990	1820	1905
T_7:NPK + FYM + $ZnSO_4$	95	94	95	23.70	23.50	23.60	2254	2208	2231
T_8:NPK + FYM + Borax	94	92	93	23.40	21.60	22.50	2202	1987	2095
T_9:NPK + FYM + $ZnSO_4$ + Borax	97	96	97	25.20	24.50	24.85	2444	2351	2397
F test	*	*****	*****	*	*****	*****	*	*****	*****
S.Em ±	**1.41**	**1.52**	**1.11**	**0.70**	**0.60**	**0.50**	**74.53**	**64.71**	**51.66**
CD at 5 %	**4.23**	**4.55**	**3.19**	**2.09**	**1.81**	**1.44**	**223.46**	**193.99**	**148.46**
CV (%)	**2.74**	**3.00**	**3.08**	**6.02**	**5.33**	**6.18**	**7.13**	**6.48**	**7.14**

NPK @ 25:60:25 kg/ha, FYM @ 6.25 t/ha, $ZnSO_4$ @ 12.5 kg/ha, Borax @ 10 kg/ha
Crop rotation: Finger millet (2005)- Soybean (2006), Soybean(2005)- Finger millet (2006)

Table 4.2.16: Nitrogen uptake by seed, haulm and total nitrogen uptake of soybean as influenced by zinc and boron application in finger millet- soybean based cropping system

Treatment	Nitrogen uptake (kg/ha)								
	Seed (kg/ha)			Haulm (kg/ha)			Total uptake (kg/ha)		
	2005	2006	Pooled	2005	2006	Pooled	2005	2006	Pooled
T_1: Control	56.85 (6.24)	47.75 (6.25)	52.30 (6.25)	15.59 (1.02)	13.69 (1.03)	14.64 (1.03)	72.44 (7.26)	61.44 (7.28)	66.94 (7.27)
T_2: NPK only	88.11 (6.28)	67.92 (6.26)	78.02 (6.27)	21.53 (1.03)	19.21 (1.02)	20.37 (1.02)	109.64 (7.31)	87.13 (7.28)	98.39 (7.29)
T_3:NPK + FYM	107.69 (6.32)	89.15 (6.30)	98.42 (6.31)	26.78 (1.03)	24.91 (1.03)	25.85 (1.03)	134.47 (7.35)	114.06 (7.33)	124.27 (7.34)
T_4:NPK+ $ZnSO_4$	102.25 (6.30)	88.41 (6.27)	95.33 (6.29)	26.84 (1.03)	24.50 (1.02)	25.67 (1.03)	129.09 (7.33)	112.91 (7.29)	121.00 (7.31)
T_5:NPK + Borax	100.10 (6.28)	86.69 (6.25)	93.40 (6.27)	26.35 (1.03)	24.14 (1.03)	25.25 (1.03)	126.45 (7.31)	110.83 (7.28)	118.64 (7.29)
T_6:NPK + $ZnSO_4$ + Borax	121.09 (6.38)	105.92 (6.40)	113.51 (6.39)	32.96 (1.11)	32.52 (1.11)	32.74 (1.11)	154.05 (7.49)	138.44 (7.51)	146.25 (7.50)
T_7:NPK + FYM + $ZnSO_4$	133.08 (6.53)	116.28 (6.54)	124.68 (6.54)	35.85 (1.13)	33.90 (1.12)	34.87 (1.12)	168.93 (7.66)	150.18 (7.66)	159.55 (7.66)
T_8:NPK + FYM + Borax	128.66 (6.42)	112.20 (6.43)	120.43 (6.43)	34.35 (1.10)	32.55 (1.09)	33.45 (1.09)	163.01 (7.52)	144.75 (7.52)	153.88 (7.52)
T_9:NPK + FYM + $ZnSO_4$ + Borax	136.36 (6.60)	118.77 (6.58)	127.57 (6.59)	36.77 (1.14)	41.49 (1.35)	39.13 (1.24)	173.13 (7.74)	160.26 (7.93)	166.70 (7.83)
F test	*	*	*	*	*	*	*	*	*
S.Em ±	**5.18**	**5.07**	**3.68**	**1.44**	**1.28**	**0.99**	**5.20**	**5.36**	**3.73**
CD at 5 %	**15.54**	**15.20**	**10.57**	**4.30**	**3.83**	**2.84**	**15.58**	**16.06**	**10.71**
CV (%)	**8.30**	**9.49**	**8.97**	**8.71**	**8.06**	**8.66**	**6.58**	**7.73**	**7.11**

NPK @ 25:60:25 kg/ha, FYM @ 6.25 t/ha, $ZnSO_4$ @ 12.5 kg/ha, Borax @ 10 kg/ha

Figures in parenthesis indicates actual concentration of nitrogen in per cent

Crop rotation: Finger millet (2005)- Soybean (2006), Soybean(2005)- Finger millet (2006)

uptake by soybean haulm. However, all these treatments were found on par with each other.

Significantly higher total nitrogen uptake by soybean plant was recorded with application of NPK + FYM + $ZnSO_4$ + borax (T_9 : 166.70 kg/ha) as compared to rest of the treatments except with application of NPK + FYM + $ZnSO_4$ (T_7 : 159.55 kg/ha). Significantly lower nitrogen uptake by soybean seed, haulm and total N uptake was observed in control (52.30, 14.64 and 66.94 kg/ha, respectively) (Table 4.2.16 and Fig. 21).

4.2.5.2 Phosphorous uptake by soybean seed, haulm and total plant uptake (kg/ha)

Phosphorus uptake by soybean seed ranged from 1.10 to 3.38 kg per ha due to micronutrients application. Significantly higher removal of phosphorus by soybean seeds (3.38 kg/ha) was noticed with application of NPK + FYM + $ZnSO_4$ + borax (T_9) which was found to be on par with application of NPK + FYM + $ZnSO_4$ (T_7 :3.22 kg/ha). The minimal removal of phosphorus was noticed in control (T_1 :1.10 kg/ha) (Table 4.2.17).

Application of NPK + FYM + $ZnSO_4$ + borax (T_9) recorded significantly higher phosphorus uptake by soybean haulm (4.04 kg/ha) and total phosphorus uptake (7.41 kg/ha) as compared to rest of the treatments. However, it was found on par with the application of NPK + FYM + $ZnSO_4$ (T_7 : 3.84 and 7.05 kg/ha uptake of phosphorus in haulm and total plant uptake, respectively). The control treatment recorded significantly lower phosphorus removal (1.30 and 2.39 kg/ha, respectively) (Table 4.2.17 and Fig. 21).

Table 4.2.17: Phosphorus uptake by seed, haulm and total phosphorus uptake of soybean as influenced by zinc and boron application in finger millet- soybean based cropping system

Treatment	Phosphorus uptake (kg/ha)								
	Seed (kg/ha)			Haulm (kg/ha)			Total uptake (kg/ha)		
	2005	2006	Pooled	2005	2006	Pooled	2005	2006	Pooled
T_1: Control	1.18 (0.130)	1.01 (0.132)	1.10 (0.131)	1.37 (0.090)	1.22 (0.092)	1.30 (0.091)	2.55 (0.220)	2.23 (0.224)	2.39 (0.222)
T_2: NPK only	2.06 (0.147)	1.58 (0.146)	1.82 (0.147)	2.04 (0.097)	1.79 (0.095)	1.92 (0.096)	4.10 (0.244)	3.37 (0.241)	3.74 (0.243)
T_3:NPK + FYM	2.69 (0.158)	2.19 (0.155)	2.44 (0.157)	3.01 (0.115)	2.72 (0.112)	2.87 (0.114)	5.70 (0.273)	4.91 (0.267)	5.31 (0.270)
T_4:NPK+ $ZnSO_4$	2.52 (0.156)	2.17 (0.154)	2.35 (0.155)	2.82 (0.108)	2.49 (0.104)	2.66 (0.106)	5.34 (0.263)	4.66 (0.258)	5.00 (0.261)
T_5:NPK + Borax	2.39 (0.150)	2.08 (0.150)	2.24 (0.150)	2.61 (0.102)	2.31 (0.098)	2.46 (0.100)	5.00 (0.252)	4.39 (0.248)	4.70 (0.250)
T_6:NPK + $ZnSO_4$ + Borax	3.06 (0.161)	2.61 (0.158)	2.84 (0.160)	3.47 (0.117)	3.30 (0.112)	3.39 (0.115)	6.53 (0.278)	5.91 (0.270)	6.22 (0.274)
T_7:NPK + FYM + $ZnSO_4$	3.46 (0.170)	2.97 (0.167)	3.22 (0.169)	3.98 (0.125)	3.69 (0.122)	3.84 (0.124)	7.44 (0.295)	6.66 (0.289)	7.05 (0.292)
T_8:NPK + FYM + Borax	3.31 (0.165)	2.84 (0.163)	3.08 (0.164)	3.79 (0.121)	3.48 (0.117)	3.64 (0.119)	7.10 (0.286)	6.32 (0.280)	6.71 (0.283)
T_9:NPK + FYM + $ZnSO_4$ + Borax	3.64 (0.176)	3.12 (0.173)	3.38 (0.175)	4.20 (0.130)	3.87 (0.126)	4.04 (0.128)	7.84 (0.306)	6.99 (0.299)	7.41 (0.303)
F test	*	*	*	*	*	*	*	*	*
S.Em ±	**0.14**	**0.14**	**0.10**	**0.15**	**0.14**	**0.10**	**0.30**	**0.21**	**0.18**
CD at 5 %	**0.41**	**0.43**	**0.28**	**0.46**	**0.43**	**0.29**	**0.89**	**0.62**	**0.51**
CV (%)	**8.81**	**10.94**	**9.60**	**8.81**	**8.92**	**8.61**	**8.97**	**7.08**	**8.08**

NPK @ 25:60:25 kg/ha, FYM @ 6.25 t/ha, $ZnSO_4$ @ 12.5 kg/ha, Borax @ 10 kg/ha

Figures in parenthesis indicate actual concentration of Phosphorus in per cent

Crop rotation: Finger millet (2005)- Soybean (2006), Soybean(2005)- Finger millet (2006)

4.2.5.3 Potassium uptake by soybean seed, haulm and total plant uptake (kg/ha)

Significantly higher potassium uptake in seed and haulm was recorded with application of NPK + FYM + $ZnSO_4$ + borax (T_9 : 9.49 and 47.16 kg/ha, respectively) over all other treatments except with NPK + FYM + $ZnSO_4$ (T_7 : 9.23 and 46.35 kg/ha, respectively), NPK + FYM + borax (T_8 : 45.43 kg/ha) and NPK + $ZnSO_4$ + borax (T_6 : 43.82 kg/ha) in haulm (Table 4.2.18).

Total potassium uptake was significantly superior with application of NPK + FYM + $ZnSO_4$ + borax (T_9 :56.65 kg/ha) over rest of the treatments. However, it was found on par with application of NPK + FYM + $ZnSO_4$ (T_7 : 55.57 kg/ha) and NPK + FYM + borax (T_8 : 53.90 kg/ha). Significantly lower potassium uptake in seed, haulm and total K uptake was recorded in control (T_1 :3.78, 20.85 and 24.63 kg/ha, respectively) (Table 4.2.18 and Fig. 21).

4.2.5.4 Zinc uptake by soybean seed, haulm and total plant uptake (g/ha)

Zinc uptake by soybean seed and haulm differed significantly due to application of zinc and boron. Application of NPK + FYM + $ZnSO_4$ + borax (T_9) and NPK + FYM + $ZnSO_4$ (T_7) recorded significantly higher zinc uptake (119.80 and 115.80 g/ha in seed, 65.85 and 63.74 g/ha, respectively in haulm). However, these two treatments were found at par with each other (Table 4.2.19).

The total zinc uptake by soybean plant was significantly higher with application of NPK + FYM + $ZnSO_4$ + borax (T_9 : 185.65 g/ha) and NPK + FYM + $ZnSO_4$ (T_7 : 179.53 g/ha) as compared to control. However, these two treatments were found on par with each other. Significantly lower zinc uptake by seed, haulm and total Zn was recorded in control

Table 4.2.18: Potassium uptake by seed, haulm and total potassium uptake of soybean as influenced by zinc and boron application in finger millet- soybean based cropping system

Treatment	Potassium uptake (kg/ha)								
	Seed (kg/ha)			Haulm (kg/ha)			Total uptake(kg/ha)		
	2005	2006	Pooled	2005	2006	Pooled	2005	2006	Pooled
T_1: Control	4.12 (0.452)	3.44 (0.450)	3.78 (0.451)	22.30 (1.462)	19.39 (1.458)	20.85 (1.460)	26.42 (1.914)	22.83 (1.908)	24.63 (1.911)
T_2: NPK only	6.48 (0.462)	4.96 (0.457)	5.72 (0.460)	30.77 (1.465)	27.49 (1.462)	29.13 (1.464)	37.25 (1.927)	32.45 (1.919)	34.85 (1.923)
T_3:NPK + FYM	8.01 (0.470)	6.61 (0.467)	7.31 (0.469)	38.68 (1.477)	35.82 (1.474)	37.25 (1.476)	46.69 (1.947)	42.43 (1.941)	44.56 (1.944)
T_4:NPK+ $ZnSO_4$	7.58 (0.467)	6.51 (0.462)	7.05 (0.465)	38.49 (1.473)	35.21 (1.470)	36.85 (1.472)	46.07 (1.940)	41.72 (1.932)	43.90 (1.936)
T_5:NPK + Borax	7.38 (0.463)	6.35 (0.458)	6.87 (0.461)	37.62 (1.468)	34.50 (1.465)	36.06 (1.467)	45.00 (1.931)	40.85 (1.923)	42.93 (1.927)
T_6:NPK + $ZnSO_4$ + Borax	9.07 (0.478)	7.86 (0.475)	8.47 (0.477)	43.94 (1.488)	43.70 (1.485)	43.82 (1.487)	53.01 (1.966)	51.56 (1.960)	52.29 (1.963)
T_7:NPK + FYM + $ZnSO_4$	9.93 (0.487)	8.52 (0.479)	9.23 (0.483)	47.68 (1.496)	45.01 (1.487)	46.35 (1.492)	57.61 (1.983)	53.53 (1.966)	55.57 (1.975)
T_8:NPK + FYM + Borax	8.68 (0.483)	8.25 (0.473)	8.47 (0.478)	46.73 (1.491)	44.13 (1.482)	45.43 (1.487)	55.41 (1.974)	52.38 (1.955)	53.90 (1.965)
T_9:NPK + FYM + $ZnSO_4$ + Borax	10.16 (0.492)	8.81 (0.488)	9.49 (0.490)	48.53 (1.502)	45.79 (1.490)	47.16 (1.496)	58.69 (1.994)	54.60 (1.978)	56.65 (1.986)
F test	*	*	*	*	*	*	*	*	*
S.Em ±	**0.19**	**0.28**	**0.17**	**1.92**	**2.05**	**1.37**	**2.04**	**2.27**	**1.49**
CD at 5 %	**0.57**	**0.85**	**0.49**	**5.77**	**6.16**	**3.95**	**6.12**	**6.80**	**4.29**
CV (%)	**4.12**	**7.17**	**5.65**	**8.45**	**9.68**	**8.84**	**7.47**	**9.01**	**8.03**

NPK @ 25:60:25 kg/ha, FYM @ 6.25 t/ha, $ZnSO_4$ @ 12.5 kg/ha, Borax @ 10 kg/ha

Figures in parenthesis indicate actual concentration of Potassium in per cent

Crop rotation: Finger millet (2005)- Soybean (2006), Soybean(2005)- Finger millet (2006)

Table 4.2.19: Zinc uptake by seed, haulm and total zinc uptake of soybean as influenced by zinc and boron application in finger millet- soybean based cropping system

Treatment	Zinc uptake (g/ha)								
	Seed (g/ha)			Haulm (g/ha)			Total uptake (g/ha)		
	2005	2006	Pooled	2005	2006	Pooled	2005	2006	Pooled
T_1: Control	36.71 (40.30)	29.05 (38.02)	32.88 (39.16)	19.83 (13.00)	16.65 (12.52)	18.24 (12.76)	56.54 (53.30)	45.70 (50.54)	51.12 (51.92)
T_2: NPK only	64.93 (46.28)	49.02 (45.18)	56.98 (45.73)	30.20 (14.38)	24.82 (13.20)	27.51 (13.79)	95.13 (60.66)	73.84 (58.38)	84.49 (59.52)
T_3:NPK + FYM	85.59 (50.23)	69.48 (49.10)	77.54 (49.67)	44.31 (16.92)	38.42 (15.81)	41.37 (16.37)	129.90 (67.15)	107.90 (64.91)	118.90 (66.03)
T_4:NPK+ $ZnSO_4$	93.00 (57.30)	79.35 (56.28)	86.18 (56.79)	52.23 (19.99)	45.19 (18.87)	48.71 (19.43)	145.23 (77.29)	124.54 (75.15)	134.89 (76.22)
T_5:NPK + Borax	77.10 (48.37)	65.58 (47.28)	71.34 (47.83)	39.37 (15.36)	33.63 (14.28)	36.50 (14.82)	116.47 (63.73)	99.21 (61.56)	107.84 (62.65)
T_6:NPK + $ZnSO_4$ + Borax	113.88 (60.00)	97.73 (59.05)	105.81 (59.53)	61.10 (20.58)	56.74 (19.28)	58.92 (19.93)	174.98 (80.58)	154.47 (78.33)	164.73 (79.46)
T_7:NPK + FYM + $ZnSO_4$	124.73 (61.20)	106.86 (60.10)	115.80 (60.65)	66.93 (21.00)	60.54 (20.00)	63.74 (20.50)	191.66 (82.20)	167.40 (80.10)	179.53 (81.15)
T_8:NPK + FYM + Borax	108.38 (54.08)	92.62 (53.08)	100.50 (53.58)	57.98 (18.50)	53.54 (17.98)	55.76 (18.24)	166.36 (72.58)	146.16 (71.06)	156.26 (71.82)
T_9:NPK + FYM + $ZnSO_4$ + Borax	129.13 (62.50)	110.47 (61.20)	119.80 (61.85)	69.47 (21.50)	62.23 (20.25)	65.85 (20.88)	198.60 (84.00)	172.70 (81.45)	185.65 (82.73)
F test	*	*	*	*	*	*	*	*	*
S.Em ±	**5.40**	**4.62**	**3.46**	**2.95**	**2.63**	**1.93**	**8.23**	**7.04**	**5.31**
CD at 5 %	**16.20**	**13.87**	**9.94**	**8.85**	**7.88**	**5.55**	**24.68**	**21.11**	**15.27**
CV (%)	**10.10**	**10.30**	**9.95**	**10.43**	**10.46**	**10.22**	**10.07**	**10.05**	**9.90**

NPK @ 25:60:25 kg/ha, FYM @ 6.25 t/ha, $ZnSO_4$ @ 12.5 kg/ha, Borax @ 10 kg/ha

Figures in parenthesis indicate actual concentration of Zinc in ppm

Crop rotation: Finger millet (2005)- Soybean (2006), Soybean(2005)- Finger millet (2006)

uptake (T_1:32.88, 18.24 and 51.12 g/ha, respectively) (Table 4.2.19 and Fig. 22).

4.2.5.5 Boron uptake by soybean seed, haulm and total plant uptake (g/ha)

Significant differences were observed in boron uptake by soybean seed, haulm and total plant uptake due to zinc and boron application (Table 4.2.20).

Application of NPK + FYM + $ZnSO_4$ + borax (T_9) recorded significantly higher boron uptake by soybean seeds (25.30 g/ha) and haulm (36.79 g/ha) as compared to rest of the treatments. Application of NPK + FYM + borax (T_8 : 21.36 and 31.92 g/ha, respectively), NPK + FYM + $ZnSO_4$ (T_7 : 19.78 and 28.87 g/ha, respectively) recorded significantly higher boron uptake in seeds and haulm as compared to rest of the treatments. However, they were found at par with each other.

With regard to total uptake of boron by soybean plant, application of NPK + FYM + $ZnSO_4$ + borax (T_9) recorded significantly higher boron uptake (62.09 g/ha) as compared to rest of the treatments. Significantly lower boron uptake by seed, haulm and total plant uptake was registered in control (9.20, 12.70 and 21.90 g/ha, respectively). Application of NPK + FYM + borax (T_8 : 53.27 g/ha) was found to be next best treatment with regard to total boron uptake (Table 4.2.20 and Fig. 22).

4.2.6 CORRELATION AND REGRESSION ANALYSIS FOR GROWTH, YIELD PARAMETERS AND TOTAL UPTAKE OF NUTRIENTS BY SOYBEAN

Seed yield of soybean had a positive and significant correlation with TDM at harvest (r = 0.782), leaf area at harvest (r = 0.805), nodule number at 60 DAS (r = 0.820), nodule dry weight at 60 DAS (r = 0.770),

Table 4.2.20: Boron uptake by seed, haulm and total boron uptake of soybean as influenced by zinc and boron application in finger millet- soybean based cropping system

Treatment	Boron uptake (g/ha)								
	Seed (g/ha)			Haulm (g/ha)			Total uptake (g/ha)		
	2005	2006	Pooled	2005	2006	Pooled	2005	2006	Pooled
T_1: Control	9.79 (10.75)	8.61 (11.27)	9.20 (11.01)	13.51 (8.86)	11.89 (8.94)	12.70 (8.90)	23.30 (19.61)	20.50 (20.21)	21.90 (19.91)
T_2: NPK only	13.23 (9.43)	9.14 (8.43)	11.19 (8.93)	17.64 (8.40)	13.82 (7.35)	15.73 (7.88)	30.87 (17.83)	22.96 (15.78)	26.92 (16.80)
T_3:NPK + FYM	16.86 (9.90)	12.57 (8.89)	14.72 (9.39)	23.24 (8.87)	19.10 (7.86)	21.17 (8.37)	40.10 (18.77)	31.67 (16.75)	35.89 (17.76)
T_4:NPK+ $ZnSO_4$	15.76 (9.71)	12.30 (8.72)	14.03 (9.22)	22.76 (8.71)	18.48 (7.72)	20.62 (8.21)	38.52 (18.42)	30.78 (16.44)	34.65 (17.43)
T_5:NPK + Borax	17.41 (10.92)	13.62 (9.82)	15.52 (10.37)	25.14 (9.81)	20.72 (8.80)	22.93 (9.31)	42.55 (20.73)	34.34 (18.62)	38.45 (19.68)
T_6:NPK + $ZnSO_4$ + Borax	21.87 (11.52)	17.40 (10.51)	19.64 (11.02)	29.24 (9.85)	25.96 (8.82)	27.60 (9.34)	51.11 (21.37)	43.36 (19.33)	47.24 (20.35)
T_7:NPK + FYM + $ZnSO_4$	22.16 (10.88)	17.39 (9.78)	19.78 (10.33)	31.19 (9.79)	26.54 (8.77)	28.87 (9.28)	53.35 (20.66)	43.93 (18.55)	48.64 (19.61)
T_8:NPK + FYM + Borax	23.77 (11.86)	18.94 (10.85)	21.36 (11.36)	34.44 (10.99)	29.39 (9.87)	31.92 (10.43)	58.21 (22.85)	48.33 (20.72)	53.27 (21.79)
T_9:NPK + FYM + $ZnSO_4$ + Borax	28.06 (13.58)	22.53 (12.48)	25.30 (13.03)	37.16 (11.50)	36.42 (11.85)	36.79 (11.68)	65.22 (25.08)	58.95 (24.33)	62.09 (24.71)
F test	*	*	*	*	*	*	*	*	*
S.Em ±	**1.09**	**0.89**	**0.71**	**1.59**	**1.43**	**1.07**	**1.91**	**1.85**	**1.32**
CD at 5 %	**3.27**	**2.67**	**2.04**	**4.76**	**4.28**	**3.08**	**5.73**	**5.54**	**3.80**
CV (%)	**10.06**	**10.49**	**10.39**	**10.56**	**10.99**	**10.81**	**7.39**	**8.60**	**7.90**

NPK @ 25:60:25 kg/ha, FYM @ 6.25 t/ha, $ZnSO_4$ @ 12.5 kg/ha, Borax @ 10 kg/ha

Figures in parenthesis indicate actual concentration of boron in ppm

Crop rotation: Finger millet (2005)- Soybean (2006), Soybean(2005)- Finger millet (2006)

Table 4.2.21: Correlation and regression equation for pooled data of soybean as influenced by zinc and boron application in finger millet- soybean based cropping system

Sl. No.	Parameters (X)	Regression equation Y{Seed yield(kg/ha))}	Correlation coefficient (r)	R^2
1	TDM at harvest (g/plant)	Y= 569.312+81.595 X	0.782**	0.611
2	Leaf area ($cm^{2/}$plant)at harvest	Y= 825.154+13.282 X	0.805**	0.648
3	Nodule number at 60 DAS	Y= 441.254+23.069 X	0.820**	0.672
4	Nodule dry weight (g/plant) at 60 DAS	Y= 725.709+1128.992 X	0.770**	0.592
5	No. of branches at harvest	Y= 733.198+209.523 X	0.753**	0.568
6	No. of pods per plant	Y= 683.290+53.138 X	0.770**	0.593
7	No. of seeds per plant	Y= -692.688+928.331 X	0.746**	0.556
8	Pod length (cm)	Y= 374.258+329.928 X	0.831**	0.690
9	Pod yield per plant (g/plant)	Y= 514.915+131.936 X	0.779**	0.607
10	Seed yield per plant (g/plant)	Y= 418.248+281.551 X	0.785**	0.617
11	Test weight (g)	Y= -1424.531+228.827 X	0.634**	0.403
12	Protein yield (kg/ha)	Y= 102.027+2.345 X	0.914**	0.835
13	Oil Yield (kg/ha)	Y= 95.105+5.105 X	0.899**	0.808
14	Total N uptake(kg/ha)	Y= 194.098+10.727 X	0.836**	0.699
15	Total P_2O_5 uptake (kg/ha)	Y =412.614+214.945 X	0.844**	0.713
16	Total K_2O uptake (kg/ha)	Y= 77.781+32.847 X	0.839**	0.704
17	Total Zn uptake (g/ha)	Y= 581.105+7.531 X	0.819**	0.670
18	Total B uptake (g/ha)	Y= 500.498+26.118 X	0.823**	0.678
$Y= - 699.119-97.924X_1+4.601X_2 -1.139 X_3- 312.270 X_4 -72.596 X_5-4.666X_6+36.084X_7-29.009X_8+129.759X_9-226.116 X_{10}+41.867X_{11}+2.196X_{12}+ 5.232X_{13}+2.599X_{14} -15.505 X_{15}+5.604 X_{16} – 1.215 X_{17}+0.753 X_{18}$			0.970	0.941

** Correlation is significant at the 0.01 level (2-tailed)

Note: The dependent variables X_1, X_2, X_3….. X_{18} refers to the parameters listed in serial number 1, 2, 3…..18, respectively

number of branches at harvest (r = 0.753), number of pods per plant (r = 0.770), number of seeds per plant (r = 0.746), pod length (r = 0.831), pod yield per plant (r = 0.779), seed yield per plant (r = 0.785), test weight (r = 0.634), protein yield (r = 0.914), oil yield (r = 0.899) and total uptake of N, P_2O_5, K_2O, Zn and B nutrients (r = 0.836, 0.844, 0.839, 0.819 and 0.823, respectively) (Table 4.2.21).

The variation in the seed yield of soybean due to growth, yield parameters and total uptake of nutrients was about 94 per cent as explained by the multiple linear regression equation.

4.3 SOIL MICROBIOLOGICAL STUDIES

4.3.1 POPULATION OF SOIL MICROORGANISMS AT 50 PER CENT FLOWERING (x 10^n cfu/g soil)

The data on the population of soil microorganisms *viz.,* bacteria, fungi and actinomycetes as influenced by micronutrients (zinc and boron) application at 50 per cent flowering are presented in Table 4.3.1; Fig. 23, 24 and 25).

4.3.1.1 Finger millet-soybean based cropping

Significantly higher population of bacteria and fungi was observed in NPK + FYM + $ZnSO_4$ + borax (T_9) at 50 per cent flowering in finger millet (50 x 10^5 and 30 x 10^4 cfu/g soil, respectively) and soybean (52.60 x 10^5 and 30 x 10^4 cfu/g soil, respectively) as compared to other treatments. However, it was found on par with application of NPK + FYM + $ZnSO_4$ (T_7:48 x10^5 and 27 x 10^4 cfu/g soil, respectively) NPK + FYM + Borax (T_8: 46 x 10^5 and 28 x10^4 cfu/g soil, respectively). Application of NPK + FYM (T_3) recorded significantly higher population of bacteria and fungi in fingermillet (45 x 10^5 and 25 x 10^4 cfu/g soil, respectively) and soybean (47.5 x 10^5 and 26.5 x 10^4 cfu/g soil, respectively) as compared to control (18 x 10^5 and 13 x 10^4 cfu/g soil, respectively) at 50 per cent

Table 4.3.1: Population of soil microorganisms at 50 per cent flowering of crops as influenced by zinc and boron application in finger millet- soybean and soybean- finger millet based cropping system

Treatment	Population of soil microorganisms (x 10 ^{n} cfu /g soil) at 50% flowering											
	Bacteria (x10^{5})				Fungi (x10^{4})				Actinomycetes (x10^{3})			
	Finger millet	Soybean	Soybean	Finger millet	Finger millet	Soybean	Soybean	Finger millet	Finger millet	Soybean	Soybean	Finger millet
	2005	2006	2005	2006	2005	2006	2005	2006	2005	2006	2005	2006
T_1: Control	18.00	31.00	20.00	25.00	13.00	17.00	15.00	15.00	6.00	5.50	5.00	5.00
T_2: NPK only	32.00	40.00	40.00	36.00	21.00	20.00	20.00	18.50	9.00	8.00	8.00	7.50
T_3:NPK + FYM	45.00	47.50	49.00	44.50	25.00	26.50	30.50	25.30	16.00	16.50	18.00	14.30
T_4:NPK+ $ZnSO_4$	36.00	45.30	41.00	42.50	19.00	24.30	25.00	23.20	12.00	8.50	12.00	7.50
T_5:NPK + Borax	34.00	43.20	39.00	40.00	16.00	23.50	24.00	21.60	11.00	8.30	10.00	7.20
T_6:NPK+$ZnSO_4$ + Borax	39.00	46.20	47.00	43.20	22.00	25.33	27.00	24.20	13.00	9.00	16.00	8.00
T_7:NPK+FYM + $ZnSO_4$	48.00	50.00	52.00	46.00	28.00	28.50	32.00	27.00	18.00	19.00	22.00	17.00
T_8:NPK + FYM + Borax	46.00	48.90	51.00	45.00	27.00	27.00	31.00	26.40	17.00	18.30	21.00	16.30
T_9:NPK + FYM + $ZnSO_4$ + Borax	50.00	52.60	54.00	48.00	30.00	30.00	33.00	28.30	20.00	21.00	23.00	18.00
F test	*	*	*	*	*	*	*	*	*	*	*	*
S.Em +	**1.38**	**1.38**	**2.37**	**1.48**	**1.26**	**1.42**	**1.75**	**1.14**	**0.83**	**0.59**	**0.97**	**0.63**
CD at 5 %	**4.15**	**4.14**	**7.12**	**4.44**	**3.78**	**4.27**	**5.25**	**3.40**	**2.49**	**1.76**	**2.91**	**1.89**
CV (%)	**6.19**	**5.32**	**9.42**	**6.24**	**9.79**	**9.98**	**11.49**	**8.45**	**10.61**	**8.01**	**11.22**	**9.75**

Initial population of soil microorganisms; Bacteria: 14x10^{5}, Fungi: 6x10^{3}; Actinomycetes: 4 x 10^{3} cfu/g soil, cfu: Colony forming units
$ZnSO_4$@ 12.50 kg/ha, Borax @ 10 kg/ha

Crop rotation: Finger millet (2005)- Soybean (2006), Soybean (2005)- Finger millet (2006)

Note: For Finger millet - NPK @ 50:40:25 kg/ha and FYM @ 7.5 t/ha
For Soybean – NPK @ 25:60:25 kg/ha and FYM @ 6.25 t/ha

flowering in both finger millet and soybean crops (Table 4.3.1; Fig. 23 and 24).

The population of actinomycetes was higher with application of NPK + FYM + $ZnSO_4$ + borax (T_9) in finger millet (20 x 10^3 cfu/g soil) and soybean (21 x 10^3 cfu/g soil) followed by NPK + FYM + $ZnSO_4$ (T_7) in finger millet and soybean (T_7: 18 x 10^3 cfu/g soil), while significantly lower population of actinomycetes was observed in control (T_1 : 6 and 5.5 x 10^3 cfu/g soil in finger millet and soybean, respectively) (Table 4.3.1; Fig. 25).

4.3.1.2 Soybean-finger millet based cropping system

Significantly maximum population of bacteria and fungi at 50 per cent flowering in soybean and finger millet was observed with application of NPK + FYM + $ZnSO_4$ + borax in soybean (T_9: 54 x 10^5 and 33 x 10^4 cfu/g soil, respectively) and fingermillet (48 x 10^5 and 28.3 x 10^4 cfu/g soil, respectively) as compared to other treatments. However, it was found on par with application of NPK + FYM + $ZnSO_4$ (T_7), NPK + FYM + borax (T_8) and NPK + FYM (T_3) (Table 4.3.1; Fig. 23 and 24).

Significantly maximum population of actinomycetes was observed at 50 per cent flowering in soybean and finger millet with application of NPK + FYM + $ZnSO_4$ + borax (T_9 : 23 and 18 x 10^3 cfu/g soil, respectively) as compared to rest of the treatments. However, it was found on par with application of NPK + FYM + $ZnSO_4$ (T_7 : 22 and 17 x 10^3 cfu/g soil, respectively) and NPK + FYM + borax (T_8 : 21 and 16.30 x 10^3 cfu/g soil, respectively). The minimum population of actinomycetes was recorded in control (T_1) (Table 4.3.1and Fig. 25).

4.3.2 POPULATION OF SOIL MICROORGANISMS AT HARVEST (x10^n cfu/g soil)

4.3.2.1 Finger millet-soybean based cropping system

Application of NPK + FYM + $ZnSO_4$ + borax (T_9) recorded significantly higher population of bacteria (36 and 36 x 10^5 cfu/g soil, respectively), fungi (22 and 24 x 10^4 cfu/g soil, respectively) in fingermillet and soybean respectively as compared to other treatments. However, it was found on par with application of NPK + FYM + $ZnSO_4$ (T_7) with regard to bacterial population at harvest in fingermillet (34 x10^5 cfu/g, soil) and fungi (20 and 21.6 x 10^4 cfu/g soil, respectively) at harvest in finger millet and soybean, respectively(Table 4.3.2; Fig. 23 and 24).

Significantly maximum population of actinomycetes was observed with application of NPK + FYM + $ZnSO_4$ + borax (T_9) at harvest of finger millet (13 x 10^3 cfu/g soil) and soybean (17.30 x 10^3 cfu/g soil) as compared to control. However, it was found on par with application of NPK + FYM + $ZnSO_4$ (T_7: 12 and 15.50 x 10^3 cfu/g soil, respectively). The least activity of actinomycetes was observed in control (T_1: 4 and 2.30 x 10^3 cfu/g soil) (Table 4.3.2 and Fig. 25).

4.3.2.2 Soybean-finger millet based cropping system

Significantly maximum population of bacteria, fungi and actinomycetes (40.6 and 34 x 10^5, 24 and 22 x 10^4 and 15 and 15.8 x 10^3 cfu/g soil, respectively) was observed with application of NPK + FYM + $ZnSO_4$ + borax (T_9) at harvest in soybean and finger millet crops as compared to rest of the treatments. However, it was found on par with application of NPK + FYM + $ZnSO_4$ (T_7: 37 x 10^5, 22 x 10^4 and 14 x 10^3 cfu/g soil, respectively) in soybean at harvest. Least activity of all the microorganisms were observed in control (T_1 : 15 and 14 x 10^5, 6 and 9 x

Table 4.3.2: Population of soil microorganisms at harvest of crops as influenced by zinc and boron application in finger millet- soybean and soybean- finger millet based cropping system

Treatment	Population of soil microorganisms (x 10 ^{n} cfu /g soil) at harvest											
	Bacteria (x10^{5})				Fungi (x10^{4})				Actinomycetes (x10^{3})			
	Finger millet	Soybean	Soybean	Finger millet	Finger millet	Soybean	Soybean	Finger millet	Finger millet	Soybean	Soybean	Finger millet
	2005	2006	2005	2006	2005	2006	2005	2006	2005	2006	2005	2006
T_1: Control	13.00	15.50	15.00	14.00	5.00	11.00	6.00	9.00	4.00	2.30	3.00	2.00
T_2: NPK only	19.00	19.33	26.00	18.20	9.00	15.00	10.00	13.00	6.50	3.50	4.00	4.50
T_3:NPK + FYM	30.00	26.40	35.60	25.00	15.00	20.30	18.00	18.50	9.00	12.00	10.00	12.10
T_4:NPK+ $ZnSO_4$	23.00	23.30	30.00	22.00	12.00	18.20	13.00	16.00	7.00	4.00	5.00	5.00
T_5:NPK + Borax	21.00	20.50	28.00	20.00	10.50	16.30	10.00	14.00	6.50	4.30	6.00	5.30
T_6:NPK+$ZnSO_4$ + Borax	24.00	25.00	33.00	24.00	14.50	20.00	15.00	18.00	8.00	6.00	8.00	7.00
T_7:NPK+FYM + $ZnSO_4$	34.00	30.00	37.00	30.00	20.00	21.60	22.00	19.30	12.00	15.50	14.00	13.20
T_8:NPK + FYM + Borax	32.00	29.00	36.00	29.00	18.00	20.00	21.00	18.50	11.00	14.30	12.00	13.00
T_9:NPK + FYM + $ZnSO_4$ + Borax	36.00	36.00	40.60	34.00	22.00	24.00	24.00	22.00	13.00	17.30	15.00	15.80
F test	*	*	*	*	*	*	*	*	*	*	*	*
S.Em ±	**1.22**	**0.86**	**1.41**	**1.06**	**0.90**	**1.01**	**0.95**	**0.89**	**0.66**	**0.75**	**0.59**	**0.37**
CD at 5 %	**3.65**	**2.58**	**4.23**	**3.19**	**2.69**	**3.03**	**2.84**	**2.67**	**1.98**	**2.26**	**1.75**	**1.11**
CV (%)	**8.18**	**5.96**	**7.81**	**7.67**	**11.12**	**9.46**	**10.63**	**9.36**	**13.34**	**14.85**	**11.85**	**7.40**

$ZnSO_4$@ 12.50 kg/ha, Borax @ 10 kg/ha

Crop rotation: Finger millet (2005)- Soybean (2006), Soybean (2005)- Finger millet (2006)

Note: For Finger millet - NPK @ 50:40:25 kg/ha and FYM @ 7.5 t/ha

For Soybean – NPK @ 25:60:25 kg/ha and FYM @ 6.25 t/ha

10^4 and 3 and 2 x 10^3 cfu/g soil, respectively) (Table 4.3.2; Fig. 23,24 and 25).

4.3.3 SOIL ENZYMES ACTIVITY AT 50 PER CENT FLOWERING

4.3.3.1 Finger millet-soybean based cropping system

The activity of dehydrogenase was significantly maximum with application of NPK + FYM + $ZnSO_4$ + borax (T_9) at 50 per cent flowering in finger millet (192 µg TPF/g soil/24 h) and soybean (170 µg TPF/g soil/24 h) as compared to control. However, it was found on par with application of NPK + FYM + $ZnSO_4$ (T_7: 185 and 160 µg TPF/g soil/24 h, respectively) and NPK + FYM + borax (T_8) at 50 per cent flowering in finger millet (175 µg TPF/g soil/24 h). The lower dehydrogenase activity (70 and 50 µg TPF/g soil, respectively) was observed in control (T_1) (Table 4.3.3 and Fig. 26).

The urease, acid and alkaline phosphatase activity was found to be higher with the application of NPK + FYM + $ZnSO_4$ + borax (T_9: 48 and 55 µg NH_4N/g soil/2 h, 163 and 180 µg PNP/g soil/h, 55 and 75 µg PNP/g soil/h, in finger millet and soybean, respectively). However, it was found on par with application of NPK + FYM + $ZnSO_4$ (T_7: 45 and 53 µg NH_4N/g soil/2 h, 155 and 176 µg PNP/g soil/h, 52 and 71 µg PNP/g soil/h, in finger millet and soybean, respectively). Indeed, least activity of dehydrogenase, urease, acid and alkaline phosphatase was observed in control (T_1: 70 and 50 µg/TPF/g soil/24 h, 13 and 28 µg NH_4 N/g soil/2 h, 65 and 80 µg PNP/g soil h; 15 and 20 µg PNP/g soil/h in finger millet and soybean, respectively) (Table 4.3.3; Fig. 27, 28 and 29).

4.3.3.1.2 Soybean-finger millet based cropping system

The activity of dehydrogenase was significantly maximum with application of NPK + FYM + $ZnSO_4$ + borax (T_9) at 50 per cent flowering in soybean (180 µg TPF/g soil) and finger millet (155 µg TPF/g soil) as

Table 4.3.3: Dehydrogenase, urease, acid phosphatase and alkaline phosphatase enzymes activity in soil at 50 % flowering of crops as influenced by zinc and boron application in finger millet- soybean and soybean- finger millet based cropping system

Treatment	Soil enzymes activity at 50 % flowering															
	Dehydrogenase (µg TPF/g soil /24 h)				Urease (µg NH_4N/g soil /2h)				Acid phosphatase (µg PNP/g soil / h)				Alkaline phosphatase (µg PNP/g soil / h)			
	Finger millet	Soybean	Soybean	Finger millet	Finger millet	Soybean	Soybean	Finger millet	Finger millet	Soybean	Soybean	Finger millet	Finger millet	Soybean	Soybean	Finger millet
	2005	2006	2005	2006	2005	2006	2005	2006	2005	2006	2005	2006	2005	2006	2005	2006
T_1	70	50	80	40	13	28	22	15	65	80	50	70	15	20	17	15
T_2	76	90	85	80	24	33	27	18	94	135	120	100	18	27	21	16
T_3	115	130	125	115	36	48	42	35	145	169	155	150	33	62	35	50
T_4	94	110	105	95	30	40	35	26	122	157	145	125	24	50	27	40
T_5	80	103	90	86	27	35	30	22	113	154	140	115	20	28	24	20
T_6	106	120	115	110	33	44	38	30	141	163	150	145	29	57	30	45
T_7	185	160	170	145	45	53	47	47	155	176	165	161	52	71	55	60
T_8	175	145	160	125	40	50	44	42	147	173	160	155	43	66	46	55
T_9	192	170	180	155	48	55	50	50	163	180	170	165	55	75	58	65
F test	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
S.Em ±	8.33	4.23	5.29	4.78	1.27	2.55	2.04	1.99	4.26	6.61	6.84	4.22	2.05	2.40	2.17	2.02
CD at 5 %	24.97	12.67	15.87	14.32	3.80	7.64	6.11	5.95	12.76	19.81	20.50	12.66	6.16	7.18	6.50	6.05
CV (%)	11.88	6.11	7.43	7.83	6.67	10.30	9.48	10.86	5.79	7.43	8.49	5.55	11.08	8.19	10.80	8.60

T_1: Control , T_2: NPK only, T_3:NPK + FYM, T_4:NPK+ $ZnSO_4$, T_5:NPK + Borax, T_6:NPK+$ZnSO_4$ + Borax, T_7:NPK+FYM + $ZnSO_4$, T_8:NPK + FYM + Borax, T_9:NPK + FYM + $ZnSO_4$ + Borax

$ZnSO_4$@ 12.50 kg/ha, Borax @ 10 kg/ha

Crop rotation: Finger millet (2005)- Soybean (2006), Soybean (2005)- Finger millet (2006)

Note: For Finger millet - NPK @ 50:40:25 kg/ha and FYM @ 7.5 t/ha

For Soybean – NPK @ 25:60:25 kg/ha and FYM @ 6.25 t/ha

compared to other treatments. However, it was found at par with application of NPK + FYM + $ZnSO_4$ (T_7: 170 and 145 µg TPF/g soil/24 h, respectively) (Table 4.3.3; Fig. 26).

Significantly higher activity of urease, acid and alkaline phosphatase was observed with application of NPK + FYM + $ZnSO_4$ + borax (T_9) at 50 per cent in soybean (50 µg PNP/g soil/2h, 170 and 58 µg PNP/g soil/h respectively) and in finger millet (50 µg NH_4N/ g soil/2h, 165 and 65 µg PNP/g soil/h, respectively), while, least activity of urease (22 and 15 µg NH_4N/ g soil/2h), acid (50 and 70 µg PNP/g soil/h) and alkaline phosphatase (17 ands 15 µg PNP/g soil/h) in soybean and finger millet respectively(Table 4.3.3; Fig. 27,28 and 29).

4.3.4 SOIL ENZYMES ACTIVITY AT HARVEST

4.3.4.1 Finger millet-soybean based cropping system

Application of NPK + FYM + $ZnSO_4$ + borax (T_9) supported significantly maximum activity of dehydrogenase at harvest in finger millet (125 µg TPF/g soil/24 h) and soybean (145 µg TPF/g soil/24 h). Application of NPK + FYM + $ZnSO_4$ (T_7: 110 and 140 µg TPF/g soil/24 h, respectively) was found on par with the former treatment. Application of NPK + FYM (T_3), NPK + FYM + borax (T_8) was found on par with each other and with former treatments with respect to dehydrogenase activity at harvest of soybean (Table 4.3.4; Fig. 26).

Significantly maximum activity urease, acid and alkaline phosphatase was observed with application of NPK + FYM + $ZnSO_4$ + borax (T_9) at harvest of fingermillet (38 µg NH_4N/ g soil/2h), 133 and 40 µg PNP/ g soil/h respectively) and soybean (40 µg NH_4N/ g soil/2h, 180 and 38 µg PNP/ g soil/h respectively) as compared to other treatments. However, it was found on par with application of NPK+ FYM + $ZnSO_4$ (T_7) with regard to activity of urease and alkaline phosphatase (38 µg NH_4N/

Table 4.3.4: Dehydrogenase, urease, acid phosphatase and alkaline phosphatase enzymes activity in soil at harvest of soybean as influenced by zinc and boron application in finger millet-soybean and soybean- finger millet based cropping system

Treatment	Soil enzymes activity at harvest															
	Dehydrogenase (µg TPF/g soil /24 h)				Urease (µg NH_4N/g soil /2h)				Acid phosphatase (µg PNP/g soil / h)				Alkaline phosphatase (µg PNP/g soil / h)			
	Finger millet	Soybean	Soybean	Finger millet	Finger millet	Soybean	Soybean	Finger millet	Finger millet	Soybean	Soybean	Finger millet	Finger millet	Soybean	Soybean	Finger millet
	2005	2006	2005	2006	2005	2006	2005	2006	2005	2006	2005	2006	2005	2006	2005	2006
T_1	24	40	36	30	12	14	15	12	47	55	42	50	10	13	13	10
T_2	37	55	50	44	15	16	18	15	72	70	60	80	11	17	15	14
T_3	73	133	128	78	24	33	29	26	119	110	101	122	27	25	33	22
T_4	51	80	73	55	19	25	24	20	95	83	70	100	17	21	22	19
T_5	46	70	62	50	16	22	22	19	87	75	62	92	13	18	18	16
T_6	55	110	90	60	22	28	27	25	110	95	83	112	23	23	27	20
T_7	110	140	135	120	31	38	35	31	127	160	150	135	36	34	40	30
T_8	100	138	130	110	27	35	32	28	123	156	143	127	32	30	37	27
T_9	125	145	140	130	38	40	40	34	133	180	170	140	40	38	45	35
F test	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
S.Em ±	**5.41**	**4.81**	**4.13**	**4.49**	**0.98**	**2.10**	**0.84**	**1.84**	**5.48**	**4.71**	**5.49**	**6.14**	**1.65**	**1.42**	**1.32**	**1.25**
CD at 5 %	**16.23**	**14.41**	**12.39**	**13.46**	**2.94**	**6.29**	**2.52**	**5.51**	**16.43**	**14.11**	**16.47**	**18.40**	**4.94**	**4.27**	**3.95**	**3.76**
CV (%)	**13.58**	**8.22**	**7.63**	**10.34**	**7.48**	**13.03**	**5.42**	**13.64**	**9.36**	**7.46**	**9.72**	**9.99**	**12.30**	**10.14**	**8.20**	**10.12**

T_1: Control , T_2: NPK only, T_3:NPK + FYM, T_4:NPK+ $ZnSO_4$, T_5:NPK + Borax, T_6:NPK+$ZnSO_4$ + Borax, T_7:NPK+FYM + $ZnSO_4$, T_8:NPK + FYM + Borax, T_9:NPK + FYM + $ZnSO_4$ + Borax

$ZnSO_4$@ 12.50 kg/ha, Borax @ 10 kg/ha

Crop rotation: Finger millet (2005)- Soybean (2006), Soybean (2005)- Finger millet (2006)

Note: For Finger millet - NPK @ 50:40:25 kg/ha and FYM @ 7.5 t/ha

For Soybean – NPK @ 25:60:25 kg/ha and FYM @ 6.25 t/ha

g soil/2h and 34 µg PNP/ g soil/h respectively) at harvest of soybean, acid and alkaline activity at harvest of fingermillet (127 and 36 µg PNP/ g soil/h respectively). The least activity of all the enzymes was observed in control (T_1) (Table 4.3.4; Fig. 27, 28 and 29).

4.3.4.2 Soybean-finger millet based cropping system

The activity of dehydrogenase and urease was encouraged significantly to a maximum extent by application of NPK + FYM + $ZnSO_4$ + borax (T_9: 140 and 130 µg TPF/ g soil/24h; 40 and 34 µg TPF/ g soil/2h, in soybean and finger millet, respectively) as compared to other treatments. However, it was found on par with application of NPK + FYM (T_7: 135 and 120 µg TPF/g soil/24h, with regard to dehydrogenase activity at harvest of soybean and finger millet, respectively and urease activity (31 µg NH_4N/g soil/2h respectively) at harvest of finger millet(Table 4.3.4; Fig. 26and 27).

Application of NPK + FYM + $ZnSO_4$ + borax (T_9) supported significantly maximum activity of acid phosphatase enzyme at harvest of soybean (170 µg PNP/g soil/h) and finger millet (140 µg PNP/g soil/h) as compared to other treatments. However, it was found on par with application of NPK + FYM + $ZnSO_4$ (T_7: 135 µg PNP/g soil/h), NPK + FYM + borax (T_8 : 127 µg PNP/g soil/h) and NPK + FYM (T_3 : 122 µg PNP/g soil/h) at harvest of finger millet. The least activity of acid phosphatase enzyme was observed in control (T_1: 42 and 50 µg PNP/g soil/h, respectively) (Table 4.3.4 and Fig. 28).

Application of NPK + FYM + $ZnSO_4$ + borax (T_9) supported maximum activity of alkaline phosphatase enzyme at harvest of soybean (45 µg PNP/g soil/h) and finger millet (35 µg PNP/g soil/h) as compared to rest of the treatments. Least activity of alkaline phosphatase enzyme

was observed in control (T_1) in both the cropping systems (Table 4.3.4 and Fig. 29).

4.4 AVAILABLE NITROGEN, PHOSPHORUS, POTASSIUM (kg/ha), ZINC AND BORON (ppm) STATUS IN SOIL AFTER HARVEST OF THE CROPS AS INFLUENCED BY ZINC AND BORON APPLICATION IN FINGER MILLET – SOYBEAN AND SOYBEAN-FINGER MILLET BASED CROPPING SYSTEMS

4.4.1 AVAILABLE NITROGEN (kg/ha)

The data on available nitrogen in soil differed significantly due to zinc and boron application in finger millet-soybean and soybean-finger millet cropping system (Table 4.4.1.).

4.4.1.1 Finger millet – soybean based cropping system

Significantly higher available nitrogen in soil was recorded with application of NPK + FYM (T_3) after harvest of finger millet (231.04 kg/ha) and soybean (226.32 kg/ha) in finger millet-soybean based cropping system whereas, lower available nitrogen content in soil was recorded in control and rest of the treatments were found to be intermediate (Table 4.4.1and Fig.30).

4.4.1.2 Soybean - finger millet based cropping system

Similar trend as above was noticed in soybean-finger millet cropping system too (Table 4.4.1and Fig.30).

4.4.2 AVAILABLE PHOSPHORUS (kg/ha)

4.4.2.1 Finger millet – soybean based cropping system

Application of NPK + FYM (T_3) recorded significantly higher available phosphorus after harvest of finger millet and soybean (110.69 and 106.46 kg/ha)in finger millet-soybean cropping system. However, it

Table 4.4.1: Available nitrogen, phosphorus and potassium status in soil after harvest of crops as influenced by zinc and boron application in finger millet- soybean and soybean- finger millet based cropping system

Treatment	Available nitrogen (kg/ha)				Available phosphorus (kg/ha)				Available potassium (kg/ha)			
	Finger millet	Soybean	Soybean	Finger millet	Finger millet	Soybean	Soybean	Finger millet	Finger millet	Soybean	Soybean	Finger millet
	2005	2006	2005	2006	2005	2006	2005	2006	2005	2006	2005	2006
T_1: Control	159.60	121.00	173.20	145.99	70.28	60.55	83.45	69.20	131.35	115.30	140.30	115.28
T_2: NPK only	186.55	163.98	178.98	175.64	96.41	95.05	98.43	97.76	130.34	138.18	153.40	134.42
T_3:NPK + FYM	231.04	226.32	192.46	211.74	110.69	106.46	109.79	110.25	154.55	170.00	179.45	189.86
T_4:NPK+ $ZnSO_4$	173.85	117.92	162.10	145.67	93.52	92.13	91.59	92.86	116.20	120.30	145.00	116.28
T_5:NPK + Borax	178.50	117.85	163.75	146.68	82.38	90.13	94.37	93.16	114.00	119.18	148.30	116.92
T_6:NPK+$ZnSO_4$+Borax	166.30	106.48	144.57	113.28	78.31	88.28	87.90	89.17	106.35	100.00	138.39	120.50
T_7:NPK+FYM + $ZnSO_4$	205.24	176.34	173.44	174.16	105.41	103.71	112.15	104.16	137.46	164.30	171.50	171.45
T_8:NPK + FYM + Borax	209.42	178.70	173.59	180.27	108.00	105.48	110.87	105.26	139.52	165.30	169.30	170.42
T_9:NPK + FYM + $ZnSO_4$ + Borax	203.07	166.73	174.27	168.97	101.86	101.99	111.86	100.19	135.26	168.30	165.30	171.72
F test	*	*	*	*	*	*	*	*	*	*	*	*
S.Em ±	**9.91**	**7.75**	**6.93**	**8.69**	**4.34**	**5.06**	**5.46**	**5.73**	**6.41**	**4.67**	**5.87**	**5.20**
CD at 5 %	**29.70**	**23.23**	**20.78**	**26.06**	**13.03**	**15.19**	**16.37**	**17.16**	**19.22**	**14.00**	**17.61**	**15.58**
CV (%)	**9.01**	**8.78**	**7.03**	**9.26**	**8.00**	**9.36**	**9.45**	**10.35**	**8.58**	**5.77**	**6.49**	**6.20**

$ZnSO_4$@ 12.50 kg/ha, Borax @ 10 kg/ha

Crop rotation: Finger millet (2005)- Soybean (2006), Soybean (2005)- Finger millet (2006)

Note: For Finger millet - NPK @ 50:40:25 kg/ha and FYM @ 7.5 t/ha

For Soybean – NPK @ 25:60:25 kg/ha and FYM @ 6.25 t/ha

was found on par with application of NPK + FYM + $ZnSO_4$ + borax (T_9: 101.86 and 101.99 kg/ha), NPK + FYM + borax (T_8: 108 and 105.48 kg/ha) and NPK + FYM + $ZnSO_4$ (T_7: 105.41 and 103.71 kg/ha) in finger millet-soybean cropping system (Table 4.4.1and Fig.31).

4.4.2.2 Soybean - finger millet based cropping system

Application of NPK + FYM + $ZnSO_4$ (T_7) and NPK + FYM (T_3) recorded significantly higher available phosphorus (112.15 kg/ha and 110.25 kg/ha, after harvest of soybean and finger millet, respectively). However, they were found on par with application of NPK + FYM + borax (T_8) and NPK + FYM + $ZnSO_4$ + borax (T_9). Lower available phosphorus was recorded in control in both the cropping systems (Table 4.4.1and Fig.31).

4.4.3 AVAILABLE POTASSIUM (kg/ha)

4.4.3.1 Finger millet – soybean based cropping system

Significantly higher available potassium content in soil was recorded with application of NPK + FYM (T_3 : 154.55 and 170 kg/ha after harvest of finger millet and soybean, respectively) in finger millet-soybean cropping system (Table 4.4.1). However, it was found on par with application of NPK + FYM + $ZnSO_4$ (T_7 : 137.46 and 164.30 kg/ha, respectively), NPK + FYM + borax (T_8 : 139.52 and 165.30 kg/ha, respectively) and NPK + FYM + $ZnSO_4$ + borax (T_9 : 168.30 kg/ha after harvest of soybean) (Table 4.4.1and Fig.32).

4.4.3.2 Soybean - finger millet based cropping system

Application of NPK + FYM (T_3) recorded significantly higher available potassium content in the soil after harvest of soybean (179.45 kg/ha) and finger millet (189.86 kg/ha) as compared to rest of the treatments in soybean-finger millet cropping system. However, it was

found on par with the application of NPK + FYM + $ZnSO_4$ + borax (T_9 : 165.30 and 171.72 kg/ha, respectively), NPK + FYM + $ZnSO_4$ (T_7 : 171.50 and 171.45 kg/ha, respectively) and NPK + FYM + borax (T_8 : 169.30 and 170.42 kg/ha, respectively) (Table 4.4.1and Fig.32).

4.4.4 AVAILABLE ZINC (ppm)

4.4.4.1 Finger millet – soybean based cropping system

Application of NPK + FYM + $ZnSO_4$+ borax (T_9), NPK + FYM + $ZnSO_4$ (T_7), NPK + $ZnSO_4$ + borax (T_6) and NPK + $ZnSO_4$ (T_4) recorded significantly higher available zinc as compared to rest of the treatments, in both finger millet-soybean cropping systems. However, they were found on par with each other, while lower available zinc content was recorded in control (T_1) (Table 4.4.2and Fig.33).

4.4.4.2 Soybean - finger millet based cropping system

Similar trend as above was noticed in soybean-finger millet cropping system too (Table 4.4.2and Fig.33).

4.4.5 AVAILABLE BORON (ppm)

4.4.5.1 Finger millet – soybean based cropping system

Significantly higher available boron content was recorded with application of NPK + FYM + $ZnSO_4$ + borax (T_9: 0.70 and 0.85 ppm after harvest of finger millet and soybean, respectively) (Table 4.4.2 and Fig.34).

However, it was found on par with the application of NPK + FYM + borax (T_8: 0.65 and 0.80 ppm, respectively), NPK + borax (T_5: 0.58 and 0.76 ppm, respectively) and NPK + $ZnSO_4$ + borax (T_6: 0.80 ppm after harvest of soybean).

Table 4.4.2: Available zinc and boron status in soil after harvest of crops and micronutrient use efficiency (MUE) as influenced by zinc and boron application in finger millet- soybean and soybean- finger millet based cropping system

Treatment	Available zinc (ppm)				Available boron (ppm)				MUE [kg of additional produce/ kg of micronutrient (s) applied]			
	Finger millet	Soybean	Soybean	Finger millet	Finger millet	Soybean	Soybean	Finger millet	Finger millet	Soybean	Soybean	Finger millet
	2005	2006	2005	2006	2005	2006	2005	2006	2005	2006	2005	2006
T_1: Control	0.40	0.36	0.41	0.36	0.37	0.34	0.38	0.35	-	-	-	-
T_2: NPK only	0.43	0.37	0.45	0.39	0.39	0.36	0.39	0.36	-	-	-	-
T_3:NPK + FYM	0.48	0.44	0.50	0.49	0.40	0.38	0.40	0.37	-	-	-	-
T_4:NPK+ $ZnSO_4$	1.51	1.50	1.53	1.50	0.38	0.35	0.38	0.35	32.08	26.00	17.60	39.36
T_5:NPK + Borax	0.42	0.36	0.44	0.38	0.58	0.76	0.64	0.87	34.80	30.20	19.10	43.60
T_6:NPK+$ZnSO_4$+ Borax	1.50	1.48	1.52	1.45	0.60	0.80	0.67	0.88	46.71	25.33	22.00	41.91
T_7:NPK+FYM + $ZnSO_4$	1.56	1.56	1.56	1.60	0.40	0.37	0.38	0.36	49.04	29.04	26.72	43.04
T_8:NPK + FYM + Borax	0.42	0.38	0.50	0.48	0.65	0.80	0.72	0.91	54.90	33.00	30.00	48.50
T_9:NPK + FYM + $ZnSO_4$ + Borax	1.57	1.58	1.56	1.62	0.70	0.85	0.71	0.90	29.29	17.33	16.09	26.22
F test	*	*	*	*	*	*	*	*	-	-	-	-
S.Em ±	**0.04**	**0.06**	**0.04**	**0.05**	**0.02**	**0.03**	**0.03**	**0.03**	-	-	-	-
CD at 5 %	**0.11**	**0.17**	**0.11**	**0.16**	**0.07**	**0.10**	**0.08**	**0.09**	-	-	-	-
CV (%)	**7.09**	**10.81**	**6.90**	**10.28**	**8.58**	**10.23**	**8.83**	**8.97**	-	-	-	-

$ZnSO_4$@ 12.50 kg/ha, Borax @ 10 kg/ha

Crop rotation: Finger millet (2005)- Soybean (2006), Soybean (2005)- Finger millet (2006)

Note: For Finger millet - NPK @ 50:40:25 kg/ha and FYM @ 7.5 t/ha

For Soybean – NPK @ 25:60:25 kg/ha and FYM @ 6.25 t/ha

4.4.5.2 Soybean - finger millet based cropping system

Similarly in case of soybean-finger millet cropping system application of NPK + FYM + $ZnSO_4$ + borax recorded significantly higher available boron (T_9 : 0.71 and 0.90 ppm, after harvest of soybean and finger millet, respectively) which was found to be on par with application of NPK + FYM + borax (T_8 : 0.72 and 0.91 ppm, respectively), NPK + $ZnSO_4$ + borax (T_6 : 0.67 and 0.88 ppm, respectively and NPK + borax (T_5 : 0.64 and 0.87 ppm, respectively) while lower available boron was recorded in control (T_1) in both the cropping system(Table 4.4.2 and Fig.34).

In general soybean – finger millet cropping system registered higher available N, P_2O_5, K_2O, Zn and B status in the soil as compared to finger millet – soybean cropping system.

4.4.6 MICRONUTRIENT USE EFFICIENCY (MUE)

The data on MUE revealed that, additional yield produced per kg of micronutrient applied was higher with application of NPK + FYM + borax (54.90 and 33 in finger millet and soybean, respectively) and with application of NPK + FYM + $ZnSO_4$ (49.04 and 29.04, respectively) in finger millet-soybean cropping system. Similarly in case of soybean-finger millet cropping system, application of NPK + FYM + borax (T_8) recorded higher MUE of 30 in soybean and 48.50 in finger millet followed by 26.72 and 43.04 in soybean and finger millet with application of NPK + FYM + $ZnSO_4$ (T_7) (Table 4.4.2).

4.5 BALANCE SHEET OF NITROGEN, PHOSPHORUS, POTASSIUM, ZINC AND BORON AS INFLUENCED BY ZINC AND BORON APPLICATION IN FINGER MILLET-SOYBEAN AND SOYBEAN-FINGER MILLET CROPPING SYSTEM

4.5.1 NITROGEN BALANCE STUDIES IN SOIL

4.5.1.1 Finger millet-soybean cropping system

The initial status of nitrogen of the experimental site was 238.00 kg per ha (Table 4.5.1). The addition of nitrogen through organics and inorganic fertilizer was higher with application of NPK + FYM (T_3) and their combination with zinc and boron nutrients (90.50 kg/ha). Maximum uptake of nitrogen by finger millet was observed with application of NPK + FYM + $ZnSO_4$ + borax (T_9 : 93.94 kg/ha) followed by NPK + FYM + $ZnSO_4$ (T_7 : 89.61 kg/ha) and lower uptake was recorded in control (T_1 : 19.01 kg/ha).

A net loss of nitrogen was observed in all the treatments. Higher loss of nitrogen was observed in control (T_1 : 59.39 kg/ha) followed by NPK + $ZnSO_4$ (T_4 : 52.62 kg/ha) whereas lower loss of nitrogen was observed in NPK + FYM (T_3 : 30.95 kg/ha).

The initial status of nitrogen before sowing of soybean was higher with application of NPK + FYM (T_3 : 231.04 kg/ha). The addition of nitrogen through organic manure and inorganic fertilizer was higher in NPK + FYM (T_3) and its combination with zinc sulphate and boron (58.75 kg/ha). Maximum uptake of nitrogen was observed with application of NPK + FYM + $ZnSO_4$ (T_7 :150.18 kg/ha). Lower amount of nitrogen was removed by soybean in control (T_1 :61.44 kg/ha). There was a positive balance in nitrogen noticed in all the treatments. The net gain of nitrogen ranged from 22.84 to 65.17 kg per ha (Table 4.5.1)

Table 4.5.1: Nitrogen balance in soil as influenced by zinc and boron application in finger millet – soybean based cropping system

Treatments	Finger millet (2005)							Soybean (2006)						
	Initial soil available N (kg/ha)	Addition of N through fertilizers and manures (kg/ha	Total N (kg/ha)	Crop uptake of N (kg/ha)	Expected N balance (kg/ha)	Actual N balance (kg/ha	Net gain (+) or Net loss (-) (kg/ha)	Initial soil available N (kg/ha)	Addition of N through fertilizers and manures (kg/ha	Total N (kg/ha)	Crop uptake of N (kg/ha)	Expected N balance (kg/ha)	Actual N balance (kg/ha	Net gain (+) or Net loss (-) (kg/ha)
	(1)	(2)	3=(1+2)	(4)	5=(3-4)	(6)	7=(6-5)	(1)	(2)	3=(1+2)	(4)	5=(3-4)	(6)	7=(6-5)
T_1	238.00	0	238.00	19.01	218.99	159.60	-59.39	159.60	0	159.60	61.44	98.16	121.00	22.84
T_2	238.00	50.00	288.00	51.75	236.25	186.55	-49.70	186.55	25.00	211.55	87.13	124.42	163.98	39.56
T_3	238.00	90.50	328.50	66.51	261.99	231.04	-30.95	231.04	58.75	289.79	114.06	175.73	226.32	50.59
T_4	238.00	50.00	288.00	61.53	226.47	173.85	-52.62	173.85	25.00	198.85	112.91	85.94	117.92	31.98
T_5	238.00	50.00	288.00	59.68	228.32	178.50	-49.82	178.50	25.00	203.50	110.83	92.67	117.85	25.18
T_6	238.00	50.00	288.00	79.78	208.22	166.30	-41.92	166.30	25.00	191.30	138.44	52.86	106.48	53.62
T_7	238.00	90.50	328.50	89.61	238.89	205.24	-33.65	205.24	58.75	263.99	150.18	113.81	176.34	62.53
T_8	238.00	90.50	328.50	83.80	244.70	209.42	-35.28	209.42	58.75	268.17	144.75	123.42	178.70	55.28
T_9	238.00	90.50	328.50	93.94	235.16	203.07	-32.09	203.07	58.75	261.82	160.26	101.56	166.73	65.17

T_1: Control (No FYM + No NPK),T_2: NPK only,T_3 : NPK + FYM,T_4 : NPK + $ZnSO_4$ @ 12.50 kg/ha,T_5 : NPK + Borax @ 10 kg/ha,
T_6: NPK + $ZnSO_4$ @ 12.50 kg/ha + Borax @ 10 kg/ha, T_7: NPK + FYM + $ZnSO_4$ @ 12.50 kg/ha, T_8 : NPK + FYM + Borax @ 10 kg/ha,
T_9 : NPK + FYM + $ZnSO_4$ @ 12.50 kg/ha + Borax @ 10 kg/ha

Crop rotation: Finger millet (2005)- Soybean (2006), Soybean (2005)- Finger millet (2006), FYM @ 7.50 t/ha (0.54 % N)

Note: For Finger millet - NPK @ 50:40:25 kg/ha and FYM @ 7.5 t/ha
For Soybean – NPK @ 25:60:25 kg/ha and FYM @ 6.25 t/ha (0.54 % N)

4.5.1.2 Soybean-finger millet cropping system

The initial status of available nitrogen of the experimental site was 238.0 kg per ha. The addition of nutrients through inorganic fertilizers and organic manures was higher with application of NPK + FYM (T_3 : 58.75 kg/ha) and their combination with micronutrients. Application of NPK + FYM + $ZnSO_4$ + borax (T_9) recorded higher removal of nitrogen by soybean crop (173.13 kg/ha), while lower uptake of nitrogen (72.44 kg/ha) was observed in control (T_1) (Table 4.5.2).

A net gain of nitrogen was observed in all the treatments. Higher gain of nitrogen was observed with application of NPK + FYM + $ZnSO_4$ + borax (T_9 :50.65 kg/ha) followed by NPK + FYM + $ZnSO_4$ (T_7 : 45.62 kg/ha).

The initial status of nitrogen of the experimental site before sowing of finger millet was higher with application of NPK + FYM (T_3 : 192.46 kg/ha). The addition of nutrients through fertilizers and manures was higher with application of NPK + FYM (T_3 :90.50 kg/ha) and its combination with micronutrients. The total nitrogen removed by finger millet crop was higher with application of NPK + FYM + $ZnSO_4$ + borax (T_9 :88.05 kg/ha) followed by NPK + FYM + $ZnSO_4$ (T_7 : 83.53 kg/ha). Lower uptake of nitrogen (21.11 kg/ha) observed in control. There was a negative balance of nitrogen observed in all the treatments. The higher negative nitrogen balance was recorded in NPK + borax (T_5 :10.50 kg/ha). In general the available nitrogen status was higher in soybean-finger millet cropping system.

4.5.2 PHOSPHORUS BALANCE STUDIES IN SOIL

4.5.2.1 Finger millet-soybean cropping system

The initial available P_2O_5 content in soil was 106.0 kg per ha (Table 4.5.3). The addition of nutrients through fertilizers and manures was

Table 4.5.2: Nitrogen balance in soil as influenced by zinc and boron application in soybean – finger millet based cropping system

Treatments	Soybean (2005)							Finger millet (2006)						
	Initial soil available N (kg/ha)	Addition of N through fertilizers and manures (kg/ha	Total N (kg/ha)	Crop uptake of N (kg/ha)	Expected N balance (kg/ha)	Actual N balance (kg/ha	Net gain (+) or Net loss (-) (kg/ha)	Initial soil available N (kg/ha)	Addition of N through fertilizers and manures (kg/ha	Total N (kg/ha)	Crop uptake of N (kg/ha)	Expected N balance (kg/ha)	Actual N balance (kg/ha	Net gain (+) or Net loss (-) (kg/ha)
	(1)	(2)	3=(1+2)	(4)	5=(3-4)	(6)	7=(6-5)	(1)	(2)	3=(1+2)	(4)	5=(3-4)	(6)	7=(6-5)
T_1	238.00	0	238.00	72.44	165.56	173.20	7.64	173.20	0	173.20	21.11	152.09	145.99	-6.10
T_2	238.00	25.00	263.00	109.64	153.36	178.98	25.62	178.98	50.00	228.98	46.26	182.72	175.64	-7.08
T_3	238.00	58.75	296.75	134.47	162.28	192.46	30.18	192.46	90.50	282.96	61.47	221.49	211.74	-9.75
T_4	238.00	25.00	263.00	129.09	133.91	162.10	28.19	162.10	50.00	212.10	58.93	153.17	145.67	-7.50
T_5	238.00	25.00	263.00	126.45	136.55	163.75	27.19	163.75	50.00	213.75	56.57	157.18	146.68	-10.50
T_6	238.00	25.00	263.00	154.05	108.95	144.57	35.62	144.57	50.00	194.57	74.39	120.18	113.28	-6.90
T_7	238.00	58.75	296.75	168.93	127.82	173.44	45.62	173.44	90.50	263.94	83.53	180.41	174.16	-6.25
T_8	238.00	58.75	296.75	163.01	133.74	173.59	39.85	173.59	90.50	264.09	78.32	185.77	180.27	-5.50
T_9	238.00	58.75	296.75	173.13	123.62	174.27	50.65	174.27	90.50	264.77	88.05	176.72	168.97	-7.75

T_1: Control (No FYM + No NPK),T_2: NPK only,T_3 : NPK + FYM,T_4 : NPK + $ZnSO_4$ @ 12.50 kg/ha,T_5 : NPK + Borax @ 10 kg/ha,
T_6: NPK + $ZnSO_4$ @ 12.50 kg/ha + Borax @ 10 kg/ha, T_7: NPK + FYM + $ZnSO_4$ @ 12.50 kg/ha, T_8 : NPK + FYM + Borax @ 10 kg/ha,
T_9 : NPK + FYM + $ZnSO_4$ @ 12.50 kg/ha + Borax @ 10 kg/ha

Crop rotation: Finger millet (2005)- Soybean (2006), Soybean (2005)- Finger millet (2006)

Note: For Finger millet - NPK @ 50:40:25 kg/ha and FYM @ 7.5 t/ha
For Soybean – NPK @ 25:60:25 kg/ha and FYM @ 6.25 t/ha (0.54 % N)

higher with application of NPK + FYM (T_3 : 57.25 kg/ha) and its combination with micronutrients. The maximum P_2O_5 uptake by finger millet crop was noticed with application of NPK + FYM + $ZnSO_4$ + borax (T_9 : 40.74 kg/ha) followed by NPK + FYM + $ZnSO_4$ (T_7 : 38.59 kg/ha) and lower was observed in control (T_1 : 8.77 kg/ha). After the harvest of finger millet all the treatments showed a negative balance of P_2O_5. Further, it is note worthy to state that, a higher negative P_2O_5 balance was recorded in control (T_1: 26.95 kg/ha) followed by application of recommended NPK (T_2 : 26.28 kg/ha) only.

The initial available P_2O_5 content in the experimental soil was higher with application of NPK + FYM (T_3) treatment before sowing of soybean crop. The addition of phosphorus was also maximum in the same treatment (74.37 kg/ha) and along with application of micronutrients. The total P_2O_5 removed by the crop was higher with application of NPK + FYM + $ZnSO_4$ + borax (T_9 : 16.0 kg/ha) followed by NPK + FYM + $ZnSO_4$ (T_7 : 15.25 kg/ha). After the harvest of soybean all the treatments showed a negative balance of P_2O_5. A higher negative P_2O_5 balance was recorded in NPK + FYM (T_3 : 67.35 kg/ha) followed by application of NPK + FYM + borax (T_8 : 62.42 kg/ha) which is note worthy finding of this experiment (Table 4.5.3).

4.5.2.2 Soybean-finger millet cropping system

The initial available P_2O_5 content in the experimental site was 106.0 kg per ha (Table 4.5.4). The addition of phosphorus through fertilizers and manures was maximum with application of NPK + FYM (T_3 : 180.37 kg/ha) and its application with micronutrients. The total P_2O_5 removed by the crop was higher with application of NPK + FYM + $ZnSO_4$ + borax (T_2 : 17.95 kg/ha) followed by application of NPK + FYM + $ZnSO_4$ (T_7 : 17.04 kg/ha). After the harvest of soybean, all the treatments showed a negative balance of P_2O_5. The higher negative P_2O_5 balance

Table 4.5.3: Phosphorus balance in soil as influenced by zinc and boron application in finger millet – soybean based cropping system

Treatments	Finger millet (2005)							Soybean (2006)						
	Initial soil available P_2O_5 (kg/ha)	Addition of P_2O_5 through fertilizers and manures (kg/ha	Total P_2O_5 (kg/ha)	Crop uptake of P_2O_5 (kg/ha) {P x2.29}	Expected P_2O_5 balance (kg/ha)	Actual P_2O_5 balance (kg/ha	Net gain (+) or Net loss (-) (kg/ha)	Initial soil available P_2O_5 (kg/ha)	Addition of N through fertilizers and manures (kg/ha	Total P_2O_5 (kg/ha)	Crop uptake of P_2O_5 (kg/ha) {P x2.29}	Expected P_2O_5 balance (kg/ha)	Actual P_2O_5 balance (kg/ha	Net gain (+) or Net loss (-) (kg/ha)
	(1)	(2)	3=(1+2)	(4)	5=(3-4)	(6)	7=(6-5)	(1)	(2)	3=(1+2)	(4)	5=(3-4)	(6)	7=(6-5)
T_1	106.00	0	106.00	8.77	97.23	70.28	-26.95	70.28	0	70.28	5.11	65.17	60.55	-4.62
T_2	106.00	40.00	146.00	23.31	122.69	96.41	-26.28	96.41	60.00	156.41	7.72	148.69	95.05	-53.64
T_3	106.00	57.25	163.25	30.92	132.33	110.69	-21.64	110.69	74.37	185.06	11.25	173.81	106.46	-67.35
T_4	106.00	40.00	146.00	28.81	117.19	93.52	-23.67	93.52	60.00	153.52	10.67	142.85	92.13	-50.72
T_5	106.00	40.00	146.00	27.37	118.63	82.38	-36.25	82.38	60.00	142.38	10.05	132.33	90.13	-42.20
T_6	106.00	40.00	146.00	36.07	109.93	78.31	-31.62	78.31	60.00	138.31	13.53	124.78	88.28	-36.50
T_7	106.00	57.25	163.25	38.59	124.66	105.41	-19.25	105.41	74.37	179.78	15.25	164.53	103.71	-60.82
T_8	106.00	57.25	163.25	37.08	126.17	108.00	-18.17	108.00	74.37	182.37	14.47	167.90	105.48	-62.42
T_9	106.00	57.25	163.25	40.74	122.51	101.86	-20.65	101.86	74.37	176.23	16.00	160.23	101.99	-58.24

T_1: Control (No FYM + No NPK),T_2: NPK only,T_3 : NPK + FYM,T_4 : NPK + $ZnSO_4$ @ 12.50 kg/ha,T_5 : NPK + Borax @ 10 kg/ha,
T_6: NPK + $ZnSO_4$ @ 12.50 kg/ha + Borax @ 10 kg/ha, T_7: NPK + FYM + $ZnSO_4$ @ 12.50 kg/ha, T_8 : NPK + FYM + Borax @ 10 kg/ha,
T_9 : NPK + FYM + $ZnSO_4$ @ 12.50 kg/ha + Borax @ 10 kg/ha

Crop rotation: Finger millet (2005)- Soybean (2006), Soybean (2005)- Finger millet (2006)

Note: For Finger millet - NPK @ 50:40:25 kg/ha and FYM @ 7.5 t/ha
For Soybean – NPK @ 25:60:25 kg/ha and FYM @ 6.25 t/ha (0.23% P_2O_5)

Table 4.5.4: Phosphorus balance in soil as influenced by zinc and boron application in soybean – finger millet based cropping system

Treatments	Soybean (2005)							Finger millet (2006)						
	Initial soil available P_2O_5 (kg/ha)	Addition of P_2O_5 through fertilizers and manures (kg/ha	Total P_2O_5 (kg/ha)	Crop uptake of P_2O_5 (kg/ha) {P x2.29}	Expected P_2O_5 balance (kg/ha)	Actual P_2O_5 balance (kg/ha	Net gain (+) or Net loss (-) (kg/ha)	Initial soil available P_2O_5 (kg/ha)	Addition of N through fertilizers and manures (kg/ha	Total P_2O_5 (kg/ha)	Crop uptake of P_2O_5 (kg/ha) {P x2.29}	Expected P_2O_5 balance (kg/ha)	Actual P_2O_5 balance (kg/ha	Net gain (+) or Net loss (-) (kg/ha)
	(1)	(2)	3=(1+2)	(4)	5=(3-4)	(6)	7=(6-5)	(1)	(2)	3=(1+2)	(4)	5=(3-4)	(6)	7=(6-5)
T_1	106.00	0	106.00	5.84	100.16	83.45	-16.71	83.45	0	83.45	10.12	73.33	69.20	-4.13
T_2	106.00	60.00	166.00	9.39	156.61	98.43	-58.18	98.43	40.00	138.43	21.92	116.51	97.76	-18.75
T_3	106.00	74.37	180.37	13.05	167.32	109.79	-57.53	109.79	57.25	167.04	28.08	138.96	110.25	-28.71
T_4	106.00	60.00	166.00	12.23	153.77	91.59	-62.18	91.59	40.00	131.59	27.59	104.00	92.86	-11.14
T_5	106.00	60.00	166.00	11.45	154.55	94.37	-60.18	94.37	40.00	134.37	26.84	107.53	93.16	-14.37
T_6	106.00	60.00	166.00	14.95	151.05	87.90	-63.15	87.90	40.00	127.90	33.41	94.49	89.17	-5.32
T_7	106.00	74.37	180.37	17.04	163.33	112.15	-51.18	112.15	57.25	169.40	36.18	133.22	104.16	-29.06
T_8	106.00	74.37	180.37	16.26	164.11	110.87	-53.24	110.87	57.25	168.12	34.74	133.38	105.26	-28.12
T_9	106.00	74.37	180.37	17.95	162.42	111.86	-50.56	111.86	57.25	169.11	38.95	130.16	100.19	-29.97

T_1: Control (No FYM + No NPK),T_2: NPK only,T_3 : NPK + FYM,T_4 : NPK + $ZnSO_4$ @ 12.50 kg/ha,T_5 : NPK + Borax @ 10 kg/ha,
T_6: NPK + $ZnSO_4$ @ 12.50 kg/ha + Borax @ 10 kg/ha, T_7: NPK + FYM + $ZnSO_4$ @ 12.50 kg/ha, T_8 : NPK + FYM + Borax @ 10 kg/ha,
T_9 : NPK + FYM + $ZnSO_4$ @ 12.50 kg/ha + Borax @ 10 kg/ha

Crop rotation: Finger millet (2005)- Soybean (2006), Soybean (2005)- Finger millet (2006)

Note: For Finger millet - NPK @ 50:40:25 kg/ha and FYM @ 7.5 t/ha
For Soybean – NPK @ 25:60:25 kg/ha and FYM @ 6.25 t/ha (0.23% P_2O_5)

was recorded in NPK + $ZnSO_4$ + borax (T_6 : 63.15 kg/ha) followed by application of NPK + $ZnSO_4$ (T_4 : 62.18 kg/ha) (Table 4.5.4).

The initial status of phosphorus before sowing of finger millet was higher with application of NPK + FYM + $ZnSO_4$ (T_7 : 112.15 kg/ha). The addition of phosphorus through organic and inorganic fertilizers was higher with application of NPK + FYM (T_3 : 57.25 kg/ha) and its combination with micronutrients. Maximum uptake of phosphorus by finger millet was registered with application of NPK + FYM + $ZnSO_4$ + borax (T_9 :38.95 kg/ha) followed by NPK + FYM + $ZnSO_4$ (T_7 : 36.18 kg/ha). On the contrary, there was a negative balance in P_2O_5 observed in all the treatments. Nevertheless, a higher negative balance was recorded with application of NPK + FYM + $ZnSO_4$ + borax (T_9 : 29.97 kg/ha) followed by NPK + FYM + $ZnSO_4$ (T_7 : 29.06 kg/ha).

4.5.3 POTASSIUM BALANCE STUDIES IN SOIL

4.5.3.1 Finger millet-soybean based cropping system

The initial status of available potassium of experimental site was 168 kg per ha (Table 4.5.5). The addition of organic manure and inorganic fertilizers was maximum with application of NPK + FYM (T_3) and its combination with micronutrients (64 kg/ha). Total K_2O removed by the crop was higher with application of NPK + FYM + $ZnSO_4$ + borax (T_9 : 88.45 kg/ha) followed by NPK + FYM + $ZnSO_4$ (T_7 : 87.42 kg/ha). After the harvest of finger millet all other treatments recorded a negative balance of K_2O. Nevertheless, a higher negative balance was observed in control (T_1:15.40 kg/ha) followed by application of NPK + borax (T_5 :13.60 kg/ha) (Table 4.5.5)

The actual K_2O status in soil (in 2005) after the harvest of finger millet would be an initial K_2O status during 2006 (i.e., before sowing of soybean) which was higher with application of NPK + FYM (T_3 : 154.55

Table 4.5.5: Potassium balance in soil as influenced by zinc and boron application in finger millet – soybean based cropping system

Treatments	Finger millet (2005)							Soybean (2006)						
	Initial soil available K_2O (kg/ha)	Addition of K_2O through fertilizers and manures (kg/ha)	Total K_2O (kg/ha)	Crop uptake of K_2O (kg/ha) {K x 1.2}	Expected K_2O balance (kg/ha)	Actual K_2O balance (kg/ha)	Net gain (+) or Net loss (-) (kg/ha)	Initial soil available K_2O (kg/ha)	Addition of K_2O through fertilizers and manures (kg/ha)	Total K_2O (kg/ha)	Crop uptake of K_2O (kg/ha) {K x 1.2}	Expected K_2O balance (kg/ha)	Actual K_2O balance (kg/ha)	Net gain (+) or Net loss (-) (kg/ha)
	(1)	(2)	3=(1+2)	(4)	5=(3-4)	(6)	7=(6-5)	(1)	(2)	3=(1+2)	(4)	5=(3-4)	(6)	7=(6-5)
T_1	168.00	0	168.00	21.25	146.75	131.35	-15.40	131.35	0	131.35	27.40	103.95	115.30	11.35
T_2	168.00	25.00	193.00	54.16	138.84	130.34	-8.50	130.34	25.00	155.34	38.94	116.40	138.18	21.78
T_3	168.00	64.00	232.00	72.17	159.83	154.55	-5.28	154.55	57.50	212.05	50.92	161.13	170.00	8.87
T_4	168.00	25.00	193.00	69.60	123.40	116.20	-7.20	116.20	25.00	141.20	50.06	91.14	120.30	29.16
T_5	168.00	25.00	193.00	65.40	127.60	114.00	-13.60	114.00	25.00	139.00	49.02	89.98	119.18	29.20
T_6	168.00	25.00	193.00	84.35	108.65	106.35	-2.30	106.35	25.00	131.35	61.87	69.48	100.00	30.52
T_7	168.00	64.00	232.00	87.42	144.58	137.46	-7.12	137.46	57.50	194.96	64.24	130.72	164.30	33.58
T_8	168.00	64.00	232.00	86.14	145.86	139.52	-6.34	139.52	57.50	197.02	62.86	134.16	165.30	31.14
T_9	168.00	64.00	232.00	88.45	143.55	135.26	-8.29	135.26	57.50	192.76	65.52	127.24	168.30	41.06

T_1: Control (No FYM + No NPK), T_2: NPK only, T_3 : NPK + FYM, T_4 : NPK + $ZnSO_4$ @ 12.50 kg/ha, T_5 : NPK + Borax @ 10 kg/ha,
T_6: NPK + $ZnSO_4$ @ 12.50 kg/ha + Borax @ 10 kg/ha, T_7: NPK + FYM + $ZnSO_4$ @ 12.50 kg/ha, T_8 : NPK + FYM + Borax @ 10 kg/ha,
T_9 : NPK + FYM + $ZnSO_4$ @ 12.50 kg/ha + Borax @ 10 kg/ha

Crop rotation: Finger millet (2005)- Soybean (2006), Soybean (2005)- Finger millet (2006)

Note: For Finger millet - NPK @ 50:40:25 kg/ha and FYM @ 7.5 t/ha
For Soybean – NPK @ 25:60:25 kg/ha and FYM @ 6.25 t/ha (0.52 % K_2O)

kg/ha). The added potassium through various sources was also higher in the same treatment and its combination with micronutrients (57.50 kg/ha). Total K_2O removed by the soybean crop was maximum with application of NPK + FYM + $ZnSO_4$ + borax (T_9 : 65.52 kg/ha) followed by NPK + FYM + $ZnSO_4$ (T_7 : 64.24 kg/ha). After the harvest of soybean all other treatments recorded positive balance of K_2O. Indeed, a higher gain of potassium status was recorded with application of NPK + FYM + $ZnSO_4$ + borax (T_9 : 41.06 kg/ha) followed by NPK + FYM + $ZnSO_4$ (T_7 : 33.58 kg/ha) (Table 4.5.5).

4.5.3.2 Soybean-finger millet cropping system

The initial status of potassium of experimental site was 168 kg per ha (Table 4.5.6). The addition of potassium was maximum with application of NPK + FYM (T_3) and its combination with micronutrients (57.50 kg/ha). The higher uptake of potassium was observed with application of NPK + FYM + $ZnSO_4$ + borax (T_9: 70.43 kg/ha) followed by NPK + FYM + $ZnSO_4$ (T_7 : 69.13 kg/ha). Lower uptake of 31.70 kg K_2O per ha was recorded in control. Nevertheless, a positive balance of potassium was recorded in all other treatments. On the contrary, higher positive balance was recorded with application of NPK + FYM + borax (T_8 :10.29 kg/ha) followed by application of NPK + FYM + $ZnSO_4$ + borax (T_9 :10.23 kg/ha), while lower gain of potassium was observed in control (T_1 :4 kg/ha).

The initial soil available K_2O status in soil before sowing of finger millet was higher with application of NPK + FYM (T_3 : 179.45 kg/ha). The addition of K_2O through various sources to different treatments was maximum with application of NPK + FYM (T_3) and its combination with micronutrients (64 kg/ha). Total K_2O removed by the crop was higher with application of NPK + FYM + $ZnSO_4$ + borax (T_9 : 85.85 kg/ha) followed by application of NPK + FYM + $ZnSO_4$ (T_7 : 84.35 kg/ha).

Table 4.5.6: Potassium balance in soil as influenced by zinc and boron application in soybean – finger millet based cropping system

Treatments	Soybean (2005)							Finger millet (2006)						
	Initial soil available K_2O (kg/ha)	Addition of K_2O through fertilizers and manures (kg/ha)	Total K_2O (kg/ha)	Crop uptake of K_2O (kg/ha) {K x 1.2}	Expected K_2O balance (kg/ha)	Actual K_2O balance (kg/ha)	Net gain (+) or Net loss (-) (kg/ha)	Initial soil available K_2O (kg/ha)	Addition of K_2O through fertilizers and manures (kg/ha)	Total K_2O (kg/ha)	Crop uptake of K_2O (kg/ha) {K x 1.2}	Expected K_2O balance (kg/ha)	Actual K_2O balance (kg/ha)	Net gain (+) or Net loss (-) (kg/ha)
	(1)	(2)	3=(1+2)	(4)	5=(3-4)	(6)	7=(6-5)	(1)	(2)	3=(1+2)	(4)	5=(3-4)	(6)	7=(6-5)
T_1	168.00	0	168.00	31.70	136.30	140.30	4.00	140.30	0	140.30	28.22	112.08	115.28	3.20
T_2	168.00	25.00	193.00	44.70	148.30	153.40	5.10	153.40	25.00	178.40	51.98	126.42	134.42	8.00
T_3	168.00	57.50	225.50	56.03	169.47	179.45	9.98	179.45	64.00	243.45	68.89	174.56	189.86	15.30
T_4	168.00	25.00	193.00	55.28	137.72	145.00	7.28	145.00	25.00	170.00	68.70	101.30	116.28	14.98
T_5	168.00	25.00	193.00	54.00	139.00	148.30	9.30	148.30	25.00	173.30	65.58	107.72	116.92	9.20
T_6	168.00	25.00	193.00	63.61	129.39	138.39	9.00	138.39	25.00	163.39	81.76	81.63	120.50	38.87
T_7	168.00	57.50	225.50	69.13	156.37	171.50	15.13	171.50	64.00	235.50	84.35	151.15	171.45	20.30
T_8	168.00	57.50	225.50	66.49	159.01	169.30	10.29	169.30	64.00	233.30	80.18	153.12	170.42	17.30
T_9	168.00	57.50	225.50	70.43	155.07	165.30	10.23	165.30	64.00	229.30	85.85	143.45	171.72	28.27

T_1: Control (No FYM + No NPK),T_2: NPK only,T_3 : NPK + FYM,T_4 : NPK + $ZnSO_4$ @ 12.50 kg/ha,T_5 : NPK + Borax @ 10 kg/ha,
T_6: NPK + $ZnSO_4$ @ 12.50 kg/ha + Borax @ 10 kg/ha, T_7: NPK + FYM + $ZnSO_4$ @ 12.50 kg/ha, T_8 : NPK + FYM + Borax @ 10 kg/ha,
T_9 : NPK + FYM + $ZnSO_4$ @ 12.50 kg/ha + Borax @ 10 kg/ha

Crop rotation: Finger millet (2005)- Soybean (2006), Soybean (2005)- Finger millet (2006)

Note: For Finger millet - NPK @ 50:40:25 kg/ha and FYM @ 7.5 t/ha
For Soybean – NPK @ 25:60:25 kg/ha and FYM @ 6.25 t/ha (0.52 % K_2O)

Indeed, a positive balance of K_2O was recorded in all other treatments. Nevertheless, a higher positive balance was recorded with application of NPK + $ZnSO_4$ + borax (T_6 : 38.87 kg/ha) followed by application of NPK + FYM + $ZnSO_4$ + borax (T_9 : 28.27 kg/ha) (Table 4.5.6).

In general, a higher available potassium status of soil in all other treatments was observed in soybean-finger millet cropping system as compared to finger millet-soybean cropping system.

4.5.4 ZINC BALANCE STUDIES IN SOIL

4.5.4.1 Finger millet-soybean based cropping system

The initial status of zinc of experimental site was 0.54 ppm (Table 4.5.7). The addition of zinc through organic manure and inorganic fertilizers was higher with application of NPK + FYM + $ZnSO_4$ + borax (T_9 : 1.24 ppm) and NPK + FYM + $ZnSO_4$ (T_7 : 1.24 ppm). Indeed, a higher uptake of zinc was recorded with application of NPK + FYM + $ZnSO_4$ + borax (T_9 : 0.06 ppm), NPK + FYM + $ZnSO_4$ (T_7 : 0.06 ppm) and NPK + $ZnSO_4$ + borax (T_6 : 0.06 ppm). On the contrary, a negative balance of zinc recorded in all other treatments. A higher loss of zinc was observed in NPK + $ZnSO_4$ (T_4 : 0.16 ppm) and NPK + FYM + $ZnSO_4$ (T_7 : 0.16 ppm) (Table 4.5.7)

The actual Zn content of soil after harvest of finger millet would be an initial zinc status before sowing of soybean and it was higher with application of NPK + FYM + $ZnSO_4$ + borax (T_9 : 1.57 ppm) followed by NPK + FYM + $ZnSO_4$ (T_7 : 1.56 ppm). Similarly addition of zinc was also higher (1.23 ppm) in the same treatments. The total zinc removed by soybean crop was higher with application of NPK + FYM + $ZnSO_4$ + borax (T_9 : 0.08 ppm). After the harvest of soybean all the treatments showed a negative balance of zinc in soil. However, a maximum negative balance

Table 4.5.7: Zinc balance in soil as influenced by zinc and boron application in finger millet –soybean based cropping system

Treatments	Finger millet (2005)							Soybean (2006)						
	Initial soil available Zn (ppm)	Addition of Zn through fertilizers and manures (ppm)	Total Zn (ppm)	Crop uptake of Zn (ppm)	Expected Zn balance (ppm)	Actual Zn balance (ppm)	Net gain (+) or Net loss (-) (ppm)	Initial soil available Zn (ppm)	Addition of Zn through fertilizers and manures (ppm)	Total Zn (ppm)	Crop uptake of Zn (ppm)	Expected Zn balance (ppm)	Actual Zn balance (ppm)	Net gain (+) or Net loss (-) (ppm)
	(1)	(2)	3=(1+2)	(4)	5=(3-4)	(6)	7=(6-5)	(1)	(2)	3=(1+2)	(4)	5=(3-4)	(6)	7=(6-5)
T_1	0.54	0	0.54	0.01	0.53	0.40	-0.13	0.40	0	0.40	0.02	0.38	0.36	-0.02
T_2	0.54	0	0.54	0.03	0.51	0.43	-0.08	0.43	0	0.43	0.03	0.40	0.37	-0.03
T_3	0.54	0.07	0.61	0.04	0.57	0.48	-0.09	0.48	0.06	0.54	0.05	0.49	0.44	-0.05
T_4	0.54	1.17	1.71	0.04	1.67	1.51	-0.16	1.51	1.17	2.68	0.06	2.62	1.50	-1.12
T_5	0.54	0	0.54	0.04	0.50	0.42	-0.08	0.42	0	0.42	0.04	0.38	0.36	-0.02
T_6	0.54	1.17	1.71	0.06	1.65	1.50	-0.15	1.50	1.17	2.67	0.07	2.60	1.48	-1.12
T_7	0.54	1.24	1.78	0.06	1.72	1.56	-0.16	1.56	1.23	2.79	0.07	2.72	1.56	-1.16
T_8	0.54	0.07	0.61	0.05	0.56	0.42	-0.06	0.42	0.06	0.48	0.07	0.41	0.38	-0.30
T_9	0.54	1.24	1.78	0.06	1.72	1.57	-0.15	1.57	1.23	2.80	0.08	2.72	1.58	-1.14

T_1: Control (No FYM + No NPK),T_2: NPK only,T_3 : NPK + FYM,T_4 : NPK + $ZnSO_4$ @ 12.50 kg/ha,T_5 : NPK + Borax @ 10 kg/ha,
T_6: NPK + $ZnSO_4$ @ 12.50 kg/ha + Borax @ 10 kg/ha, T_7: NPK + FYM + $ZnSO_4$ @ 12.50 kg/ha, T_8 : NPK + FYM + Borax @ 10 kg/ha,
T_9 : NPK + FYM + $ZnSO_4$ @ 12.50 kg/ha + Borax @ 10 kg/ha

Crop rotation: Finger millet (2005)- Soybean (2006), Soybean (2005)- Finger millet (2006)

Note: For Finger millet - NPK @ 50:40:25 kg/ha and FYM @ 7.5 t/ha
For Soybean – NPK @ 25:60:25 kg/ha and FYM @ 6.25 t/ha (22 ppm Zn)

was observed in application of NPK + FYM + $ZnSO_4$ + borax (T_9 :1.14 ppm) (Table 4.5.7).

4.5.4.2 Soybean-finger millet cropping system

The initial status of available zinc of the experimental site was 0.54 ppm (Table 4.5.8). Addition of zinc through different sources was higher with application of NPK + FYM + $ZnSO_4$ + borax (T_9: 1.23 ppm) and NPK + FYM + $ZnSO_4$ (T_7 : 1.23 ppm). The total zinc removed by the crop was higher with application of NPK + FYM + $ZnSO_4$ + borax (T_9 :0.09 ppm) and with application of NPK + FYM + $ZnSO_4$ (T_7 : 0.09 ppm). A negative balance of zinc was observed in all other treatments. On the contrary, a higher negative balance of 0.12 ppm was observed with application of NPK + FYM + $ZnSO_4$ + borax (T_9 :0.12 ppm), NPK + FYM + $ZnSO_4$ (T_7 :0.12 ppm) and NPK + $ZnSO_4$ (T_4 :0.12 ppm) (Table 4.5.8).

The initial status of zinc of the experimental site before sowing of finger millet was higher with application of NPK + FYM + $ZnSO_4$ + borax (T_9 : 1.56 ppm) and NPK + FYM + $ZnSO_4$ (T_7 : 1.56 ppm). The addition of zinc through fertilizers and manures was also higher in the same treatments. The higher uptake of zinc was observed with the application of NPK + FYM + $ZnSO_4$ + borax (T_9 :0.06 ppm), NPK + FYM + $ZnSO_4$ (T_7 :0.06 ppm) and NPK + $ZnSO_4$ + borax (T_6 : 0.06 ppm). Nevertheless, a net loss of zinc was observed in all other treatments. On the contrary, a higher loss of zinc was observed with application of NPK + $ZnSO_4$ + borax (T_6 :1.18 ppm) followed by NPK + $ZnSO_4$ (T_4 :1.16 ppm) (Table 4.5.8).

The actual zinc balance was higher in soybean-finger millet cropping system as compared to finger millet-soybean cropping system (Table 4.5.7 and 4.5.8).

Table 4.5.8: Zinc balance in soil as influenced by zinc and boron application in soybean – finger millet based cropping system

Treatments	Soybean (2005)							Finger millet (2006)						
	Initial soil available Zn (ppm)	Addition of Zn through fertilizers and manures (ppm)	Total Zn (ppm)	Crop uptake of Zn (ppm)	Expected Zn balance (ppm)	Actual Zn balance (ppm)	Net gain (+) or Net loss (-) (ppm)	Initial soil available Zn (ppm)	Addition of Zn through fertilizers and manures (ppm)	Total Zn (ppm)	Crop uptake of Zn (ppm)	Expected Zn balance (ppm)	Actual Zn balance (ppm)	Net gain (+) or Net loss (-) (ppm)
	(1)	(2)	3=(1+2)	(4)	5=(3-4)	(6)	7=(6-5)	(1)	(2)	3=(1+2)	(4)	5=(3-4)	(6)	7=(6-5)
T_1	0.54	0	0.54	0.03	0.51	0.41	-0.10	0.41	0	0.41	0.01	0.40	0.36	-0.04
T_2	0.54	0	0.54	0.04	0.50	0.45	-0.05	0.45	0	0.45	0.03	0.42	0.39	-0.03
T_3	0.54	0.06	0.60	0.06	0.54	0.50	-0.04	0.50	0.07	0.57	0.04	0.53	0.49	-0.04
T_4	0.54	1.17	1.71	0.06	1.65	1.53	-0.12	1.53	1.17	2.70	0.04	2.66	1.50	-1.16
T_5	0.54	0	0.54	0.05	0.49	0.44	-0.05	0.44	0	0.44	0.04	0.40	0.38	-0.02
T_6	0.54	1.17	1.71	0.08	1.63	1.52	-0.11	1.52	1.17	2.69	0.06	2.63	1.45	-1.18
T_7	0.54	1.23	1.77	0.09	1.68	1.56	-0.12	1.56	1.24	2.80	0.06	2.74	1.60	-1.14
T_8	0.54	0.06	0.60	0.07	0.53	0.50	-0.03	0.50	0.07	0.57	0.05	0.52	0.48	-0.04
T_9	0.54	1.23	1.77	0.09	1.68	1.56	-0.12	1.56	1.24	2.80	0.06	2.74	1.62	-1.12

T_1: Control (No FYM + No NPK),T_2: NPK only,T_3 : NPK + FYM,T_4 : NPK + $ZnSO_4$ @ 12.50 kg/ha,T_5 : NPK + Borax @ 10 kg/ha,
T_6: NPK + $ZnSO_4$ @ 12.50 kg/ha + Borax @ 10 kg/ha, T_7: NPK + FYM + $ZnSO_4$ @ 12.50 kg/ha, T_8 : NPK + FYM + Borax @ 10 kg/ha,
T_9 : NPK + FYM + $ZnSO_4$ @ 12.50 kg/ha + Borax @ 10 kg/ha

Crop rotation: Finger millet (2005)- Soybean (2006), Soybean (2005)- Finger millet (2006)

Note: For Finger millet - NPK @ 50:40:25 kg/ha and FYM @ 7.5 t/ha
For Soybean – NPK @ 25:60:25 kg/ha and FYM @ 6.25 t/ha (22 ppm Zn)

4.5.5 BORON BALANCE STUDIES IN SOIL

4.5.5.1 Finger millet-soybean based cropping system

The initial status of boron of the experimental site was 0.43 ppm (Table 4.5.9). The addition of boron through fertilizers and manures was higher with application of NPK + FYM + $ZnSO_4$ + borax (T_9 : 0.51 ppm) and NPK + FYM + $ZnSO_4$ (T_8 : 0.51 ppm). A higher uptake of boron (0.03 ppm) was registered in all other treatments except in control (T_1 : 0.01 ppm), 0.02 ppm in T_2 (NPK only) and NPK + $ZnSO_4$ (T_4 : 0.02 ppm). Nevertheless, a negative balance of boron noticed in all the treatments. On the contrary, a higher negative boron balance was recorded with the application of NPK + borax (T_5 :0.31 ppm) followed by NPK + $ZnSO_4$ + borax (T_6 :0.29 ppm).

The actual soil boron content after harvest of finger millet would be an initial boron status during 2006. The initial available boron status in soil was higher in NPK + FYM + $ZnSO_4$ + borax (T_9 : 0.70 ppm) applied treatment. The addition of boron through fertilizer and manure was also higher in the same treatment (0.50ppm) and with application of NPK + FYM + borax (T_8 : 0.50 ppm). The uptake of boron was higher with application of NPK + FYM + $ZnSO_4$ + borax (T_9 : 0.03 ppm). After the harvest of soybean, all the treatments showed negative balance of boron. The higher loss of boron was recorded in NPK + FYM + borax (T_8 :0.33 ppm) (Table 4.5.9).

4.5.5.2 Soybean-finger millet cropping system

The initial status of boron of experimental site was 0.43 ppm (Table 4.5.10). The addition of boron was maximum in NPK + FYM + $ZnSO_4$ + borax (T_9 : 0.50 ppm) and NPK + FYM + borax (T_8 : 0.50 ppm) applied treatments. Similarly, the total boron removed by soybean was also higher (0.03 ppm) in the same treatments. A net loss of boron was

Table 4.5.9: Boron balance in soil as influenced by zinc and boron application in finger millet –soybean based cropping system

Treatments	Finger millet (2005)							Soybean (2006)						
	Initial soil available B (ppm)	Addition of B through fertilizers and manures (ppm)	Total B (ppm)	Crop uptake of B (ppm)	Expected B balance (ppm)	Actual B balance (ppm)	Net gain (+) or Net loss (-) (ppm)	Initial soil available B (ppm)	Addition of B through fertilizers and manures (ppm)	Total B (ppm)	Crop uptake of B (ppm)	Expected B balance (ppm)	Actual B balance (ppm)	Net gain (+) or Net loss (-) (ppm)
	(1)	(2)	3=(1+2)	(4)	5=(3-4)	(6)	7=(6-5)	(1)	(2)	3=(1+2)	(4)	5=(3-4)	(6)	7=(6-5)
T_1	0.43	0	0.43	0.01	0.42	0.37	-0.05	0.37	0	0.37	0.01	0.36	0.34	-0.02
T_2	0.43	0	0.43	0.02	0.41	0.39	-0.02	0.39	0	0.39	0.01	0.38	0.36	-0.02
T_3	0.43	0.02	0.45	0.03	0.42	0.40	-0.02	0.40	0.01	0.41	0.01	0.40	0.38	-0.02
T_4	0.43	0	0.43	0.02	0.41	0.38	-0.03	0.38	0	0.38	0.01	0.37	0.35	-0.02
T_5	0.43	0.49	0.92	0.03	0.89	0.58	-0.31	0.58	0.49	1.07	0.02	1.05	0.76	-0.29
T_6	0.43	0.49	0.92	0.03	0.89	0.60	-0.29	0.60	0.49	1.09	0.02	1.07	0.80	-0.27
T_7	0.43	0.02	0.45	0.03	0.42	0.40	-0.02	0.40	0.01	0.41	0.02	0.39	0.37	-0.02
T_8	0.43	0.51	0.94	0.03	0.91	0.65	-0.26	0.65	0.50	1.15	0.02	1.13	0.80	-0.33
T_9	0.43	0.51	0.94	0.03	0.91	0.70	-0.21	0.70	0.50	1.20	0.03	1.17	0.85	-0.32

T_1: Control (No FYM + No NPK),T_2: NPK only,T_3 : NPK + FYM,T_4 : NPK + $ZnSO_4$ @ 12.50 kg/ha,T_5 : NPK + Borax @ 10 kg/ha,
T_6: NPK + $ZnSO_4$ @ 12.50 kg/ha + Borax @ 10 kg/ha, T_7: NPK + FYM + $ZnSO_4$ @ 12.50 kg/ha, T_8 : NPK + FYM + Borax @ 10 kg/ha,
T_9 : NPK + FYM + $ZnSO_4$ @ 12.50 kg/ha + Borax @ 10 kg/ha

Crop rotation: Finger millet (2005)- Soybean (2006), Soybean (2005)- Finger millet (2006)

Note: For Finger millet - NPK @ 50:40:25 kg/ha and FYM @ 7.5 t/ha
For Soybean – NPK @ 25:60:25 kg/ha and FYM @ 6.25 t/ha (5 ppm B)

observed in all the treatments. Indeed, a higher loss of boron was observed with application of NPK + borax (T_5 : 0.26 ppm) and NPK + $ZnSO_4$ (T_6 : 0.23 ppm).

The actual soil boron content after harvest of soybean would be an initial boron status during 2006 and it was higher in NPK + FYM + borax (T_8 : 0.72 ppm) applied treatment followed by NPK + FYM + $ZnSO_4$ + borax (T_9 : 0.71 ppm).

The addition of boron through organic manure and fertilizers was also higher in the same treatments. Higher uptake of boron (0.03 ppm) was observed in all the treatments except in control (T_1 : 0.01 ppm), application of NPK (T_2 : 0.02 ppm) and NPK + $ZnSO_4$ (T_4 : 0.02 ppm) treatments. After the harvest of finger millet, all the treatments showed a negative balance of boron. Nevertheless, a higher net loss of boron was observed in NPK + FYM + $ZnSO_4$ + borax (T_9 :0.29 ppm) and NPK + FYM + borax (T_8 :0.29 ppm) treatments.

In general, the available boron status in soil was higher in soybean-finger millet cropping system as compared to finger millet-soybean cropping system.

4.6 ECONOMICS OF FINGER MILLET-SOYBEAN AND SOYBEAN-FINGER MILLET BASED CROPPING SYSTEMS AS INFLUENCED BY ZINC AND BORON APPLICATION

4.6.1 FINGER MILLET-SOYBEAN BASED CROPPING SYSTEM

Among the different nutrient management practices, a higher gross returns was recorded with application of NPK + FYM + $ZnSO_4$ + borax (T_9 : Rs. 68,760/ha) followed by NPK + FYM + $ZnSO_4$ (Rs. 67,886/ha). Lower gross returns (Rs.23,464/ha) was recorded in control and rest of the treatments were found to be intermediate.

Table 4.5.10: Boron balance in soil as influenced by zinc and boron application in soybean – finger millet based cropping system

Treatments	Soybean (2005)							Finger millet (2006)						
	Initial soil available B (ppm)	Addition of B through fertilizers and manures (ppm)	Total B (ppm)	Crop uptake of B (ppm)	Expected B balance (ppm)	Actual B balance (ppm)	Net gain (+) or Net loss (-) (ppm)	Initial soil available B (ppm)	Addition of B through fertilizers and manures (ppm)	Total B (ppm)	Crop uptake of B (ppm)	Expected B balance (ppm)	Actual B balance (ppm)	Net gain (+) or Net loss (-) (ppm)
	(1)	(2)	3=(1+2)	(4)	5=(3-4)	(6)	7=(6-5)	(1)	(2)	3=(1+2)	(4)	5=(3-4)	(6)	7=(6-5)
T_1	0.43	0	0.43	0.01	0.42	0.38	-0.04	0.38	0	0.38	0.01	0.37	0.35	-0.02
T_2	0.43	0	0.43	0.01	0.42	0.39	-0.03	0.39	0	0.39	0.02	0.37	0.36	-0.01
T_3	0.43	0.01	0.44	0.02	0.42	0.40	-0.02	0.40	0.02	0.42	0.03	0.39	0.37	-0.02
T_4	0.43	0	0.43	0.02	0.41	0.38	-0.03	0.38	0	0.38	0.02	0.36	0.35	-0.01
T_5	0.43	0.49	0.92	0.02	0.90	0.64	-0.26	0.64	0.49	1.13	0.03	1.10	0.87	-0.23
T_6	0.43	0.49	0.92	0.02	0.90	0.67	-0.23	0.67	0.49	1.16	0.03	1.13	0.88	-0.25
T_7	0.43	0.01	0.44	0.02	0.42	0.38	-0.04	0.38	0.02	0.40	0.03	0.37	0.36	-0.01
T_8	0.43	0.50	0.93	0.03	0.90	0.72	-0.18	0.72	0.51	1.23	0.03	1.20	0.91	-0.29
T_9	0.43	0.50	0.93	0.03	0.90	0.71	-0.19	0.71	0.51	1.22	0.03	1.19	0.90	-0.29

T_1: Control (No FYM + No NPK),T_2: NPK only,T_3 : NPK + FYM,T_4 : NPK + $ZnSO_4$ @ 12.50 kg/ha,T_5 : NPK + Borax @ 10 kg/ha,
T_6: NPK + $ZnSO_4$ @ 12.50 kg/ha + Borax @ 10 kg/ha, T_7: NPK + FYM + $ZnSO_4$ @ 12.50 kg/ha, T_8 : NPK + FYM + Borax @ 10 kg/ha,
T_9 : NPK + FYM + $ZnSO_4$ @ 12.50 kg/ha + Borax @ 10 kg/ha

Crop rotation: Finger millet (2005)- Soybean (2006), Soybean (2005)- Finger millet (2006)

Note: For Finger millet - NPK @ 50:40:25 kg/ha and FYM @ 7.5 t/ha
For Soybean – NPK @ 25:60:25 kg/ha and FYM @ 6.25 t/ha (5 ppm B)

Maximum cost of cultivation was incurred due to application of NPK + FYM + $ZnSO_4$ + borax (T_9 : Rs. 24,648/ha) followed by NPK + FYM + $ZnSO_4$ (T_7 : Rs. 23,748/ha) whereas, lower cost of cultivation was recorded in control (T_1 : Rs.15,165/ha) (Table 4.6.1).

Maximum net returns was realized due to application of NPK + FYM + $ZnSO_4$ (T_7 : Rs. 44,138/ha) followed by NPK + FYM + $ZnSO_4$ + borax (T_9 : Rs. 44,112/ha) while, lower net returns was recorded in control (T_1 : Rs.8299/ha) (Table 4.6.1 and Fig. 35).

Maximum profit per rupee spent on cultivation was obtained with application of NPK + $ZnSO_4$ + borax (T_6: 2.14) followed by NPK + FYM + borax (T_8:1.90). The control treatment recorded lower profit per rupee spent on cultivation (0.55) and rest of the treatments were found to be intermediate (Table 4.6.1 and Fig. 35).

4.6.2 SOYBEAN-FINGER MILLET BASED CROPPING SYSTEM

Among the different treatments, relatively higher gross returns was recorded with application of NPK + FYM + $ZnSO_4$ + borax (T_9 : Rs.72,473/ha) followed by NPK + FYM + $ZnSO_4$ (T_7 : Rs. 71,453/ha). Lower gross returns was recorded in control (Rs. 26,837/ha) (Table 4.6.2).

Maximum cost of cultivation was incurred due to application of NPK + FYM + $ZnSO_4$ + borax (T_9 : Rs. 24,648/ha) followed by NPK + FYM + $ZnSO_4$ (T_8 : Rs. 23,748/ha). Lower cost of cultivation was recorded in control (T_1 : Rs. 15,165/ha).

Maximum net returns was realized due to application of NPK + FYM + $ZnSO_4$ + borax (T_9 : Rs. 47,825/ha) followed by NPK + FYM + $ZnSO_4$ (Rs.47,705/ha). However, lower net returns of Rs. 11,672 per ha was recorded in control (Table 4.6.2 and Fig. 36).

Table 4.6.1: Economics of finger millet- soybean based cropping system as influenced by zinc and boron application

Treatment	Gross returns (Rs./ha)			Cost of cultivation (Rs./ha)			Net returns (Rs./ha)			B: C ratio		
	Finger millet	Soybean	Total	Finger millet	Soybean	Total	Finger millet	Soybean	Total	Finger millet	Soybean	Total
	2005	2006		2005	2006		2005	2006		2005	2006	
T_1: Control	7918	15546	23464	7688	7477	15165	230	8069	8299	0.03	1.08	0.55
T_2: NPK only	21669	22076	43745	9049	8900	17949	12620	13176	25796	1.39	1.48	1.44
T_3:NPK + FYM	26472	28786	55258	11299	10775	22074	15173	18011	33184	1.34	1.67	1.50
T_4:NPK+ $ZnSO_4$	25139	28679	53818	9886	9737	19623	15253	18942	34195	1.54	1.95	1.74
T_5:NPK + Borax	24679	28211	52890	9499	9350	18849	15180	18861	34041	1.60	2.02	1.81
T_6:NPK+ $ZnSO_4$ + Borax	30753	33689	64442	10336	10187	20523	20417	23502	43919	1.98	2.31	2.14
T_7:NPK + FYM + $ZnSO_4$	31721	36165	67886	12136	11612	23748	19585	24553	44138	1.61	2.11	1.86
T_8:NPK + FYM + Borax	31232	35496	66728	11749	11225	22974	19483	24271	43754	1.66	2.16	1.90
T_9:NPK+FYM+$ZnSO_4$ + Borax	32045	36715	68760	12586	12062	24648	19459	24653	44112	1.55	2.04	1.79

$ZnSO_4$@ 12.50 kg/ha, Borax @ 10 kg/ha

Crop rotation: Finger millet (2005)- Soybean (2006), Soybean (2005)- Finger millet (2006)

Note: For Finger millet - NPK @ 50:40:25 kg/ha and FYM @ 7.5 t/ha

For Soybean – NPK @ 25:60:25 kg/ha and FYM @ 6.25 t/ha

Table 4.6.2: Economics of soybean- finger millet based cropping system as influenced by zinc and boron application

Treatment	Gross returns (Rs./ha)			Cost of cultivation (Rs./ha)			Net returns (Rs./ha)			B: C ratio		
	Soybean	Finger millet	Total	Soybean	Finger millet	Total	Soybean	Finger millet	Total	Soybean	Finger millet	Cropping system
	2005	2006		2005	2006		2005	2006		2005	2006	
T_1: Control	18525	8312	26837	7477	7688	15165	11048	624	11672	1.48	0.08	0.77
T_2: NPK only	28480	20436	48916	8900	9049	17949	19580	11387	30967	2.20	1.26	1.73
T_3:NPK + FYM	34604	25254	59858	10775	11299	22074	23829	13955	37784	2.21	1.24	1.71
T_4:NPK+ $ZnSO_4$	32983	24647	57630	9737	9886	19623	23246	14761	38007	2.39	1.49	1.94
T_5:NPK + Borax	32393	24264	56657	9350	9499	18849	23043	14765	37808	2.46	1.55	2.01
T_6:NPK+ $ZnSO_4$ + Borax	38554	28874	67428	10187	10336	20523	28367	18538	46905	2.78	1.79	2.29
T_7:NPK + FYM + $ZnSO_4$	41397	30056	71453	11612	12136	23748	29785	17920	47705	2.57	1.48	2.01
T_8:NPK + FYM + Borax	40707	29649	70356	11225	11749	22974	29482	17900	47382	2.63	1.52	2.06
T_9:NPK+FYM+$ZnSO_4$ + Borax	41966	30507	72473	12062	12586	24648	29904	17921	47825	2.48	1.42	1.94

$ZnSO_4$@ 12.50 kg/ha, Borax @ 10 kg/ha

Crop rotation: Finger millet (2005)- Soybean (2006), Soybean (2005)- Finger millet (2006)

Note: For Finger millet - NPK @ 50:40:25 kg/ha and FYM @ 7.5 t/ha

For Soybean – NPK @ 25:60:25 kg/ha and FYM @ 6.25 t/ha

The data on B: C ratio indicated that, application of NPK + $ZnSO_4$ + borax (T_6) recorded higher B: C ratio of 2.29 followed by NPK + FYM + borax (T_8 : 2.06). Lower profit per rupee spent on cultivation (0.77) was recorded in control and rests of the treatments were found to be intermediate (Table 4.6.2 and Fig. 36).

4.7 Experiment-IIa : RESPONSE OF FINGER MILLET – SOYBEAN ROTATION TO CONJUNCTIVE USE OF ZINC, BORON AND MICROBIAL INOCULANTS

Crop: Finger millet

4.7.1 GROWTH PARAMETERS OF FINGER MILLET AS INFLUENCED BY ZINC, BORON AND MICROBIAL INOCULANTS APPLICATION

4.7.1.1 Plant height (cm)

Application of micronutrients and microbial inoculants caused significant effect on plant height at all the stages of crop growth (Table 4.7.1).

At 30 DAT, higher plant height was recorded with application of NPK + FYM + $ZnSO_4$ + borax + *Azospirillum brasilense* + Vesicular Arbuscular Mycorrhizae (VAM) (T_{10} : 10.01 cm) as compared to rest of the treatments. However, it was found on par with application of NPK + FYM + $ZnSO_4$ + *A. brasilense* (T_6 : 9.78 cm) and NPK + FYM + $ZnSO_4$ + VAM (T_8 : 9.24 cm). Application of NPK + FYM + borax + *A.brasilense* (T_7 : 8.24 cm), NPK + FYM + $ZnSO_4$ (T_2 : 8.15 cm), NPK + FYM + borax + VAM (T_9 : 7.69 cm) and NPK + FYM + borax (T_3 : 7.49 cm) were found to be the next best treatments, whereas significantly lower plant height (T_1 : 5.75 cm) was recorded in control (NPK + FYM) treatment.

Table 4.7.1: Plant height of finger millet at different growth stages as influenced by zinc, boron and microbial inoculants application in finger millet- soybean based cropping system

Treatment	Plant height (cm)											
	30 DAT			60 DAT			90 DAT			At harvest		
	2005	2006	Pooled	2005	2006	Pooled	2005	2006	Pooled	2005	2006	Pooled
T_1: Control (NPK + FYM only)	6.00	5.50	5.75	27.00	25.00	26.00	68.38	64.00	66.19	69.00	66.60	67.80
T_2 : NPK + FYM +$ZnSO_4$	8.40	7.89	8.15	36.25	34.15	35.20	83.53	79.13	81.33	85.06	80.66	82.86
T_3 : NPK + FYM + Borax	7.75	7.23	7.49	33.20	30.50	31.85	79.68	75.23	77.46	81.00	79.14	80.07
T_4: NPK + FYM + *A brasilense*	7.25	6.72	6.99	31.50	28.90	30.20	78.20	73.76	75.98	82.93	78.55	80.74
T_5 : NPK + FYM + VAM	7.05	6.52	6.79	29.58	27.08	28.33	77.93	73.43	75.68	80.34	75.97	78.16
T_6 : NPK + FYM + $ZnSO_4$ + *A. brasilense*	10.03	9.52	9.78	40.63	38.33	39.48	94.50	90.10	92.30	96.20	91.85	94.03
T_7 : NPK + FYM + Borax + *A. brasilense*	8.50	7.98	8.24	37.15	34.75	35.95	84.25	79.93	82.09	86.27	81.92	84.09
T_8: NPK + FYM + $ZnSO_4$+ VAM	9.50	8.97	9.24	39.65	37.60	38.63	90.25	85.85	88.05	93.07	88.66	90.86
T_9: NPK + FYM + FYM + Borax + VAM	7.95	7.42	7.69	34.20	32.20	33.20	82.80	78.30	80.55	83.70	79.29	81.50
T_{10}: NPK+ FYM +$ZnSO_4$+ Borax + *A. brasilense*+ VAM	10.27	9.75	10.01	43.62	41.52	42.57	97.80	93.38	95.59	99.27	94.90	97.08
F test	*	*	*	*	*	*	*	*	*	*	*	*
S.Em ±	**0.58**	**0.57**	**0.40**	**1.99**	**1.75**	**1.37**	**3.41**	**3.53**	**2.49**	**3.85**	**3.12**	**2.44**
CD at 5 %	**1.72**	**1.70**	**1.13**	**5.92**	**5.20**	**3.92**	**10.13**	**10.49**	**7.14**	**11.43**	**9.26**	**6.98**
CV (%)	**12.13**	**12.76**	**12.11**	**9.78**	**9.19**	**9.81**	**7.05**	**7.71**	**7.50**	**7.78**	**6.60**	**7.14**

DAT: Days after transplanting, NPK @ 50:40:25 kg/ha, FYM @ 7.5 t/ha, $ZnSO_4$ @ 12.50 kg/ha, Borax @ 10 kg/ha, *A - Azospirillum*
Crop rotation: Finger millet (2005)- Soybean (2006), Soybean(2005)- Finger millet (2006)

At 60 and 90 DAT, application of NPK + FYM + $ZnSO_4$ + borax + *A.brasilense* + VAM (T_{10}) recorded significantly higher plant height (42.57 and 95.59 cm, respectively) as compared to all other treatments except with application of NPK + FYM + $ZnSO_4$ + *A.brasilense* (T_6 :39.48 and 92.30 cm, respectively). Significantly lower plant height was recorded in control (T_1) (NPK + FYM).

Significantly higher plant height was recorded with application of NPK + FYM + $ZnSO_4$ + borax + *A.brasilense* + VAM (T_{10} :97.08 cm) at harvest which was closely followed by application of NPK + FYM + $ZnSO_4$ + *A.brasilense* (T_6 :94.03 cm) and NPK + FYM + $ZnSO_4$ + VAM (T_8 :90.86 cm). Significantly lower plant height was recorded in control (T_1:67.80 cm) (Table 4.7.1 and Fig. 37).

4.7.1.2 Number of tillers per hill

Application of NPK + FYM + $ZnSO_4$ + borax + *A.brasilense* + VAM (T_{10}) recorded significantly higher number of tillers per hill (1.78) at 30 DAT which was found to be on par with application of NPK + FYM + $ZnSO_4$ + *A.brasilense* (T_6 : 1.73) and NPK + FYM + $ZnSO_4$ + VAM (T_8 : 1.69). Nevertheless, application of NPK + FYM + borax + *A.brasilense* (T_7 : 1.53), NPK + FYM + $ZnSO_4$ (T_2 : 1.48) and NPK + FYM + borax + VAM (T_9 : 1.47) do recorded significantly higher number of tillers per hill as compared to NPK + FYM + VAM (T_5 : 1.20) and NPK + FYM (T_1 : 1.09). However, all these treatments were found on par with each other while rest of the treatments were found to be intermediate (Table 4.7.2 and Fig. 38).

Significantly higher number of tillers per hill was noticed by application of NPK + FYM + $ZnSO_4$ + borax + *A.brasilense* + VAM (T_{10}) at 60 DAT (5.21), 90 DAT (6.93) and at harvest (7.09) followed by application of NPK + FYM + $ZnSO_4$ + *A.brasilense* (T_6 : 5.08, 6.62 and

Table 4.7.2: Number of tillers per hill of finger millet at different growth stages as influenced by zinc, boron and microbial inoculants application in finger millet- soybean based cropping system

Treatment	Number of tillers per hill											
	30DAT			60DAT			90DAT			At harvest		
	2005	2006	Pooled	2005	2006	Pooled	2005	2006	Pooled	2005	2006	Pooled
T_1: Control (NPK + FYM only)	1.16	1.02	1.09	3.80	3.60	3.70	4.92	4.30	4.61	4.69	4.70	4.70
T_2 : NPK + FYM +$ZnSO_4$	1.54	1.41	1.48	4.70	4.50	4.60	6.10	5.85	5.98	6.16	5.96	6.06
T_3 : NPK + FYM + Borax	1.41	1.29	1.35	4.53	4.34	4.44	5.75	5.50	5.63	5.82	5.59	5.71
T_4: NPK + FYM + *A brasilense*	1.38	1.26	1.32	4.40	4.21	4.31	5.65	5.39	5.52	5.78	5.54	5.66
T_5 : NPK + FYM + VAM	1.27	1.13	1.20	4.35	4.14	4.25	5.50	5.26	5.38	5.58	5.33	5.46
T_6 : NPK + FYM + $ZnSO_4$ + *A. brasilense*	1.80	1.66	1.73	5.18	4.97	5.08	6.73	6.50	6.62	6.80	6.59	6.70
T_7 : NPK + FYM + Borax + *A. brasilense*	1.60	1.46	1.53	4.73	4.55	4.64	6.15	5.91	6.03	6.22	6.00	6.11
T_8: NPK + FYM + $ZnSO_4$+ VAM	1.75	1.62	1.69	5.06	4.85	4.96	6.53	6.30	6.42	6.66	6.45	6.56
T_9: NPK + FYM + FYM + Borax + VAM	1.53	1.40	1.47	4.65	4.42	4.54	5.86	5.65	5.76	5.98	5.76	5.87
T_{10}: NPK+ FYM +$ZnSO_4$+ Borax + *A. brasilense*+ VAM	1.85	1.71	1.78	5.26	5.15	5.21	7.03	6.83	6.93	7.20	6.98	7.09
F test	*	*	*	*	*	*	*	*	*	*	*	*
S.Em +	**0.08**	**0.07**	**0.06**	**0.17**	**0.15**	**0.11**	**0.25**	**0.26**	**0.18**	**0.27**	**0.26**	**0.19**
CD at 5 %	**0.23**	**0.21**	**0.16**	**0.50**	**0.44**	**0.32**	**0.76**	**0.77**	**0.52**	**0.80**	**0.78**	**0.55**
CV (%)	**8.80**	**8.92**	**9.43**	**6.21**	**5.76**	**5.90**	**7.32**	**7.80**	**7.53**	**7.67**	**7.75**	**7.83**

DAT: Days after transplanting, NPK @ 50:40:25 kg/ha, FYM @ 7.5 t/ha, $ZnSO_4$ @ 12.5 kg/ha, Borax @ 10 kg/ha, *A - Azospirillum*
Crop rotation: Finger millet (2005) - Soybean (2006), Soybean (2005) - Finger millet (2006)

6.70 tillers per hill, respectively) and NPK + FYM + $ZnSO_4$ + VAM (T_8 : 4.96, 6.42 and 6.56 tillers per hill, respectively). Whereas, application of NPK + FYM + borax + *A.brasilense* (T_7 : 4.64, 6.03 and 6.11 tillers per hill, respectively) and NPK + FYM + $ZnSO_4$ (T_2 : 4.60, 5.98 and 6.06 tillers per hill, respectively), NPK + FYM + borax + VAM (T_9 : 4.54, 5.76 and 5.87 tillers per hill, respectively) were found on par with each other but recorded significantly higher number of tillers per hill over NPK + FYM (T_1 : 3.70, 4.61 and 4.70 tillers per hill, respectively).

4.7.1.3 Number of green leaves per hill

Significantly lower number of green leaves per hill at 30, 60, 90 DAT and at harvest was recorded with application of NPK + FYM (T_1 :13.40, 28.75, 19.88 and 16.50 green leaves per hill, respectively).

Similarly, at 30, 60, 90 DAT and at harvest, significantly higher number of green leaves per hill was reported with application of NPK + FYM + $ZnSO_4$ + borax + *A.brasilense* + VAM (T_{10} : 26.90, 40.78, 31.89 and 28.75 green leaves per hill, respectively) over the rest of the treatments, but it was found on par with application of NPK + FYM + $ZnSO_4$ + *A.brasilense* (T_6 : 25.14, 38.15, 29.87 and 27.84 green leaves per hill, respectively) (Table 4.7.3).

4.7.1.4 Leaf area (cm^2/plant)

The data on leaf area differed significantly due to micronutrients and microbial inoculants application at different growth stages of crop growth. At 30, 90 DAT and at harvest, significantly higher leaf area was observed with application of NPK + FYM + $ZnSO_4$ + borax + *A.brasilense* + VAM (T_{10} :25.56, 555.25 and 530.20 cm^2/plant). Nevertheless, it was found on par with application of NPK + FYM + $ZnSO_4$ + *A.brasilense* (T_6 :24.58, 539.15 and 523.72 cm^2/plant, respectively) and NPK + FYM + $ZnSO_4$ + VAM (T_8 :23.75, 530.25 and 510.10 cm^2/plant, respectively). At

Table 4.7.3: Number of green leaves per hill of finger millet at different growth stages as influenced by zinc, boron and microbial inoculants application in finger millet- soybean based cropping system

Treatment	Number of green leaves per hill											
	30DAT			60DAT			90DAT			At harvest		
	2005	2006	Pooled	2005	2006	Pooled	2005	2006	Pooled	2005	2006	Pooled
T_1: Control (NPK + FYM only)	14.00	12.80	13.40	30.25	27.25	28.75	20.25	19.50	19.88	16.90	16.10	16.50
T_2 : NPK + FYM +$ZnSO_4$	21.25	20.02	20.64	36.50	34.25	35.38	25.25	24.50	24.88	22.95	22.14	22.55
T_3 : NPK + FYM + Borax	19.57	18.33	18.95	34.56	31.16	32.86	24.10	23.33	23.72	21.10	20.27	20.69
T_4: NPK + FYM + *A brasilense*	18.63	17.38	18.01	33.50	30.20	31.85	23.25	22.47	22.86	20.25	19.42	19.84
T_5 : NPK + FYM + VAM	17.50	16.24	16.87	32.25	28.98	30.62	22.15	21.30	21.73	19.33	18.50	18.92
T_6 : NPK + FYM + $ZnSO_4$ + *A. brasilense*	26.25	24.02	25.14	39.80	36.50	38.15	30.25	29.48	29.87	27.85	27.82	27.84
T_7 : NPK + FYM + Borax + *A. brasilense*	22.50	20.27	21.39	37.75	34.49	36.12	28.00	27.20	27.60	25.05	26.25	25.65
T_8: NPK + FYM + $ZnSO_4$+ VAM	24.70	22.48	23.59	38.95	35.70	37.33	29.25	28.45	28.85	26.15	25.30	25.73
T_9: NPK + FYM + FYM + Borax + VAM	20.03	17.81	18.92	35.92	32.65	34.29	24.50	23.72	24.11	21.25	20.43	20.84
T_{10}: NPK+ FYM +$ZnSO_4$+ Borax + *A. brasilense*+ VAM	28.00	25.80	26.90	41.95	39.60	40.78	32.25	31.52	31.89	29.15	28.34	28.75
F test	*	*	*	*	*	*	*	*	*	*	*	*
S.Em ±	**1.69**	**1.36**	**1.06**	**1.39**	**1.24**	**0.93**	**1.25**	**1.27**	**0.92**	**1.37**	**0.67**	**0.81**
CD at 5 %	**5.03**	**4.05**	**3.04**	**4.13**	**3.69**	**2.66**	**3.72**	**3.77**	**2.63**	**4.07**	**1.99**	**2.31**
CV (%)	**13.80**	**12.10**	**12.77**	**6.66**	**6.50**	**6.58**	**8.37**	**8.74**	**8.80**	**10.31**	**5.18**	**8.68**

DAT: Days after transplanting, NPK @ 50:40:25 kg/ha, FYM @ 7.5 t/ha, $ZnSO_4$ @ 12.5 kg/ha, Borax @ 10 kg/ha, *A - Azospirillum*
Crop rotation: Finger millet (2005) - Soybean (2006), Soybean (2005) - Finger millet (2006)

60 DAT, significantly higher leaf area (895.28 cm^2/plant) was registered with application of NPK + FYM + $ZnSO_4$ + borax + *A.brasilense* + VAM(T_{10}) which was followed by application of NPK + FYM + *A.brasilense* (T_6 : 885.34 cm^2/plant). Significantly lower leaf area per plant was obtained with application of NPK + FYM (T_1 : 13.95, 625.35, 390.35 and 370.24 cm^2/plant at 30, 60, 90 DAT and at harvest, respectively) (Table 4.7.4).

4.7.1.5 Leaf area index (LAI)

LAI varied significantly among the treatments. At 30 and 60 DAT, significantly higher LAI was recorded with application of NPK + FYM + $ZnSO_4$ + borax + *A.brasilense* + VAM (T_{10} : 0.085 and 2.984, respectively) which was followed by NPK + FYM + $ZnSO_4$ + *A.brasilense* (T_6 : 0.082 and 2.951, respectively). However, all these treatments were found on par with application of NPK + FYM + $ZnSO_4$ + VAM (T_8 : 0.079) at 30 DAT (Table 4.7.5 and Fig. 37).

LAI recorded at later growth stages viz., 90 DAT and at harvest was significantly higher with application of NPK + FYM + $ZnSO_4$ + borax + *A.brasilense* + VAM (T_{10} : 1.851 and 1.767, respectively) which was followed by NPK + FYM + $ZnSO_4$ + *A.brasilense* (T_6 : 1.797 and 1.746, respectively) and NPK + FYM + $ZnSO_4$ + VAM (T_8 : 1.768 and 1.7, respectively). Significantly lower LAI was observed with application of NPK + FYM (T_1 : 0.047, 2.085, 1.301 and 1.234 at 30, 60, 90 DAT and at harvest, respectively).

4.7.1.6 Leaf area duration (LAD) (days)

A longer LAD was noticed with application of NPK + FYM + $ZnSO_4$ + borax + *A.brasilense* + VAM (T_{10} : 46.04 and 72.53 days, respectively) at (30-60) DAT and (60-90) DAT, which was followed by application of

Table 4.7.4: Leaf area of finger millet at different growth stages as influenced by zinc, boron and microbial inoculants application in finger millet- soybean based cropping system

Treatment	Leaf area (cm^2/plant)											
	30DAT			60DAT			90DAT			At harvest		
	2005	2006	Pooled	2005	2006	Pooled	2005	2006	Pooled	2005	2006	Pooled
T_1: Control (NPK + FYM only)	14.20	13.70	13.95	645.35	605.35	625.35	400.35	380.35	390.35	380.23	360.25	370.24
T_2 : NPK + FYM +$ZnSO_4$	19.50	19.03	19.27	783.65	740.65	762.15	498.15	477.15	487.65	471.45	451.35	461.40
T_3 : NPK + FYM + Borax	17.71	17.20	17.46	740.65	699.35	720.00	479.15	458.20	468.68	459.85	438.65	449.25
T_4: NPK + FYM + *A brasilense*	16.50	15.98	16.24	725.35	685.15	705.25	465.35	440.20	452.78	440.25	421.15	430.70
T_5 : NPK + FYM + VAM	15.30	14.82	15.06	720.65	679.35	700.00	445.12	425.12	435.12	430.10	410.10	420.10
T_6 : NPK + FYM + $ZnSO_4$ + *A. brasilense*	24.84	24.32	24.58	905.38	865.30	885.34	550.15	528.15	539.15	533.82	513.62	523.72
T_7 : NPK + FYM + Borax + *A. brasilense*	22.22	21.70	21.96	820.23	779.23	799.73	508.25	486.25	497.25	490.20	470.20	480.20
T_8: NPK + FYM + $ZnSO_4$+ VAM	23.69	23.82	23.75	830.65	789.65	810.15	540.25	520.25	530.25	520.15	500.05	510.10
T_9: NPK + FYM + FYM + Borax + VAM	18.50	18.00	18.25	780.68	737.68	759.18	492.15	471.10	481.63	465.45	445.25	455.35
T_{10}: NPK+ FYM +$ZnSO_4$+ Borax + *A. brasilense*+ VAM	25.82	25.30	25.56	915.25	875.30	895.28	565.25	545.25	555.25	540.15	520.25	530.20
F test	*	*	*	*	*	*	*	*	*	*	*	*
S.Em ±	**1.17**	**1.15**	**0.81**	**29.91**	**29.81**	**20.63**	**18.55**	**17.01**	**12.41**	**16.08**	**16.01**	**11.12**
CD at 5 %	**3.48**	**3.42**	**2.31**	**88.88**	**88.57**	**59.05**	**55.13**	**50.55**	**35.52**	**47.77**	**47.58**	**31.83**
CV (%)	**10.24**	**10.27**	**10.09**	**6.59**	**6.92**	**6.60**	**6.50**	**6.23**	**6.28**	**5.89**	**6.12**	**5.88**

DAT: Days after transplanting, NPK @ 50:40:25 kg/ha, FYM @ 7.5 t/ha, $ZnSO_4$ @ 12.5 kg/ha, Borax @ 10 kg/ha, *A - Azospirillum*

Crop rotation: Finger millet (2005) - Soybean (2006), Soybean (2005) - Finger millet (2006)

Table 4.7.5: Leaf area index of finger millet at different growth stages as influenced by zinc, boron and microbial inoculants application in finger millet- soybean based cropping system

Treatment	Leaf area index											
	30DAT			60DAT			90DAT			At harvest		
	2005	2006	Pooled	2005	2006	Pooled	2005	2006	Pooled	2005	2006	Pooled
T_1: Control (NPK + FYM only)	0.047	0.046	0.047	2.151	2.018	2.085	1.335	1.268	1.301	1.267	1.201	1.234
T_2 : NPK + FYM +$ZnSO_4$	0.065	0.063	0.064	2.612	2.469	2.541	1.661	1.591	1.626	1.572	1.505	1.538
T_3 : NPK + FYM + Borax	0.059	0.057	0.058	2.469	2.331	2.400	1.597	1.527	1.562	1.533	1.462	1.498
T_4: NPK + FYM + *A brasilense*	0.055	0.053	0.054	2.418	2.284	2.351	1.551	1.467	1.509	1.468	1.404	1.436
T_5 : NPK + FYM + VAM	0.051	0.049	0.050	2.402	2.265	2.333	1.484	1.417	1.450	1.434	1.367	1.400
T_6 : NPK + FYM + $ZnSO_4$ + *A. brasilense*	0.083	0.081	0.082	3.018	2.884	2.951	1.834	1.761	1.797	1.779	1.712	1.746
T_7 : NPK + FYM + Borax + *A. brasilense*	0.074	0.072	0.073	2.734	2.597	2.666	1.694	1.621	1.658	1.634	1.567	1.601
T_8: NPK + FYM + $ZnSO_4$+ VAM	0.079	0.079	0.079	2.769	2.632	2.701	1.801	1.734	1.768	1.734	1.667	1.700
T_9: NPK + FYM + FYM + Borax + VAM	0.062	0.060	0.061	2.602	2.459	2.531	1.641	1.570	1.605	1.552	1.484	1.518
T_{10}: NPK+ FYM +$ZnSO_4$+ Borax + *A. brasilense*+ VAM	0.086	0.084	0.085	3.051	2.918	2.984	1.884	1.818	1.851	1.801	1.734	1.767
F test	*	*	*	*	*	*	*	*	*	*	*	*
S.Em ±	**0.003**	**0.004**	**0.003**	**0.100**	**0.099**	**0.069**	**0.062**	**0.063**	**0.044**	**0.054**	**0.053**	**0.037**
CD at 5 %	**0.010**	**0.011**	**0.007**	**0.296**	**0.295**	**0.197**	**0.184**	**0.187**	**0.125**	**0.159**	**0.159**	**0.106**
CV (%)	**8.976**	**10.272**	**9.427**	**6.585**	**6.923**	**6.595**	**6.500**	**6.916**	**6.617**	**5.885**	**6.122**	**5.881**

DAT: Days after transplanting, NPK @ 50:40:25 kg/ha, FYM @ 7.5 t/ha, $ZnSO_4$ @ 12.5 kg/ha, Borax @ 10 kg/ha, *A - Azospirillum*
Crop rotation: Finger millet (2005) - Soybean (2006), Soybean (2005) - Finger millet (2006)

NPK + FYM + $ZnSO_4$ + *A.brasilense* (T_6 : 45.50 and 71.22 days, respectively) (Table 4.7.6 and Fig. 38).

AT 90 DAT – harvest, significantly longer LAD was observed with application of NPK + FYM + $ZnSO_4$ + borax + *A.brasilense* + VAM (T_{10} : 54.27 days) as compared to all other treatments except with application of NPK + FYM + $ZnSO_4$ + *A.brasilense* (T_6 : 53.14 days) and NPK + FYM + $ZnSO_4$ + VAM (T_8 : 52.02 days). Significantly shorter LAD was observed in NPK + FYM (T_1 : 31.97, 50.79 and 38.03 days at 30-60, 60-90 DAT and 90 DAT – harvest, respectively). In general, LAD decreased with the advance in age of crop from 60-90 DAT to till harvest.

4.7.1.7 Dry matter accumulation (DMA) and its distribution (g/plant)

4.7.1.7.1 DMA in leaf, stem and TDMA at 30 DAT (g/plant)

At 30 DAT, application of NPK + FYM + $ZnSO_4$ + borax + *A.brasilense* + VAM (T_{10}) registered significantly higher leaf (1.68 g/plant) and stem dry matter (1.30 g/plant) which was closely followed by application of NPK + FYM + $ZnSO_4$ + *A. brasilense* (T_6 : 1.66 and 1.25 g/plant, respectively) and NPK + FYM + $ZnSO_4$ + VAM (T_8 : 1.60 and 1.20 g/plant, respectively) (Table 4.7.7).

Significantly higher total dry matter accumulation was recorded with application of NPK + FYM + $ZnSO_4$ + borax + *A.brasilense* + VAM (T_{10} : 2.98 g/plant) as compared to all other treatments. However, application of NPK + FYM + $ZnSO_4$ + *A.brasilense* (T_6 : 2.91 g/plant) and NPK + FYM + borax + VAM (T_8 : 2.80 g/plant) were found on par with former treatment. Significantly lower leaf, stem and TDMA was recorded in NPK + FYM (T_1 : 1.10, 0.70 and 1.79 g/plant, respectively) as compared to other treatments.

Table 4.7.6: Leaf area duration of finger millet at different growth stages as influenced by zinc, boron and microbial inoculants application in finger millet- soybean based cropping system

Treatment	Leaf area duration (Days)								
	(30- 60)DAT			(60-90)DAT			90DAT- harvest		
	2005	2006	Pooled	2005	2006	Pooled	2005	2006	Pooled
T_1: Control (NPK + FYM only)	32.98	30.95	31.97	52.29	49.29	50.79	39.03	37.03	38.03
T_2 : NPK + FYM +$ZnSO_4$	40.16	37.98	39.07	64.09	60.89	62.49	48.48	46.43	47.45
T_3 : NPK + FYM + Borax	37.92	35.83	36.87	60.99	57.88	59.43	46.95	44.84	45.90
T_4: NPK + FYM + *A brasilense*	37.09	35.06	36.07	59.54	56.27	57.90	45.28	43.07	44.17
T_5 : NPK + FYM + VAM	36.80	34.71	35.75	58.29	55.22	56.76	43.76	41.76	42.76
T_6 : NPK + FYM + $ZnSO_4$ + *A. brasilense*	46.51	44.48	45.50	72.78	69.67	71.22	54.20	52.09	53.14
T_7 : NPK + FYM + Borax + *A. brasilense*	42.12	40.05	41.08	66.42	63.27	64.85	49.92	47.82	48.87
T_8: NPK + FYM + $ZnSO_4$+ VAM	42.72	40.67	41.70	68.55	65.50	67.02	53.02	51.02	52.02
T_9: NPK + FYM + FYM + Borax + VAM	39.96	37.78	38.87	63.64	60.44	62.04	47.88	45.82	46.85
T_{10}: NPK+ FYM +$ZnSO_4$+ Borax + *A. brasilense*+ VAM	47.05	45.03	46.04	74.03	71.03	72.53	55.27	53.28	54.27
F test	*	*	*	*	*	*	*	*	*
S.Em ±	**1.48**	**1.49**	**1.03**	**1.94**	**2.23**	**1.44**	**1.64**	**1.68**	**1.15**
CD at 5 %	**4.41**	**4.42**	**2.94**	**5.76**	**6.62**	**4.13**	**4.89**	**4.99**	**3.29**
CV (%)	**6.37**	**6.74**	**6.40**	**5.24**	**6.33**	**5.65**	**5.89**	**6.28**	**5.95**

DAT: Days after transplanting, NPK @ 50:40:25 kg/ha, FYM @ 7.5 t/ha, $ZnSO_4$ @ 12.5 kg/ha, Borax @ 10 kg/ha, *A - Azospirillum*

Crop rotation: Finger millet (2005) - Soybean (2006), Soybean (2005) - Finger millet (2006)

Table 4.7.7: Dry matter accumulation in leaf, stem and total dry matter accumulation (TDMA) of finger millet at 30 DAT as influenced by zinc, boron and microbial inoculants application in finger millet- soybean based cropping system

Treatment	Leaf dry matter (g/plant)			Stem dry matter (g/plant)			TDMA (g/plant)		
	2005	2006	Pooled	2005	2006	Pooled	2005	2006	Pooled
T_1: Control (NPK + FYM only)	1.15	1.05	1.10	0.75	0.64	0.70	1.90	1.69	1.79
T_2 : NPK + FYM +$ZnSO_4$	1.45	1.33	1.39	1.06	0.95	1.01	2.51	2.28	2.40
T_3 : NPK + FYM + Borax	1.37	1.26	1.32	0.96	0.85	0.91	2.33	2.11	2.22
T_4: NPK + FYM + *A brasilense*	1.30	1.19	1.25	0.85	0.74	0.80	2.15	1.93	2.04
T_5 : NPK + FYM + VAM	1.25	1.15	1.20	0.80	0.69	0.75	2.05	1.84	1.95
T_6 : NPK + FYM + $ZnSO_4$ + *A. brasilense*	1.71	1.60	1.66	1.30	1.20	1.25	3.01	2.80	2.91
T_7 : NPK + FYM + Borax + *A. brasilense*	1.55	1.42	1.49	1.10	1.01	1.06	2.65	2.43	2.54
T_8: NPK + FYM + $ZnSO_4$+ VAM	1.65	1.55	1.60	1.25	1.15	1.20	2.90	2.70	2.80
T_9: NPK + FYM + FYM + Borax + VAM	1.40	1.30	1.35	1.01	0.90	0.96	2.41	2.20	2.31
T_{10}: NPK+ FYM +$ZnSO_4$+ Borax + *A. brasilense*+ VAM	1.75	1.62	1.68	1.35	1.25	1.30	3.10	2.87	2.98
F test	*	*	*	*	*	*	*	*	*
S.Em ±	**0.06**	**0.06**	**0.04**	**0.06**	**0.06**	**0.04**	**0.09**	**0.10**	**0.07**
CD at 5 %	**0.17**	**0.19**	**0.13**	**0.18**	**0.19**	**0.12**	**0.26**	**0.28**	**0.19**
CV (%)	**6.75**	**8.24**	**7.84**	**9.98**	**11.92**	**10.74**	**6.13**	**7.22**	**6.89**

DAT: Days after transplanting, NPK @ 50:40:25 kg/ha, FYM @ 7.5 t/ha, $ZnSO_4$ @12.5 kg/ha, Borax @ 10 kg/ha, *A* – *Azospirillum*
Crop rotation: Finger millet (2005)- Soybean (2006), Soybean(2005)- Finger millet (2006)

4.7.1.7.2 DMA in leaf, stem and TDMA at 60 DAT (g/plant)

Application of NPK + FYM + $ZnSO_4$ + borax + *A.brasilense* + VAM (T_{10}) recorded significantly higher TDMA (5.24 and 7.03 g/plant, respectively) as compared to other treatments, but it was found on par with application of NPK + FYM + $ZnSO_4$ + *A.brasilense* (T_6 :5.14 and 6.88 g/plant, respectively) and NPK + FYM + $ZnSO_4$ + VAM (T_8 :4.99 and 6.76 g/plant, respectively). Significantly lower leaf and stem dry matter was recorded in NPK + FYM (T_1 :3.80 and 4.83 g/plant, respectively) (Table 4.7.8).

The TDMA was significantly higher with application of NPK + FYM + $ZnSO_4$ + borax + *A.brasilense* + VAM (T_{10} : 12.27 g/plant) which was followed by application of NPK + FYM + $ZnSO_4$ + *A.brasilense* (T_6 : 12.02 g/plant) and NPK + FYM + $ZnSO_4$ + VAM (T_8 : 11.75 g/plant). While significantly lower TDMA was recorded with application of NPK + FYM (T_1 : 8.63 g/plant).

4.7.1.7.3 DMA in leaf, stem, earhead and TDMA at 90 DAT (g/plant)

Application of NPK + FYM + $ZnSO_4$ + borax + *A.brasilense* + VAM (T_{10}) recorded significantly higher leaf and stem dry matter (8.45 and 14.78 g/plant, respectively) as compared to all other treatments. However, it was found on par with application of NPK + FYM + $ZnSO_4$ + *A.brasilense* (T_6 : 8.15 and 14.43 g/plant of DM in leaf and stem, respectively) and NPK + FYM + $ZnSO_4$ + VAM (T_8 : 7.80 and 14.08 g/plant of dry matter in leaf and stem, respectively) (Table 4.7.9).

Significantly higher ear head dry matter (12.87 g/plant) and TDMA (36.10 g/plant) was registered with application of NPK + FYM + $ZnSO_4$ + *A.brasilense* + VAM(T_{10}), but it was found to be on par with application of NPK + FYM + $ZnSO_4$ + *A.brasilense* (T_6 : 12.32 and 34.90 g/plant in ear head dry matter and TDMA, respectively) and NPK + FYM + $ZnSO_4$ + VAM

Table 4.7.8: Dry matter accumulation in leaf, stem and total dry matter accumulation (TDMA) of finger millet at 60 DAT as influenced by zinc, boron and microbial inoculants application in finger millet- soybean based cropping system

Treatment	Leaf dry matter (g/plant)			Stem dry matter (g/plant)			TDMA (g/plant)		
	2005	2006	Pooled	2005	2006	Pooled	2005	2006	Pooled
T_1: Control (NPK + FYM only)	3.90	3.70	3.80	4.90	4.75	4.83	8.80	8.45	8.63
T_2 : NPK + FYM +$ZnSO_4$	4.70	4.50	4.60	5.90	5.75	5.83	10.60	10.25	10.43
T_3 : NPK + FYM + Borax	4.59	4.38	4.49	5.70	5.55	5.63	10.29	9.93	10.11
T_4: NPK + FYM + *A brasilense*	4.45	4.23	4.34	5.59	5.44	5.52	10.04	9.67	9.86
T_5 : NPK + FYM + VAM	4.30	4.08	4.19	5.40	5.25	5.33	9.70	9.33	9.52
T_6 : NPK + FYM + $ZnSO_4$ + *A. brasilense*	5.25	5.03	5.14	7.00	6.75	6.88	12.25	11.78	12.02
T_7 : NPK + FYM + Borax + *A. brasilense*	4.82	4.60	4.71	6.25	6.10	6.18	11.07	10.70	10.89
T_8: NPK + FYM + $ZnSO_4$+ VAM	5.10	4.88	4.99	6.83	6.68	6.76	11.93	11.56	11.75
T_9: NPK + FYM + FYM + Borax + VAM	4.65	4.43	4.54	5.85	5.70	5.78	10.50	10.13	10.32
T_{10}: NPK+ FYM +$ZnSO_4$+ Borax + *A. brasilense*+ VAM	5.35	5.13	5.24	7.10	6.95	7.03	12.45	12.08	12.27
F test	*	*	*	*	*	*	*	*	*
S.Em ±	**0.16**	**0.16**	**0.11**	**0.23**	**0.25**	**0.17**	**0.40**	**0.41**	**0.28**
CD at 5 %	**0.48**	**0.47**	**0.32**	**0.68**	**0.75**	**0.48**	**1.19**	**1.21**	**0.81**
CV (%)	**5.93**	**6.12**	**6.04**	**6.55**	**7.38**	**6.83**	**6.44**	**6.78**	**6.58**

DAT: Days after transplanting, NPK @ 50:40:25 kg/ha, FYM @ 7.5 t/ha, $ZnSO_4$ @12.5 kg/ha, Borax @10 kg/ha, *A - Azospirillum*
Crop rotation: Finger millet (2005) - Soybean (2006), Soybean (2005) - Finger millet (2006)

Table 4.7.9: Dry matter accumulation in leaf, stem, ear head and total dry matter accumulation (TDMA) of finger millet at 90 DAT as influenced by zinc, boron and microbial inoculants application in finger millet- soybean based cropping system

Treatment	Leaf dry matter (g/plant)			Stem dry matter (g/plant)			Ear head dry matter (g/plant)			TDMA (g/plant)		
	2005	2006	Pooled	2005	2006	Pooled	2005	2006	Pooled	2005	2006	Pooled
T_1: Control (NPK + FYM only)	5.60	5.50	5.55	8.65	8.50	8.58	8.45	8.40	8.43	22.70	22.40	22.55
T_2 : NPK + FYM +$ZnSO_4$	6.98	6.87	6.93	11.40	11.25	11.33	10.90	10.83	10.87	29.28	28.95	29.12
T_3 : NPK + FYM + Borax	6.65	6.55	6.60	11.95	10.70	11.33	10.10	10.02	10.06	28.70	27.27	27.99
T_4: NPK + FYM + *A brasilense*	6.40	6.30	6.35	11.75	10.50	11.13	9.70	9.63	9.67	27.85	26.43	27.14
T_5 : NPK + FYM + VAM	6.25	6.15	6.20	11.55	10.30	10.93	9.25	9.19	9.22	27.05	25.64	26.35
T_6 : NPK + FYM + $ZnSO_4$ + *A. brasilense*	8.20	8.10	8.15	15.05	13.80	14.43	12.35	12.29	12.32	35.60	34.19	34.90
T_7 : NPK + FYM + Borax + *A. brasilense*	7.30	7.20	7.25	13.15	11.90	12.53	11.22	11.16	11.19	31.67	30.26	30.97
T_8: NPK + FYM + $ZnSO_4$+ VAM	7.85	7.75	7.80	14.75	13.40	14.08	11.80	11.72	11.76	34.40	32.87	33.64
T_9: NPK + FYM + FYM + Borax + VAM	6.80	6.70	6.75	12.00	10.75	11.38	10.25	10.19	10.22	29.05	27.64	28.35
T_{10}: NPK+ FYM +$ZnSO_4$+ Borax + *A. brasilense*+ VAM	8.50	8.40	8.45	15.40	14.15	14.78	12.90	12.84	12.87	36.80	35.39	36.10
F test	*	*	*	*	*	*	*	*	*	*	*	*
S.Em ±	**0.32**	**0.34**	**0.23**	**0.65**	**0.70**	**0.47**	**0.51**	**0.52**	**0.36**	**0.90**	**1.51**	**0.86**
CD at 5 %	**0.95**	**1.00**	**0.66**	**1.93**	**2.09**	**1.34**	**1.52**	**1.53**	**1.02**	**2.68**	**4.50**	**2.46**
CV (%)	**7.82**	**8.41**	**8.10**	**8.94**	**10.58**	**9.50**	**8.26**	**8.41**	**8.16**	**5.16**	**9.01**	**7.08**

DAT: Days after transplanting, NPK @ 50:40:25 kg/ha, FYM @ 7.5 t/ha, $ZnSO_4$ @12.5 kg/ha, Borax @ 10 kg/ha, *A - Azospirillum*

Crop rotation: Finger millet (2005) - Soybean (2006), Soybean (2005) - Finger millet (2006)

(T_8 : 33.64 g/plant of TDMA). Significantly lower leaf, stem, ear head dry matter and TDMA (5.55, 8.58, 8.43 and 22.55 g/plant, respectively) was observed in control (T_1 :NPK + FYM).

4.7.1.7.4 DMA in leaf, stem, ear head and TDMA at harvest (g/plant)

Significant differences was observed in dry matter accumulation in leaf, stem, ear head and TDMA due to micronutrients (zinc and boron) and microbial inoculants application.

Application of NPK + FYM + $ZnSO_4$ + borax + *A.brasilense* + VAM (T_{10}) recorded significantly higher DMA in leaf, stem and ear head (7.45, 14.19 and 15.32 g/plant, respectively) as compared to other treatments. However, it was found on par with application of NPK + FYM + $ZnSO_4$ + *A.brasilense* (T_6 :7.15, 13.89 and 14.98 g/plant, respectively) and NPK + FYM + $ZnSO_4$ + VAM (T_8 :6.90 and 14.96 g/plant in leaf and ear head dry matter, respectively).

Combined application of zinc sulphate and borax along with recommended NPK, FYM, *A.brasilense* and VAM (T_{10}) recorded significantly higher TDMA (37.29 g/plant) as compared to rest of the treatments except with application of NPK + FYM + $ZnSO_4$ + *A.brasilense* (T_6 :36.02 g/plant). Significantly lower DMA in leaf, stem, ear head and TDMA was registered with application of NPK + FYM (T_1 :5.05, 9.27, 11.48 and 25.79 g/plant, respectively), but it was found on par with application of NPK + FYM + VAM (T_5 :5.60 and 10.24 g/plant in leaf and stem, respectively) (Table 4.7.10 and Fig. 39).

4.7.2 YIELD ATTRIBUTES OF FINGER MILLET AS INFLUENCED BY ZINC, BORON AND MICROBIAL INOCULANTS APPLICATION

4.7.2.1 Number of productive tillers per hill

Productive tillers increased significantly due to micronutrients and microbial inoculants application. Application of NPK + FYM + $ZnSO_4$ +

Table 4.7.8: Dry matter accumulation in leaf, stem and total dry matter accumulation (TDMA) of finger millet at 60 DAT as influenced by zinc, boron and microbial inoculants application in finger millet- soybean based cropping system

Treatment	Leaf dry matter (g/plant)			Stem dry matter (g/plant)			TDMA (g/plant)		
	2005	2006	Pooled	2005	2006	Pooled	2005	2006	Pooled
T_1: Control (NPK + FYM only)	3.90	3.70	3.80	4.90	4.75	4.83	8.80	8.45	8.63
T_2 : NPK + FYM +$ZnSO_4$	4.70	4.50	4.60	5.90	5.75	5.83	10.60	10.25	10.43
T_3 : NPK + FYM + Borax	4.59	4.38	4.49	5.70	5.55	5.63	10.29	9.93	10.11
T_4: NPK + FYM + *A brasilense*	4.45	4.23	4.34	5.59	5.44	5.52	10.04	9.67	9.86
T_5 : NPK + FYM + VAM	4.30	4.08	4.19	5.40	5.25	5.33	9.70	9.33	9.52
T_6 : NPK + FYM + $ZnSO_4$ + *A. brasilense*	5.25	5.03	5.14	7.00	6.75	6.88	12.25	11.78	12.02
T_7 : NPK + FYM + Borax + *A. brasilense*	4.82	4.60	4.71	6.25	6.10	6.18	11.07	10.70	10.89
T_8: NPK + FYM + $ZnSO_4$+ VAM	5.10	4.88	4.99	6.83	6.68	6.76	11.93	11.56	11.75
T_9: NPK + FYM + FYM + Borax + VAM	4.65	4.43	4.54	5.85	5.70	5.78	10.50	10.13	10.32
T_{10}: NPK+ FYM +$ZnSO_4$+ Borax + *A. brasilense*+ VAM	5.35	5.13	5.24	7.10	6.95	7.03	12.45	12.08	12.27
F test	*	*	*	*	*	*	*	*	*
S.Em ±	**0.16**	**0.16**	**0.11**	**0.23**	**0.25**	**0.17**	**0.40**	**0.41**	**0.28**
CD at 5 %	**0.48**	**0.47**	**0.32**	**0.68**	**0.75**	**0.48**	**1.19**	**1.21**	**0.81**
CV (%)	**5.93**	**6.12**	**6.04**	**6.55**	**7.38**	**6.83**	**6.44**	**6.78**	**6.58**

DAT: Days after transplanting, NPK @ 50:40:25 kg/ha, FYM @ 7.5 t/ha, $ZnSO_4$ @12.5 kg/ha, Borax @10 kg/ha, *A - Azospirillum*
Crop rotation: Finger millet (2005) - Soybean (2006), Soybean (2005) - Finger millet (2006)

borax + *A.brasilense* + VAM (T_{10}) recorded significantly higher number of productive tillers per hill (5.84) as compared to other treatments. However, it was found on par with that of NPK + FYM + $ZnSO_4$ + *A.brasilense* (T_6 : 5.64). Whereas, application of NPK + FYM + $ZnSO_4$ + VAM (T_8 : 5.39), NPK + FYM + borax + *A.brasilense* (T_7 : 5.15) and NPK + FYM + borax + VAM (T_9 : 5) were found to be the next best treatments and were found on par with each other. Significantly lower number of productive tillers per hill was noticed in NPK + FYM (T_1 : 4.10) as compared to other treatments, but found on par with application of NPK + FYM + VAM (T_5 : 4.40). The increase in number of productive tillers per hill due to application of NPK + FYM + $ZnSO_4$ + borax + *A.brasilense* + VAM (T_{10}) and NPK + FYM + $ZnSO_4$ + *A.brasilense* (T_6) was 42.44 and 37.56 per cent respectively over control (T_1) (Table 4.7.11 and Fig. 40).

4.7.2.2 Number of fingers per ear head

Significantly higher number of fingers per ear head (7.76) was recorded with application of NPK + FYM + $ZnSO_4$ + borax + *A.brasilense* + VAM (T_{10}) which was found on par with application of NPK + FYM + $ZnSO_4$ + *A.brasilense* (T_6 : 7.60) and NPK + FYM + $ZnSO_4$ + VAM (T_8 : 7.50). Application of NPK + FYM + borax + *A.brasilense* (T_7: 6.95), NPK + FYM + $ZnSO_4$ (T_2 : 6.80), NPK + FYM + borax + VAM (T_9 : 6.75) and NPK + FYM + borax (T_3 : 6.72) were found to be the next best treatments, which were found on par with each other. Significantly lower number of fingers per ear head was observed with application of NPK + FYM (T_1 : 5.96) closely followed by NPK + FYM + VAM (T_5 : 6.40). Application of NPK + FYM + $ZnSO_4$ + borax + *A.brasilense* + VAM (T_{10}) and NPK + FYM + *A.brasilense* (T_6) recorded 30.2 and 27.52 per cent higher number of fingers per ear head respectively over control (T_1 : NPK + FYM) (Table 4.7.11 and Fig. 40).

Table 4.7.11: Number of productive tillers per hill, number of fingers per ear head, ear head length finger length of finger millet as influenced by zinc, boron and microbial inoculants application in finger millet- soybean based cropping system

Treatment	Number of productive tillers per hill			Number of fingers per ear head			Ear head length (cm)			Finger length (cm)		
	2005	2006	Pooled	2005	2006	Pooled	2005	2006	Pooled	2005	2006	Pooled
T_1: Control (NPK + FYM only)	4.20	4.00	4.10	6.01	5.90	5.96	7.80	7.60	7.70	5.95	5.70	5.83
T_2 : NPK + FYM +$ZnSO_4$	5.10	5.00	5.05	6.85	6.75	6.80	8.70	8.60	8.65	6.70	6.45	6.58
T_3 : NPK + FYM + Borax	4.82	4.70	4.76	6.77	6.66	6.72	8.55	8.35	8.45	6.58	6.33	6.46
T_4: NPK + FYM + *A brasilense*	4.60	4.50	4.55	6.50	6.40	6.45	8.30	8.10	8.20	6.45	6.20	6.33
T_5 : NPK + FYM + VAM	4.45	4.35	4.40	6.45	6.35	6.40	8.15	7.95	8.05	6.30	6.05	6.18
T_6 : NPK + FYM + $ZnSO_4$ + *A. brasilense*	5.69	5.58	5.64	7.65	7.55	7.60	9.35	9.15	9.25	7.20	6.95	7.08
T_7 : NPK + FYM + Borax + *A. brasilense*	5.20	5.10	5.15	7.00	6.90	6.95	8.95	8.75	8.85	6.95	6.70	6.83
T_8: NPK + FYM + $ZnSO_4$+ VAM	5.44	5.34	5.39	7.55	7.45	7.50	9.28	9.08	9.18	7.10	6.85	6.98
T_9: NPK + FYM + FYM + Borax + VAM	5.05	4.95	5.00	6.80	6.70	6.75	8.63	8.43	8.53	6.65	6.40	6.53
T_{10}: NPK+ FYM +$ZnSO_4$+ Borax + *A. brasilense*+ VAM	5.89	5.79	5.84	7.81	7.70	7.76	9.67	9.47	9.57	7.57	7.32	7.45
F test	*	*	*	*	*	*	*	*	*	*	*	*
S.Em ±	**0.20**	**0.19**	**0.14**	**0.24**	**0.25**	**0.17**	**0.23**	**0.23**	**0.17**	**0.17**	**0.17**	**0.11**
CD at 5 %	**0.59**	**0.57**	**0.39**	**0.72**	**0.73**	**0.48**	**0.69**	**0.67**	**0.49**	**0.50**	**0.49**	**0.33**
CV (%)	**6.83**	**6.79**	**6.67**	**6.03**	**6.23**	**5.97**	**4.61**	**4.59**	**4.85**	**4.28**	**4.40**	**4.24**

NPK @ 50:40:25 kg/ha, FYM @ 7.5 t/ha, $ZnSO_4$ @ 12.50 kg/ha, Borax @ 10 kg/ha, *A* - *Azospirillum*

Crop rotation: Finger millet (2005) - Soybean (2006), Soybean (2005) - Finger millet (2006)

4.7.2.3 Ear head length (cm)

Significantly longer ear head length (9.57 cm) was registered with application of NPK + FYM + $ZnSO_4$ + borax + *A.brasilense* + VAM (T_{10}) followed by NPK + FYM + $ZnSO_4$ + *A.brasilense* (T_6 : 9.25 cm) and NPK + FYM + $ZnSO_4$ + VAM (T_8 : 9.18 cm). However, all these treatments were found to be on par with each other. While application of NPK + FYM (T_1) recorded significantly shorter ear length (7.70 cm) which was found to be on par with NPK + FYM + VAM (T_5 : 8.05 cm) and rest of treatments were intermediate. The increase in ear head length due to application of NPK + FYM + $ZnSO_4$ + borax + *A.brasilense* + VAM (T_{10}) was 24.28 per cent over control (T_1) (Table 4.7.11 and Fig. 41).

4.7.2.4 Finger length (cm)

Finger length differed significantly due to influence of micronutrients and microbial inoculants. Application of NPK + FYM + $ZnSO_4$ + borax + *A.brasilense* + VAM (T_{10}) recorded significantly longer finger length (7.45 cm) as compared to all other treatments. Application of NPK + FYM (T_1) recorded significantly shorter finger length (5.83 cm) as compared to all other treatments. The increase in finger length due to application of NPK + FYM + $ZnSO_4$ + borax + *A.brasilense* + VAM (T_{10}) was 27.79 per cent as compared to control (T_1) (Table 4.7.11 and Fig. 41).

4.7.2.5 Grain yield per hill (g)

Application of NPK + FYM + $ZnSO_4$ + borax + *A.brasilense* + VAM (T_{10}) registered significantly higher grain yield per hill (12.43 g/plant) over all other treatments except NPK + FYM + $ZnSO_4$ + *A.brasilense* (T_6 : 12.05 g/plant) and NPK + FYM + $ZnSO_4$ + VAM (T_8 : 11.98 g/plant) while, significantly lower grain yield per plant (8.45 g/plant) was recorded in control (T_1 : NPK + FYM) and the rest of the treatments were intermediate. Application of NPK + FYM + $ZnSO_4$ + borax + *A.brasilense*

+ VAM (T_{10}) and NPK + FYM + $ZnSO_4$ + *A.brasilense* (T_6) recorded 47.10 and 42.60 per cent higher grain yield per plant over control (T_1) (Table 4.7.11 and Fig. 42).

4.7.2.6 1000-grain weight (g)

Significantly higher 1000-grain weight (3.80 g) was recorded with application of NPK + FYM + $ZnSO_4$ + borax + *A.brasilense* + VAM (T_{10}) over other treatments. However, it was found on par with application of NPK + FYM + $ZnSO_4$ + *A.brasilense* (T_6 : 3.74 g) and NPK + FYM + $ZnSO_4$ + VAM (T_8 : 3.66 g), whereas, lower 1000-grain weight (2.95 g) was obtained in control (T_1). The increase in 1000-grain weight due to application of NPK + FYM + $ZnSO_4$ + borax + *A.brasilense* + VAM (T_{10}) and NPK + FYM + $ZnSO_4$ + *A.brasilense* (T_6) was 28.81 and 26.78 per cent higher as compared to control (T_1) (Table 4.7.12 and Fig. 42).

4.7.2.7 Threshing percentage (%)

Data on threshing percentage did not differ significantly due to zinc, boron and microbial inoculants application. (Table 4.7.12).

4.7.3 GRAIN YIELD, STRAW YIELD AND HARVEST INDEX OF FINGER MILLET AS INFLUENCED BY ZINC, BORON AND MICROBIAL INOCULANTS APPLICATION

4.7.3.1 Grain yield (kg/ha)

Application of NPK + FYM + $ZnSO_4$ + borax + *A.brasilense* + VAM (T_{10}) recorded significantly higher grain yield of finger millet (4143 kg/ha) over rest of the treatments. However, it was found on par with application of NPK + FYM + $ZnSO_4$ + *A. brasilense* (T_6 : 4043 kg/ha) and NPK + FYM + $ZnSO_4$ + VAM (T_8 : 4018 kg/ha). Application of NPK + FYM + borax + *A.brasilense* (T_7 : 3498 kg/ha), NPK + FYM + borax + VAM (T_9 : 3386 kg/ha), NPK + FYM + $ZnSO_4$ (T_2 : 3480 kg/ha), NPK + FYM + borax

Table 4.7.12: Grain yield per hill, 1000-grain weight, threshing percentage of finger millet as influenced by zinc, boron and microbial inoculants application in finger millet- soybean based cropping system

Treatment	Grain yield per hill (g)			1000-grain weight (g)			Threshing percentage (%)		
	2005	2006	Pooled	2005	2006	Pooled	2005	2006	Pooled
T_1: Control (NPK + FYM only)	8.50	8.40	8.45	3.00	2.90	2.95	74.39	73.35	73.87
T_2 : NPK + FYM +$ZnSO_4$	10.85	9.90	10.38	3.70	3.80	3.75	79.09	77.41	78.25
T_3 : NPK + FYM + Borax	10.40	9.65	10.03	3.35	3.25	3.30	78.03	76.59	77.31
T_4: NPK + FYM + *A brasilense*	10.37	9.53	9.95	3.31	3.20	3.26	78.17	75.93	77.05
T_5 : NPK + FYM + VAM	10.12	9.40	9.76	3.27	3.16	3.22	77.05	75.02	76.03
T_6 : NPK + FYM + $ZnSO_4$ + *A. brasilense*	12.50	11.60	12.05	3.78	3.69	3.74	81.90	79.40	80.65
T_7 : NPK + FYM + Borax + *A. brasilense*	10.90	9.96	10.43	3.50	3.40	3.45	80.33	77.53	78.93
T_8: NPK + FYM + $ZnSO_4$+ VAM	12.40	11.55	11.98	3.70	3.61	3.66	82.00	78.97	80.49
T_9: NPK + FYM + FYM + Borax + VAM	10.45	9.84	10.15	3.65	3.56	3.61	80.23	77.38	78.81
T_{10}: NPK+ FYM +$ZnSO_4$+ Borax + *A. brasilense*+ VAM	12.82	12.04	12.43	3.85	3.75	3.80	82.10	80.27	81.19
F test	*	*	*	*	*	*			
S.Em ±	**0.61**	**0.40**	**0.36**	**0.11**	**0.10**	**0.08**	**3.33**	**3.90**	**2.73**
CD at 5 %	**1.82**	**1.19**	**1.02**	**0.33**	**0.30**	**0.22**	**NS**	**NS**	**NS**
CV (%)	**9.69**	**6.83**	**8.26**	**5.50**	**5.11**	**5.38**	**7.28**	**8.76**	**8.56**

NPK @ 50:40:25 kg/ha, FYM @ 7.5 t/ha, $ZnSO_4$ @ 12.50 kg/ha, Borax @ 10 kg/ha, *A – Azospirillum*, NS: Non significant

Crop rotation: Finger millet (2005) - Soybean (2006), Soybean (2005) - Finger millet (2006)

(T_3 : 3384 kg/ha), NPK + FYM + *A.brasilense* (T_4 : 3352 kg/ha) and NPK + FYM + VAM (T_5 : 3276 kg/ha) were found to be the next best treatments and were found to be on par with each other. Significantly lower grain yield (2851 kg/ha) was recorded in control (T_1 : NPK + FYM). The increase in grain yield due to application of NPK + FYM + $ZnSO_4$ + borax + *A.brasilense* + VAM (T_{10}), NPK + FYM + $ZnSO_4$ + *A.brasilense* (T_6) and NPK + FYM + $ZnSO_4$ + VAM (T_8) was 45.31, 41.80 and 40.93 per cent over control (T_1 : NPK + FYM) (Table 4.7.13 and Fig. 43).

4.7.3.2 Straw yield (kg/ha)

Straw yield differed significantly due to treatment effects. Application of NPK + FYM + $ZnSO_4$ + borax + *A.brasilense* + VAM (T_{10}) registered significantly higher straw yield (6467 kg/ha) which was found to be on par with application of NPK + FYM + $ZnSO_4$ + *A.brasilense* (T_6 : 6109 kg/ha) and NPK + FYM + $ZnSO_4$ + VAM (T_8 : 6060 kg/ha). Significantly lower straw yield (4261 kg/ha) was recorded in control (T_1 :NPK + FYM) and rest of the treatments were found to be intermediate (Table 4.7.13 and Fig. 43).

4.7.3.3 Harvest index (HI)

Data on harvest index of finger millet did not differ significantly due to micronutrients and microbial inoculants application (Table 4.7.13 and Fig. 43).

4.7.4 SEED QUALITY PARAMETERS

The data on seed quality parameters viz., germination, dry weight of root and shoot and seed vigour index of finger millet differed significantly due to zinc, boron and microbial inoculants application (Table 4.7.14).

Table 4.7.13: Grain yield, straw yield and harvest index of finger millet as influenced by zinc, boron and microbial inoculants application in finger millet- soybean based cropping system

Treatment	Grain yield (kg/ha)			Straw yield (kg/ha)			Harvest index		
	2005	2006	Pooled	2005	2006	Pooled	2005	2006	Pooled
T_1: Control (NPK + FYM only)	2870	2832	2851	4172	4350	4261	0.41	0.39	0.40
T_2 : NPK + FYM +$ZnSO_4$	3620	3340	3480	5558	5318	5438	0.40	0.39	0.39
T_3 : NPK + FYM + Borax	3509	3259	3384	5198	4907	5053	0.40	0.40	0.40
T_4: NPK + FYM + *A brasilense*	3489	3215	3352	4768	4863	4816	0.42	0.40	0.41
T_5 : NPK + FYM + VAM	3371	3181	3276	4721	4823	4772	0.42	0.40	0.41
T_6 : NPK + FYM + $ZnSO_4$ + *A. brasilense*	4180	3905	4043	6250	5968	6109	0.40	0.40	0.40
T_7 : NPK + FYM + Borax + *A. brasilense*	3633	3363	3498	5592	5335	5464	0.39	0.39	0.39
T_8: NPK + FYM + $ZnSO_4$+ VAM	4150	3885	4018	6228	5892	6060	0.40	0.40	0.40
T_9: NPK + FYM + FYM + Borax + VAM	3490	3283	3386	5221	5431	5326	0.40	0.38	0.39
T_{10}: NPK+ FYM +$ZnSO_4$+ Borax + *A. brasilense*+ VAM	4273	4013	4143	6617	6317	6467	0.39	0.39	0.39
F test	*	*	*	*	*	*			
S.Em ±	**213.18**	**140.26**	**132.46**	**444.61**	**179.84**	**240.71**	**0.03**	**0.01**	**0.02**
CD at 5 %	**633.42**	**416.74**	**379.14**	**1321.05**	**534.35**	**688.99**	**NS**	**NS**	**NS**
CV (%)	**10.09**	**7.09**	**9.16**	**14.18**	**5.85**	**10.97**	**11.52**	**6.03**	**9.24**

NPK @ 50:40:25 kg/ha, FYM @ 7.5 t/ha, $ZnSO_4$ @ 12.50 kg/ha, Borax @ 10 kg/ha, *A – Azospirillum*, NS: Non significant

Crop rotation: Finger millet (2005) - Soybean (2006), Soybean (2005) - Finger millet (2006)

4.7.4.1 Germination (%)

Application of NPK + FYM + $ZnSO_4$ + borax + *A.brasilense* + VAM (T_{10}) registered significantly higher germination per cent (99). However, it was found on par with application of NPK + FYM + $ZnSO_4$ + *A.brasilense* (T_6 : 98%) and NPK + FYM + $ZnSO_4$ + VAM (T_8 : 97%). Application of NPK + FYM + borax + *A.brasilense* (T_7 : 94%), NPK + FYM + $ZnSO_4$ + (T_2 : 93%), NPK + FYM + borax + VAM (T_9 : 92%) and NPK + FYM + borax (T_3 : 91%) recorded significantly higher germination per cent as compared to control (T_1 : NPK + FYM (85%). However, all these treatments were found on par with each other and the remaining treatments were found intermediate (Table 4.7.14 and Fig. 44).

4.7.4.2 Dry weight of root and shoot (mg)

The data on dry weight of root and shoot differed significantly among the treatments. Significantly higher dry weight of root and shoot (5.70 mg) was registered with application of NPK + FYM + $ZnSO_4$ + borax + *A.brasilense* + VAM (T_{10} : 5.70 mg) as compared to other treatments but it was found on par with application of NPK + FYM + $ZnSO_4$ + *A.brasilense* (T_6 : 5.30 mg), while, significantly lower shoot and root dry weight (1.55 mg) was recorded in control (T_1 : NPK + FYM) (Table 4.7.14).

4.7.4.3 Seed vigour index

Significantly higher seed vigour index was recorded with conjunctive use of zinc sulphate, borax, *A.brasilense* and VAM along with recommended NPK and FYM (T_{10} : 561) as compared to all other treatments. Application of NPK + FYM + $ZnSO_4$ + *A.brasilense* (T_6 : 517) and NPK + FYM + $ZnSO_4$ + VAM (T_8 : 483) were found on par with each other, but recorded significantly higher seed vigour index as compared to remaining treatments. While significantly lower seed vigour index (132) was recorded in NPK + FYM (T_1 : Control) (Table 4.7.14 and Fig. 44).

Table 4.7.14: Germination, dry weight of root and shoot and seed vigour index of finger millet as influenced by zinc, boron and microbial inoculants application in finger millet- soybean based cropping system

Treatment	Germination (%)			Dry weight of root and shoot (mg)			Seed vigour index		
	2005	2006	Pooled	2005	2006	Pooled	2005	2006	Pooled
T_1: Control (NPK + FYM only)	87	83	85	1.60	1.50	1.55	139	125	132
T_2 : NPK + FYM +$ZnSO_4$	94	92	93	3.30	2.90	3.10	310	267	289
T_3 : NPK + FYM + Borax	92	89	91	2.90	2.20	2.55	267	197	232
T_4: NPK + FYM + *A brasilense*	91	88	90	1.90	2.00	1.95	173	177	175
T_5 : NPK + FYM + VAM	90	87	89	1.80	1.80	1.80	162	157	160
T_6 : NPK + FYM + $ZnSO_4$ + *A. brasilense*	99	96	98	5.60	5.00	5.30	554	480	517
T_7 : NPK + FYM + Borax + *A. brasilense*	95	93	94	5.00	3.00	4.00	475	278	377
T_8: NPK + FYM + $ZnSO_4$+ VAM	98	95	97	5.40	4.60	5.00	529	436	483
T_9: NPK + FYM + FYM + Borax + VAM	93	91	92	3.00	2.70	2.85	279	246	263
T_{10}: NPK+ FYM +$ZnSO_4$+ Borax + *A. brasilense*+ VAM	99	98	99	5.80	5.60	5.70	573	549	561
F test	*	*	*	*	*	*	*	*	*
S.Em +	**1.29**	**1.66**	**1.08**	**0.21**	**0.19**	**0.14**	**19.02**	**19.60**	**13.57**
CD at 5 %	**3.84**	**4.94**	**3.10**	**0.63**	**0.58**	**0.41**	**56.52**	**58.23**	**38.85**
CV (%)	**2.38**	**3.16**	**2.87**	**10.14**	**10.72**	**10.30**	**9.52**	**11.65**	**10.43**

NPK @ 50:40:25 kg/ha, FYM @ 7.5 t/ha, $ZnSO_4$ @ 12.50 kg/ha, Borax @ 10 kg/ha, *A - Azospirillum*
Crop rotation: Finger millet (2005) - Soybean (2006), Soybean (2005) - Finger millet (2006)

4.7.5 NUTRIENT UPTAKE STUDIES

4.7.5.1 Nitrogen uptake by finger millet grain, straw and total plant uptake (kg/ha)

Uptake of nitrogen by finger millet grain differed significantly due to application of zinc, boron and microbial inoculants.

Application of NPK + FYM + $ZnSO_4$ + borax + *A.brasilense* + VAM (T_{10}) recorded significantly higher nitrogen uptake by finger millet grain (60.11 kg/ha) which was closely followed by application of NPK + FYM + *A.brasilense* (T_6 : 57.45 kg/ha) and NPK + FYM + $ZnSO_4$ + VAM (T_8 : 55.48 kg/ha). Significantly lower uptake of nitrogen (34.93 kg/ha) was recorded in control (T_1 : NPK + FYM) (Table 4.7.15).

Significantly higher uptake of nitrogen by finger millet straw (50.48 kg/ha) was recorded due to application of NPK + FYM + $ZnSO_4$ + borax + *A.brasilense* + VAM (T_{10}) as compared to rest of the treatments.

Total nitrogen uptake raised from 61.11 to 110.59 kg per ha due to various treatments tested. Significantly higher total uptake of nitrogen (110.59 kg/ha) was observed with application of NPK + FYM + $ZnSO_4$ + borax + *A.brasilense* + VAM (T_{10}) as compared to rest of the treatments. Application of NPK + FYM + $ZnSO_4$ + *A .brasilense* (T_6 : 103.9 kg/ha) and NPK + FYM + $ZnSO_4$ + VAM (T_8 : 100.36 kg/ha) recorded significantly higher uptake of total nitrogen as compared to other treatments. However, they were found on par with each other (Table 4.7.15 and Fig. 45).

4.7.5.2 Phosphorus uptake by finger millet grain, straw and total plant uptake (kg/ha)

The uptake of phosphorus by finger millet grain was higher (11.82 kg/ha) with application of NPK + FYM + $ZnSO_4$ + borax + *A.brasilense* +

Table 4.7.15: Nitrogen uptake by grain, straw and total nitrogen uptake of finger millet as influenced by zinc, boron and microbial inoculants application in finger millet- soybean based cropping system

Treatment	Nitrogen uptake (kg/ha)								
	Grain (kg/ha)			Straw (kg/ha)			Total uptake (kg/ha)		
	2005	2006	Pooled	2005	2006	Pooled	2005	2006	Pooled
T_1: Control (NPK + FYM only)	35.30 (1.23)	34.55 (1.22)	34.93 (1.23)	26.70 (0.64)	25.66 (0.59)	26.18 (0.62)	62.00 (1.87)	60.21 (1.81)	61.11 (1.84)
T_2 : NPK + FYM +$ZnSO_4$	48.87 (1.35)	43.09 (1.29)	45.98 (1.32)	38.91 (0.70)	36.16 (0.68)	37.54 (0.69)	87.78 (2.05)	79.25 (1.97)	83.5 (2.01)
T_3 : NPK + FYM + Borax	45.62 (1.30)	41.39 (1.27)	43.51 (1.29)	34.83 (0.67)	31.40 (0.64)	33.12 (0.66)	80.45 (1.97)	72.79 (1.91)	76.62 (1.94)
T_4: NPK + FYM + *A brasilense*	44.31 (1.27)	40.51 (1.26)	42.41 (1.27)	31.47 (0.66)	30.15 (0.62)	30.81 (0.64)	75.78 (1.93)	70.66 (1.88)	73.22 (1.91)
T_5 : NPK + FYM + VAM	42.14 (1.25)	39.44 (1.24)	40.79 (1.25)	30.69 (0.65)	29.94 (0.60)	30.32 (0.63)	72.83 (1.90)	69.38 (1.84)	71.11 (1.87)
T_6 : NPK + FYM + $ZnSO_4$ + *A. brasilense*	60.61 (1.45)	54.28 (1.39)	57.45 (1.42)	48.75 (0.78)	44.16 (0.74)	46.46 (0.76)	109.36 (2.23)	98.44 (2.13)	103.9 (2.18)
T_7 : NPK + FYM + Borax + *A. brasilense*	49.77 (1.37)	44.39 (1.32)	47.08 (1.35)	40.82 (0.73)	37.34 (0.70)	39.08 (0.72)	90.59 (2.10)	81.73 (2.02)	86.16 (2.06)
T_8: NPK + FYM + $ZnSO_4$+ VAM	58.51 (1.41)	52.45 (1.35)	55.48 (1.38)	47.33 (0.76)	42.42 (0.72)	44.88 (0.74)	105.84 (2.17)	94.87 (2.07)	100.36 (2.12)
T_9: NPK + FYM + FYM + Borax + VAM	46.07 (1.32)	42.02 (1.28)	44.05 (1.30)	35.50 (0.68)	35.84 (0.66)	35.67 (0.67)	81.57 (2.00)	77.86 (1.94)	79.72 (1.97)
T_{10}: NPK+ FYM +$ZnSO_4$+ Borax + *A. brasilense*+ VAM	63.24 (1.48)	56.98 (1.42)	60.11 (1.45)	52.94 (0.80)	48.01 (0.76)	50.48 (0.78)	116.18 (2.28)	104.99 (2.18)	110.59 (2.23)
F test	*	*	*	*	*	*	*	*	*
S.Em +	**2.45**	**2.27**	**1.69**	**2.04**	**1.64**	**1.38**	**3.29**	**2.64**	**2.23**
CD at 5 %	**7.28**	**6.75**	**4.83**	**6.07**	**4.88**	**3.96**	**9.76**	**7.86**	**6.39**
CV (%)	**8.59**	**8.76**	**8.77**	**9.12**	**7.88**	**9.04**	**6.45**	**5.65**	**6.47**

NPK @ 50:40:25 kg/ha, FYM @ 7.5 t/ha, $ZnSO_4$ @ 12.50 kg/ha, Borax @ 10 kg/ha, *A – Azospirillum,* Figures in parenthesis indicates actual concentration of nitrogen in per cent, **Crop rotation**: Finger millet (2005) - Soybean (2006), Soybean (2005) - Finger millet (2006)

VAM (T_{10}) as compared to all other treatments. Application of NPK + FYM + $ZnSO_4$ + *A.brasilense* (T_6) registered higher uptake of phosphorus (10.92 kg/ha) by finger millet grain as compared to other treatments. Significantly lower uptake of phosphorus (5.71 kg/ha) by finger millet grain was recorded in NPK + FYM (T_1 : Control) (Table 4.7.16).

Significantly higher uptake of phosphorus by finger millet straw (9.73 kg/ha) was recorded due to application of NPK + FYM + $ZnSO_4$ + borax + *A.brasilense* + VAM (T_{10}) as compared to rest of the treatments. Application of NPK + FYM + $ZnSO_4$ + VAM (T_8) and NPK + FYM + $ZnSO_4$ + *A.brasilense* (T_6) recorded significantly higher uptake of phosphorus by finger millet straw (8.88 and 8.46 kg/ha, respectively) as compared to other treatments, except with application of NPK + FYM + $ZnSO_4$ + borax + *A.brasilense* + VAM (T_{10}). However, these two treatments were found on par with each other.

Indeed, there was a marked improvement in total phosphorus uptake (21.55 kg/ha) by finger millet plant as a result of application of NPK + FYM + $ZnSO_4$ + borax + *A.brasilense* + VAM (T_{10}). Significantly higher total phosphorus uptake (19.37 kg/ha) was recorded in NPK + FYM + $ZnSO_4$ + *A.brasilense* (T_6) as compared to other treatments. However, significantly lower total phosphorus uptake (11.82 kg/ha) was recorded in control (T_1 : NPK + FYM) (Table 4.7.16 and Fig. 45).

4.7.5.3 Potassium uptake by finger millet grain, straw and total plant uptake (kg/ha)

Application of NPK + FYM + $ZnSO_4$ + borax + *A.brasilense* + VAM (T_{10}) registered significantly higher potassium uptake by finger millet grain (19.79 kg/ha), which was found to be on par with application of NPK + FYM + $ZnSO_4$ + *A.brasilense* (T_6 :19.21 kg/ha) and NPK + FYM +

Table 4.7.16: Phosphorus uptake by grain, straw and total phosphorus uptake of finger millet as influenced by zinc, boron and microbial inoculants application in finger millet- soybean based cropping system

Treatment	Phosphorus uptake (kg/ha)								
	Grain (kg/ha)			Straw (kg/ha)			Total uptake (kg/ha)		
	2005	2006	Pooled	2005	2006	Pooled	2005	2006	Pooled
T_1: Control (NPK + FYM only)	6.03 (0.210)	5.38 (0.190)	5.71 (0.200)	5.92 (0.142)	6.31 (0.145)	6.12 (0.144)	11.95 (0.352)	11.69 (0.335)	11.82 (0.344)
T_2 : NPK + FYM +$ZnSO_4$	7.60 (0.210)	6.68 (0.200)	7.14 (0.205)	8.11 (0.146)	7.60 (0.143)	7.86 (0.145)	15.71 (0.356)	14.28 (0.343)	15.00 (0.350)
T_3 : NPK + FYM + Borax	7.02 (0.200)	6.19 (0.190)	6.61 (0.195)	7.54 (0.145)	6.87 (0.140)	7.21 (0.143)	14.56 (0.345)	13.06 (0.330)	13.81 (0.338)
T_4: NPK + FYM + *A brasilense*	6.98 (0.200)	5.79 (0.180)	6.39 (0.190)	6.82 (0.143)	6.66 (0.137)	6.74 (0.140)	13.80 (0.343)	12.45 (0.317)	13.13 (0.330)
T_5 : NPK + FYM + VAM	7.42 (0.220)	6.36 (0.200)	6.89 (0.210)	6.80 (0.144)	6.84 (0.142)	6.82 (0.143)	14.22 (0.364)	13.20 (0.342)	13.71 (0.353)
T_6 : NPK + FYM + $ZnSO_4$ + *A. brasilense*	11.29 (0.270)	10.54 (0.270)	10.92 (0.270)	8.56 (0.137)	8.35 (0.140)	8.46 (0.139)	19.85 (0.407)	18.89 (0.410)	19.37 (0.409)
T_7 : NPK + FYM + Borax + *A. brasilense*	8.72 (0.240)	7.40 (0.220)	8.06 (0.230)	8.22 (0.147)	7.63 (0.143)	7.93 (0.145)	16.94 (0.387)	15.03 (0.363)	15.99 (0.375)
T_8: NPK + FYM + $ZnSO_4$+ VAM	10.37 (0.250)	8.93 (0.230)	9.65 (0.240)	9.22 (0.148)	8.54 (0.146)	8.88 (0.147)	19.59 (0.398)	17.47 (0.375)	18.5 (0.387)
T_9: NPK + FYM + FYM + Borax + VAM	8.03 (0.230))	6.89 (0.210)	7.46 (0.220)	7.94 (0.152)	7.93 (0.146)	7.94 (0.149)	15.97 (0.382)	14.82 (0.356)	15.40 (0.369)
T_{10}: NPK+ FYM +$ZnSO_4$+ Borax + *A. brasilense*+ VAM	12.39 (0.290)	11.24 (0.280)	11.82 (0.285)	9.99 (0.151)	9.47 (0.150)	9.73 (0.151)	22.38 (0.441)	20.71 (0.430)	21.55 (0.436)
F test	*	*	*	*	*	*	*	*	*
S.Em +	**0.32**	**0.23**	**0.19**	**0.19**	**0.17**	**0.13**	**0.33**	**0.26**	**0.21**
CD at 5 %	**0.96**	**0.68**	**0.56**	**0.57**	**0.49**	**0.37**	**0.97**	**0.78**	**0.59**
CV (%)	**6.50**	**5.27**	**5.90**	**4.23**	**3.76**	**4.07**	**3.41**	**3.01**	**3.17**

NPK @ 50:40:25 kg/ha, FYM @ 7.5 t/ha, $ZnSO_4$ @ 12.50 kg/ha, Borax @ 10 kg/ha, *A - Azospirillum*, Figures in parenthesis indicate actual concentration of Phosphorus in per cent, **Crop rotation**: Finger millet (2005) - Soybean (2006), Soybean (2005) - Finger millet (2006)

$ZnSO_4$ + VAM (T_8 :18.79 kg/ha). The minimal removal of potassium (12.26 kg/ha) was noticed in control (T_1 : NPK + FYM) (Table 4.7.17).

Significantly higher potassium uptake in straw and total potassium uptake (68.88 and 88.67 kg/ha, respectively) was recorded with application of NPK + FYM + $ZnSO_4$ + borax + *A.brasilense* + VAM (T_{10}) as compared to other treatments. However, it was found on par with application of NPK + FYM + $ZnSO_4$ + VAM (T_8 : 67.39 and 86.18 kg/ha, respectively). Significantly lower potassium uptake in straw and total uptake was recorded in control (NPK + FYM) (38.98 and 51.24 kg/ha, respectively) (Table 4.7.17 and Fig. 45).

4.7.5.4 Zinc uptake by finger millet grain, straw and total plant uptake (g/ha)

Zinc uptake by finger millet grain, straw and total uptake differed significantly due to application of micronutrients and microbial inoculants. Application of zinc + boron + *A.brasilense* + VAM along with recommended dose of NPK and FYM (T_{10}) recorded significantly higher zinc uptake by finger millet grain (102.20 g/ha) as compared to other treatments. However, it was found on par with application of NPK + FYM + $ZnSO_4$ + *A.brasilense* (T_6 : 98.10 g/ha) and NPK + FYM + $ZnSO_4$ + VAM (T_8 : 94.21 g/ha). Significantly lower zinc uptake by finger millet grain (59.45 g/ha) was recorded in NPK + FYM (T_1 : Control) (Table 4.7.18).

Significantly higher uptake of zinc by finger millet straw and total uptake (65.02 and 167.21 g/ha) was registered with application of NPK + FYM + $ZnSO_4$ + borax + *A.brasilense* + VAM (T_{10}) as compared to rest of the treatments, while application of NPK + FYM + $ZnSO_4$ + *A.brasilense* (T_6 : 55.53 and 153.63 g/ha, respectively) and NPK + FYM + $ZnSO_4$ + VAM (T_8 : 57.61 and 151.82 g/ha, respectively) were found on par with

Table 4.7.17: Potassium uptake by grain, straw and total potassium nitrogen uptake of finger millet as influenced by zinc, boron and microbial inoculants application in finger millet- soybean based cropping system

Treatment	Potassium uptake (kg/ha)								
	Grain (kg/ha)			Straw (kg/ha)			Total uptake(kg/ha)		
	2005	2006	Pooled	2005	2006	Pooled	2005	2006	Pooled
T_1: Control (NPK + FYM only)	12.40 (0.432)	12.12 (0.428)	12.26 (0.430)	38.80 (0.930)	39.15 (0.900)	38.98 (0.915)	51.20 (1.362)	51.27 (1.328)	51.24 (1.345)
T_2 : NPK + FYM +$ZnSO_4$	16.58 (0.458)	15.20 (0.455)	15.89 (0.457)	56.14 (1.010)	53.45 (1.005)	54.80 (1.008)	72.72 (1.468)	68.65 (1.460)	70.69 (1.464)
T_3 : NPK + FYM + Borax	15.79 (0.450)	14.99 (0.460)	15.39 (0.455)	50.94 (0.980)	47.60 (0.970)	49.27 (0.975)	66.73 (1.430)	62.59 (1.430)	64.66 (1.430)
T_4: NPK + FYM + *A brasilense*	15.53 (0.445)	14.15 (0.440)	14.84 (0.443)	45.30 (0.950)	45.96 (0.945)	45.63 (0.948)	60.83 (1.395)	60.11 (1.385)	60.47 (1.390)
T_5 : NPK + FYM + VAM	14.83 (0.440)	13.36 (0.420)	14.10 (0.430)	41.97 (0.889)	41.72 (0.865)	41.85 (0.877)	56.80 (1.329)	55.08 (1.285)	55.94 (1.307)
T_6 : NPK + FYM + $ZnSO_4$ + *A. brasilense*	18.95 (0.477)	18.47 (0.473)	19.21 (0.475)	55.38 (0.886)	53.77 (0.901)	54.58 (0.894)	75.32 (1.363)	72.24 (1.374)	73.78 (1.369)
T_7 : NPK + FYM + Borax + *A. brasilense*	16.89 (0.465)	15.54 (0.462)	16.22 (0.464)	54.24 (0.970)	51.22 (0.960)	52.73 (0.965)	71.13 (1.435)	66.76 (1.422)	68.95 (1.429)
T_8: NPK + FYM + $ZnSO_4$+ VAM	19.51 (0.470)	18.07 (0.465)	18.79 (0.468)	69.38 (1.114)	65.40 (1.110)	67.39 (1.112)	88.89 (1.584)	83.47 (1.575)	86.18 (1.580)
T_9: NPK + FYM + FYM + Borax + VAM	15.91 (0.456)	14.87 (0.453)	15.39 (0.455)	51.95 (0.995)	52.64 (0.969)	52.30 (0.982)	67.86 (1.451)	67.51 (1.422)	67.69 (1.437)
T_{10}: NPK+ FYM +$ZnSO_4$+ Borax + *A. brasilense*+ VAM	20.51 (0.480)	19.06 (0.475)	19.79 (0.478)	70.67 (1.068)	67.09 (1.062)	68.88 (1.065)	91.18 (1.548)	86.15 (1.537)	88.67 (1.543)
F test	*	*	*	*	*	*	*	*	*
S.Em +	**0.87**	**0.95**	**0.64**	**2.75**	**2.72**	**2.09**	**3.09**	**2.93**	**2.29**
CD at 5 %	**2.57**	**2.83**	**1.84**	**8.19**	**8.09**	**5.99**	**9.18**	**8.72**	**6.56**
CV (%)	**8.94**	**10.60**	**9.73**	**8.92**	**9.10**	**9.73**	**7.61**	**7.54**	**8.16**

NPK @ 50:40:25 kg/ha, FYM @ 7.5 t/ha, $ZnSO_4$ @ 12.50 kg/ha, Borax @ 10 kg/ha, *A - Azospirillum*, Figures in parenthesis indicate actual concentration of Potassium in per cent, **Crop rotation**: Finger millet (2005) - Soybean (2006), Soybean (2005) - Finger millet (2006)

Table 4.7.18: Zinc uptake by grain, straw and total zinc uptake of finger millet as influenced by zinc, boron and microbial inoculants application in finger millet- soybean based cropping system

Treatment	Zinc uptake (g/ha)								
	Grain (g/ha)			Straw (g/ha)			Total uptake (g/ha)		
	2005	2006	Pooled	2005	2006	Pooled	2005	2006	Pooled
T_1: Control (NPK + FYM only)	61.13 (21.30)	57.77 (20.40)	59.45 (20.85)	27.95 (6.70)	28.28 (6.50)	28.12 (6.60)	89.08 (28.00)	86.05 (26.90)	87.57 (27.45)
T_2 : NPK + FYM +$ZnSO_4$	84.64 (23.38)	74.38 (22.27)	79.51 (22.83)	47.24 (8.50)	51.29 (9.64)	49.27 (9.07)	131.88 (31.88)	125.67 (31.91)	128.78 (31.90)
T_3 : NPK + FYM + Borax	78.60 (22.40)	69.09 (21.20)	73.85 (21.80)	40.54 (7.80)	45.29 (9.23)	42.92 (8.51)	119.14 (30.20)	114.38 (30.43)	116.76 (30.31)
T_4: NPK + FYM + *A brasilense*	76.06 (21.80)	67.19 (20.90)	71.63 (21.35)	33.38 (7.00)	38.25 (7.87)	35.82 (7.43)	109.44 (28.80)	105.44 (28.77)	107.44 (28.78)
T_5 : NPK + FYM + VAM	77.16 (22.89)	69.03 (21.70)	73.10 (22.30)	38.71 (8.20)	41.84 (8.68)	40.28 (8.44)	115.87 (31.09)	110.87 (30.38)	113.37 (30.73)
T_6 : NPK + FYM + $ZnSO_4$ + *A. brasilense*	10.3.25 (24.70)	92.94 (23.80)	98.10 (24.25)	55.56 (8.89)	55.51 (9.30)	55.53 (9.10)	158.81 (33.59)	148.45 (33.10)	153.63 (33.35)
T_7 : NPK + FYM + Borax + *A. brasilense*	82.47 (22.70)	72.30 (21.50)	77.39 (22.10)	46.97 (8.40)	47.95 (8.99)	47.46 (8.69)	129.44 (31.10)	120.25 (30.49)	124.85 (30.79)
T_8: NPK + FYM + $ZnSO_4$+ VAM	97.11 (23.40)	91.30 (23.50)	94.21 (23.45)	61.66 (9.90)	53.56 (9.09)	57.61 (9.50)	158.77 33.30)	144.86 (32.59)	151.82 (32.95)
T_9: NPK + FYM + FYM + Borax + VAM	79.92 (22.90)	71.57 (21.80)	75.75 (22.35)	48.03 (9.20)	46.42 (8.55)	47.23 (8.87)	127.95 (32.10)	117.99 (30.35)	122.97 (31.22)
T_{10}: NPK+ FYM +$ZnSO_4$+ Borax + *A. brasilense*+ VAM	107.68 (25.20)	96.71 (24.10)	102.20 (24.65)	67.49 (10.20)	62.54 (9.90)	65.02 (10.05)	175.17 (35.40)	159.25 (34.00)	167.21 (34.70)
F test	*	*	*	*	*	*	*	*	*
S.Em +	**4.68**	**3.46**	**2.91**	**1.90**	**2.06**	**1.37**	**5.42**	**4.65**	**3.56**
CD at 5 %	**13.92**	**10.28**	**8.33**	**5.64**	**6.13**	**3.91**	**16.11**	**13.83**	**10.18**
CV (%)	**9.57**	**7.86**	**8.85**	**7.03**	**7.58**	**7.13**	**7.14**	**6.54**	**6.84**

NPK @ 50:40:25 kg/ha, FYM @ 7.5 t/ha, $ZnSO_4$ @ 12.50 kg/ha, Borax @ 10 kg/ha. *A - Azospirillum*, Figures in parenthesis indicate actual concentration of Zinc in ppm, **Crop rotation**: Finger millet (2005) - Soybean (2006), Soybean (2005) - Finger millet (2006)

each other. Significantly lower zinc uptake by finger millet straw and total uptake (28.12 and 87.57 g/ha) was recorded in control (T_1 : NPK + FYM) (Table 4.7.18 and Fig. 46).

4.7.5.5 Boron uptake by finger millet grain, straw and total plant uptake (g/ha)

Significant differences was observed in boron uptake by finger millet grain, straw and total plant uptake due to zinc, boron and microbial inoculants application (Table 4.7.19).

Application of NPK + FYM + $ZnSO_4$ + borax + *A.brasilense* + VAM (T_{10}) recorded significantly higher boron uptake by finger millet grain (21.02 g/ha) and straw (53.95 g/ha). However, it was found on par with application of NPK + FYM + borax + *A.brasilense* (T_7 : 20.29 and 53.17 g/ha, respectively) and NPK + FYM + borax + VAM (T_9 : 19.59 and 52.31 g/ha, respectively).

With regard to total uptake of boron by finger millet plant, application of NPK + FYM + $ZnSO_4$ + borax + *A.brasilense* + VAM (T_{10}) recorded significantly higher boron uptake (74.96 g/ha) as compared to rest of the treatments except with application of NPK + FYM + borax + *A.brasilense* (T_7 : 73.46 g/ha) and NPK + FYM + borax + VAM (T_9 : 71.90 g/ha). Application of NPK + FYM (T_1) recorded significantly lower total boron uptake (57.44 g/ha) as compared to all other treatments (Table 4.7.19 and Fig. 46).

4.7.6 CORRELATION AND REGRESSION ANALYSIS FOR GROWTH, YIELD PARAMETERS AND TOTAL UPTAKE OF NUTRIENTS IN FINGER MILLET

The data pertaining to Karl Pearson correlation coefficient values (r) and regression coefficient worked out for grain yield versus growth,

Table 4.7.19: Boron uptake by grain, straw and total boron uptake of finger millet as influenced by zinc, boron and microbial inoculants application in finger millet- soybean based cropping system

Treatment	Boron uptake (g/ha)								
	Grain (g/ha)			Straw (g/ha)			Total uptake (g/ha)		
	2005	2006	Pooled	2005	2006	Pooled	2005	2006	Pooled
T_1: Control (NPK + FYM only)	15.18 (5.29)	14.83 (5.24)	15.01 (5.26)	44.82 (10.74)	40.05 (9.21)	42.44 (9.98)	60.00 (16.03)	54.88 (14.44)	57.44 (15.24)
T_2 : NPK + FYM +$ZnSO_4$	16.77 (4.63)	15.36 (4.60)	16.07 (4.62)	48.23 (8.68)	45.88 (8.63)	47.06 (8.65)	65.00 (13.31)	61.24 (13.23)	63.12 (13.27)
T_3 : NPK + FYM + Borax	18.87 (5.38)	17.43 (5.35)	18.15 (5.36)	51.13 (9.84)	48.17 (9.82)	49.65 (9.83)	70.00 (15.21)	65.60 (15.16)	67.80 (15.19)
T_4: NPK + FYM + *A brasilense*	16.19 (4.64)	14.85 (4.62)	15.52 (4.63)	46.81 (9.82)	47.69 (9.81)	47.25 (9.81)	63.00 (14.46)	62.54 (14.43)	62.77 (14.44)
T_5 : NPK + FYM + VAM	15.87 (4.71)	14.92 (4.69)	15.40 (4.70)	46.13 (9.77)	47.06 (9.76)	46.60 (9.76)	62.00 (14.48)	61.98 (14.45)	61.99 (14.46)
T_6 : NPK + FYM + $ZnSO_4$ + *A. brasilense*	17.17 (4.11)	15.96 (4.09)	16.57 (4.10)	48.83 (7.81)	46.47 (7.79)	47.65 (7.80)	66.00 (11.92)	62.43 (11.87)	64.22 (11.90)
T_7 : NPK + FYM + Borax + *A. brasilense*	21.02 (5.79)	19.55 (5.81)	20.29 (5.80)	53.98 (9.65)	52.36 (9.81)	53.17 (9.73)	75.00 (15.44)	71.91 (15.63)	73.46 (15.53)
T_8: NPK + FYM + $ZnSO_4$+ VAM	17.76 (4.28)	16.53 (4.26)	17.15 (4.27)	49.25 (7.91)	46.47 (7.89)	47.86 (7.90)	67.01 (12.19)	63.00 (12.14)	65.01 (12.16)
T_9: NPK + FYM + FYM + Borax + VAM	19.80 (5.37)	19.38 (5.90)	19.59 (5.64)	53.20 (10.19)	51.42 (9.47)	52.31 (9.83)	73.00 (15.56)	70.80 (15.37)	71.90 (15.47)
T_{10}: NPK+ FYM +$ZnSO_4$+ Borax + *A. brasilense*+ VAM	21.74 (5.09)	20.29 (5.06)	21.02 (5.07)	55.26 (8.35)	52.63 (8.33)	53.95 (8.34)	77.00 (13.44)	72.92 (13.39)	74.96 (13.41)
F test	*	*	*	*	*	*	*	*	*
S.Em +	**0.75**	**0.76**	**0.56**	**1.45**	**1.56**	**1.05**	**1.92**	**1.51**	**1.22**
CD at 5 %	**2.24**	**2.27**	**1.59**	**4.31**	**4.62**	**3.00**	**5.69**	**4.49**	**3.49**
CV (%)	**7.24**	**7.82**	**7.79**	**5.04**	**5.63**	**5.25**	**4.90**	**4.04**	**4.51**

NPK @ 50:40:25 kg/ha, FYM @ 7.5 t/ha, $ZnSO_4$ @ 12.50 kg/ha, Borax @ 10 kg/ha, *A - Azospirillum*, Figures in parenthesis indicate actual concentration of boron in ppm, **Crop rotation**: Finger millet (2005) - Soybean (2006), Soybean (2005) - Finger millet (2006)

yield parameters and total uptake of nutrients as influenced by zinc, boron and microbial inoculants application in finger millet are presented in Table 4.7.20.

The grain yield was significantly correlated with growth parameters like TDM at harvest (r = 0.705), leaf area at harvest (r = 0.707) and number of tillers at harvest (r = 0.674), and yield components like number of productive tillers at harvest (r = 0.749), number of fingers per ear head (r = 0.692), earhead length (r = 0.741), finger length (r = 0.697), grain yield per plant (r = 0.623), test weight (r = 0.581). Similarly, the grain yield was also significantly positively correlated with total uptake of N, P_2O_5, K_2O, Zn and B nutrients (r = 0.831, 0.781, 0.752, 0.770 and 0.428, respectively).

Multiple regression equation was also fitted for finger millet grain yield with growth, yield parameters and total uptake of nutrients (Table 4.7.20). Thus all these parameters showed a predictability of 73 per cent of the pooled finger millet yield.

4.8 Experiment-II(b) : RESPONSE OF FINGER MILLET-SOYBEAN ROTATION TO CONJUNCTIVE USE OF ZINC, BORON AND MICROBIAL INOCULANTS

Crop: Soybean

4.8.1 GROWTH PARAMETERS OF SOYBEAN AS INFLUENCED BY ZINC, BORON AND MICROBIAL INOCULANTS APPLICATION

4.8.1.1 Plant height (cm)

Plant height (Pooled over two years) was significantly higher at 30 DAS, due to application of NPK + FYM + $ZnSO_4$ + borax + *Bradyrhizobium japonicum* + VAM (T_{10} : 18 cm). However, it was found on par with application of NPK + FYM + $ZnSO_4$ + *Bradyrhizobium*

Table 4.7.20: Correlation and regression equation for pooled data of finger millet as influenced by zinc, boron and microbial inoculants application in finger millet- soybean based cropping system

Sl. No.	Parameters (X)	Regression equation Y{Grain yield(kg/ha))}	Correlation coefficient (r)	R^2
1	TDM at harvest (g/plant)	Y= 777.805+87.551X	0.705**	0.497
2	Leaf area (cm^2) at harvest	Y= 599.395+6.356 X	0.707**	0.499
3	No. of tillers at harvest	Y= 1011.784+422.614 X	0.674**	0.455
4	No. of productive tillers at harvest	Y= 534.499+603.215 X	0.749**	0.561
5	No. of fingers per ear head	Y= 53.110+506.704 X	0.692**	0.479
6	Ear head length (cm)	Y= -1162.825+544.470 X	0.741**	0.549
7	Finger length (cm)	Y= -703.537+641.476 X	0.697**	0.485
8	Grain yield per plant (g)	Y=1315.829+210.929 X	0.623**	0.388
9	Test weight (g)	Y= 467.733+885.871 X	0.581**	0.338
10	Threshing (%)	Y= 2067.033+18.861 X	0.229	0.053
11	Total N uptake(kg/ha)	Y= 1440.442+24.845 X	0.831**	0.690
12	Total P_2O_5 uptake (kg/ha)	Y =1585.281+123.685 X	0.781**	0.610
13	Total K_2O uptake (kg/ha)	Y=1520.676+29.384 X	0.752**	0.565
14	Total Zn uptake (g/ha)	Y=1595.540+15.282 X	0.770**	0.593
15	Total B uptake (g/ha)	Y=1343.945+33.186 X	0.428**	0.183
$Y= 1394.005 -19.812X_1\ 0.355\ X_2 + 46.198\ X_3 +38.571\ X_4 + 112.864\ X_5 +135.336\ X_6+14.771\ X_7 – 44.134\ X_8 -65.684\ X_9 -9.215\ X_{10}+ 22.919\ X_{11} – 2.193\ X_{12}+ 2.601X_{13}-1.215\ X_{14} -7.344\ X_{15}$			0.856	0.733

** Correlation is significant at the 0.01 level (2-tailed)

Note: The dependent variables X_1, X_2, X_3….. X_{15} refers to the parameters listed in serial number 1, 2, 3 ….15, respectively

japonicum (T_6 : 16.45 cm) whereas, application of NPK + FYM + $ZnSO_4$ + VAM (T_8 : 15.65 cm) and NPK + FYM + borax + *Bradyrhizobium japonicum* (T_7 : 14.75 cm) were found on par with each other, but recorded significantly higher plant height over other treatments.

At 60 DAS and at harvest, significantly higher plant height was recorded with application of NPK + FYM + $ZnSO_4$ + borax + *Bradyrhizobium japonicum* + VAM (T_{10} : 35.05 and 39.75 cm, respectively) followed by application of NPK + FYM + $ZnSO_4$ + *Bradyrhizobium japonicum* (T_6 : 32.65 and 38.10 cm, respectively), while, application of NPK + FYM (T_1) registered significantly lower plant height at 30 DAS (8.20 cm), 60 DAT (18.20 cm) and at harvest (18.95 cm) as compared to other treatments except with application of NPK + FYM + VAM (T_5 : 9.30 and 20.55 cm at 30 and 60 DAS, respectively) (Table 4.8.1 and Fig. 47).

4.8.1.2 Number of green leaves per plant

Number of green leaves differed significantly among the treatments at all the growth stages (Table 4.8.2).

Significantly higher number of green leaves per plant at 30 (10.25) and 60 DAS (20.95) was noticed with application of NPK + FYM + $ZnSO_4$ + borax + *Bradyrhizobium japonicum* + VAM (T_{10}) as compared to other treatments but it was on par with application of NPK + FYM + $ZnSO_4$ + *Bradyrhizobium japonicum* (T_6 : 9.25 and 19.90). Significantly lower number of green leaves per plant was recorded in NPK + FYM (T_1 : 3.75 and 9/plant, respectively).

At harvest, application of NPK + FYM + $ZnSO_4$ + borax + *Bradyrhizobium japonicum* + VAM (T_{10} : 2.80), NPK + FYM + $ZnSO_4$ + *Bradyrhizobium japonicum* (T_6 : 2.69) and NPK + FYM + $ZnSO_4$ + VAM (T_8 : 2.59) recorded significantly higher number of green leaves as

Table 4.8.1: Plant height of soybean at different growth stages as influenced by zinc, boron and microbial inoculants application in finger millet- soybean based cropping system

Treatment	Plant height (cm)								
	30DAS			60DAS			At harvest		
	2005	2006	Pooled	2005	2006	Pooled	2005	2006	Pooled
T_1 : Control(NPK + FYM only)	9.15	7.25	8.20	19.20	17.20	18.20	20.00	17.90	18.95
T_2 : NPK+ FYM + $ZnSO_4$	14.20	13.70	13.95	28.25	26.75	27.50	31.50	29.90	30.70
T_3 : NPK+ FYM + Borax	12.20	10.60	11.40	25.00	23.30	24.15	27.90	26.10	27.00
T_4 : NPK + FYM + *B.japonicum*	11.30	9.60	10.45	23.80	22.00	22.90	25.50	23.60	24.55
T_5 : NPK + FYM + VAM	10.20	8.40	9.30	21.50	19.60	20.55	24.50	22.50	23.50
T_6 : NPK+ FYM + $ZnSO_4$+ *B.japonicum*	17.00	15.90	16.45	33.25	32.05	32.65	38.75	37.45	38.10
T_7 : NPK+ FYM + Borax + *B. japonicum*	15.40	14.10	14.75	29.80	28.40	29.10	33.10	31.60	32.35
T_8 : NPK + FYM + $ZnSO_4$ + VAM	16.25	15.05	15.65	31.00	29.70	30.35	35.50	34.10	34.80
T_9 : NPK + FYM + Borax + VAM	13.27	11.77	12.52	27.50	25.90	26.70	30.25	28.55	29.40
T_{10} : NPK + FYM + $ZnSO_4$ + Borax + *B. japonicum* + VAM	18.50	17.50	18.00	35.60	34.50	35.05	40.35	39.15	39.75
F test	*	*	*	*	*	*	*	*	*
S.Em ±	**0.89**	**0.99**	**0.66**	**1.81**	**1.80**	**1.27**	**2.35**	**2.09**	**1.58**
CD at 5 %	**2.63**	**2.94**	**1.88**	**5.37**	**5.34**	**3.63**	**6.99**	**6.20**	**4.53**
CV (%)	**11.15**	**13.84**	**12.29**	**11.39**	**11.99**	**11.61**	**13.26**	**12.42**	**12.95**

DAS: Days after sowing, NPK @ 25:60:25 kg/ha and FYM @ 6.25 t/ha, $ZnSO_4$ @ 12.5 kg/ha, Borax @ 10 kg/ha, NS - Non significant, *B*: *Bradyrhizobium* **Crop rotation**: Finger millet (2005)- Soybean (2006), Soybean (2005)- Finger millet (2006)

Table 4.8.2: Number of green leaves per plant of soybean at different growth stages as influenced by zinc, boron and microbial inoculants application in finger millet- soybean based cropping system

Treatment	Number of green leaves per plant								
	30 DAS			60 DAS			At harvest		
	2005	2006	Pooled	2005	2006	Pooled	2005	2006	Pooled
T_1 : Control(NPK + FYM only)	4.00	3.50	3.75	10.00	8.00	9.00	0.80	0.60	0.70
T_2 : NPK+ FYM + $ZnSO_4$	7.70	7.20	7.45	16.50	15.00	15.75	2.30	2.08	2.19
T_3 : NPK+ FYM + Borax	6.50	6.00	6.25	14.10	12.40	13.25	2.20	2.00	2.10
T_4 : NPK + FYM + *B.japonicum*	6.00	5.55	5.78	13.50	11.70	12.60	2.00	1.78	1.89
T_5 : NPK + FYM + VAM	5.50	5.00	5.25	12.50	10.60	11.55	1.90	1.68	1.79
T_6 : NPK+ FYM + $ZnSO_4$+ *B.japonicum*	9.50	9.00	9.25	20.50	19.30	19.90	2.80	2.58	2.69
T_7 : NPK+ FYM + Borax + *B.japonicum*	8.10	7.60	7.85	17.00	15.60	16.30	2.45	2.23	2.34
T_8 : NPK + FYM + $ZnSO_4$ +VAM	8.75	8.25	8.50	18.50	17.20	17.85	2.70	2.48	2.59
T_9 : NPK + FYM + Borax + VAM	7.30	6.80	7.05	15.75	14.15	14.95	2.25	2.03	2.14
T_{10} : NPK + FYM + $ZnSO_4$ + Borax + *B.japonicum* + VAM	10.50	10.00	10.25	21.50	20.40	20.95	2.90	2.70	2.80
F test	*	*	*	*	*	*	*	*	*
S.Em ±	**0.68**	**0.59**	**0.45**	**1.31**	**1.29**	**0.92**	**0.13**	**0.13**	**0.09**
CD at 5 %	**2.01**	**1.76**	**1.29**	**3.90**	**3.83**	**2.64**	**0.38**	**0.40**	**0.26**
CV (%)	**15.87**	**14.91**	**15.41**	**14.21**	**15.46**	**14.87**	**10.05**	**11.55**	**10.58**

DAS-Days after sowing, NPK @ 25:60:25 kg/ha and FYM @ 6.25 t/ha, $ZnSO_4$ @ 12.5 kg/ha, Borax @10 kg/ha, *B*: *Bradyrhizobium*
Crop rotation: Finger millet (2005)- Soybean (2006), Soybean (2005)- Finger millet (2006)

compared to other treatments. However, all these treatments were found on par with each other and NPK + FYM + $ZnSO_4$ + VAM (T_8) was found at par with application of NPK + FYM + borax + *Bradyrhizobium japonicum* (T_7 : 2.34). Significantly lower number of green leaves was recorded in control (T_1 : 0.70).

4.8.1.3 Leaf area (cm^2/plant)

At 30 DAS, significantly higher leaf area was recorded with application of NPK + FYM + $ZnSO_4$ + borax + *Bradyrhizobium japonicum* + VAM (T_{10} : 480.30 cm^2/plant) over other treatments, but it was on par with application of NPK + FYM + $ZnSO_4$ + *Bradyrhizobium japonicum* (T_6 :459.20 cm^2/plant) and NPK + FYM + $ZnSO_4$ + VAM (T_8 : 438.75 cm^2/plant) (Table 4.8.3).

At 60 DAS and at harvest, significantly higher leaf area was recorded with application of NPK + FYM + $ZnSO_4$ + borax + *Bradyrhizobium japonicum* + VAM (T_{10} :1133 and 107.9 cm^2/plant, respectively) as compared to other treatments. However, it was comparable with application of NPK + FYM + $ZnSO_4$ + *Bradyrhizobium japonicum* (T_6 : 102.90 cm^2/plant) at harvest.

4.8.1.4 Leaf area index (LAI)

The leaf area index of soybean differed significantly due to zinc, boron and microbial inoculants application (Table 4.8.4).

Application of NPK + FYM + $ZnSO_4$ + borax + *Bradyrhizobium japonicum* + VAM (T_{10}) recorded significantly higher LAI at 30 DAS (1.60) and 60 DAS (3.78) as compared to other treatments, while it was found on par with application of NPK + FYM + $ZnSO_4$ + *Bradyrhizobium japonicum* (T_6 :1.53) and NPK + FYM + $ZnSO_4$ + VAM (T_8 :1.46) at 30 DAS.

Table 4.8.3: Leaf area of soybean at different growth stages as influenced by zinc, boron and microbial inoculants application in finger millet- soybean based cropping system

Treatment	Leaf area (cm^2/plant)								
	30 DAS			60 DAS			At harvest		
	2005	2006	Pooled	2005	2006	Pooled	2005	2006	Pooled
T_1 : Control(NPK + FYM only)	270.00	240.00	255.00	465.00	419.00	442.00	60.70	45.00	52.85
T_2 : NPK+ FYM + $ZnSO_4$	375.00	350.00	362.50	880.50	841.50	861.00	92.50	77.00	84.75
T_3 : NPK+ FYM + Borax	365.00	338.00	351.50	700.00	659.00	679.50	87.50	72.00	79.75
T_4 : NPK + FYM + *B.japonicum*	355.00	327.00	341.00	680.00	638.00	659.00	80.20	65.00	72.60
T_5 : NPK + FYM + VAM	343.00	314.00	328.50	650.00	607.00	628.50	77.30	60.00	68.65
T_6 : NPK+ FYM + $ZnSO_4$+ *B.japonicum*	470.20	448.20	459.20	980.50	944.50	962.50	110.50	95.30	102.90
T_7 : NPK+ FYM + Borax + *B.japonicum*	400.30	376.30	388.30	910.00	872.00	891.00	100.30	85.20	92.75
T_8 : NPK + FYM + $ZnSO_4$ + VAM	450.25	427.25	438.75	950.00	913.00	931.50	105.80	90.80	98.30
T_9 : NPK + FYM + Borax + VAM	350.50	324.50	337.50	740.50	700.50	720.50	90.30	75.40	82.85
T_{10} : NPK + FYM + $ZnSO_4$ + Borax + *B.japonicum* + VAM	490.80	469.80	480.30	1150.50	1115.50	1133.00	115.30	100.50	107.90
F test	*	*	*	*	*	*	*	*	*
S.Em ±	**26.49**	**28.27**	**19.42**	**66.16**	**65.75**	**45.73**	**4.39**	**4.12**	**3.03**
CD at 5 %	**78.71**	**83.99**	**55.58**	**196.57**	**195.37**	**130.90**	**13.04**	**12.24**	**8.67**
CV (%)	**11.86**	**13.54**	**12.71**	**14.13**	**14.77**	**14.16**	**8.26**	**9.31**	**8.80**

DAS-Days after sowing, NPK @ 25:60:25 kg/ha and FYM @ 6.25 t/ha, $ZnSO_4$ @ 12.5 kg/ha, Borax @ 10 kg/ha, *B*: *Bradyrhizobium*
Crop rotation: Finger millet (2005)- Soybean (2006), Soybean (2005)- Finger millet (2006)

Table 4.8.4: Leaf area index of soybean at different growth stages as influenced by zinc, boron and microbial inoculants application in finger millet- soybean based cropping system

Treatment	Leaf area index								
	30 DAS			60 DAS			At harvest		
	2005	2006	Pooled	2005	2006	Pooled	2005	2006	Pooled
T_1 : Control(NPK + FYM only)	0.90	0.80	0.85	1.55	1.40	1.47	0.20	0.15	0.18
T_2 : NPK+ FYM + $ZnSO_4$	1.25	1.17	1.21	2.94	2.81	2.87	0.31	0.26	0.28
T_3 : NPK+ FYM + Borax	1.22	1.13	1.17	2.33	2.20	2.27	0.29	0.24	0.27
T_4 : NPK + FYM + *B.japonicum*	1.18	1.09	1.14	2.27	2.13	2.20	0.27	0.22	0.24
T_5 : NPK + FYM + VAM	1.14	1.05	1.10	2.17	2.02	2.10	0.26	0.20	0.23
T_6 : NPK+ FYM + $ZnSO_4$+ *B.japonicum*	1.57	1.49	1.53	3.27	3.15	3.21	0.37	0.32	0.34
T_7 : NPK+ FYM + Borax + *B.japonicum*	1.33	1.25	1.29	3.03	2.91	2.97	0.33	0.28	0.31
T_8 : NPK + FYM + $ZnSO_4$ + VAM	1.50	1.42	1.46	3.17	3.04	3.11	0.35	0.30	0.33
T_9 : NPK + FYM + Borax + VAM	1.17	1.08	1.13	2.47	2.34	2.40	0.30	0.25	0.28
T_{10} : NPK + FYM + $ZnSO_4$ + Borax + *B.japonicum* + VAM	1.64	1.57	1.60	3.84	3.72	3.78	0.38	0.34	0.36
F test	*	*	*	*	*	*	*	*	*
S.Em +	**0.09**	**0.09**	**0.06**	**0.22**	**0.22**	**0.15**	**0.01**	**0.01**	**0.01**
CD at 5 %	**0.26**	**0.28**	**0.19**	**0.66**	**0.65**	**0.44**	**0.04**	**0.04**	**0.03**
CV (%)	**11.86**	**13.54**	**12.71**	**14.13**	**14.77**	**14.16**	**8.26**	**9.31**	**8.80**

DAS-Days after sowing, NPK @ 25:60:25 kg/ha and FYM @ 6.25 t/ha, $ZnSO_4$ @ 12.5 kg/ha, Borax @10 kg/ha, *B*: *Bradyrhizobium*
Crop rotation: Finger millet (2005)- Soybean (2006), Soybean (2005)- Finger millet (2006)

At harvest, significantly higher LAI of soybean was recorded with application of NPK + FYM + $ZnSO_4$ + borax + *Bradyrhizobium japonicum* + VAM (T_{10} :0.36) as compared to other treatments. However, it was comparable with application of NPK + FYM + $ZnSO_4$ + *Bradyrhizobium japonicum* (T_6 : 0.34) and NPK + FYM + $ZnSO_4$ + VAM (T_8 :0.33). Significantly lower LAI at all the growth stages was recorded in control (T_1 :0.85, 1.47 and 0.18, respectively) over the rest of the treatments (Table 4.8.4 and Fig. 47).

4.8.1.5 Leaf area duration (LAD) and number of branches

4.8.1.5.1 Leaf area duration (days)

In general LAD decreased with advancement in age of crop during different crop growth stages till harvest (Table 4.8.5).

The longer LAD was noticed with application of NPK + FYM + $ZnSO_4$ + borax + *Bradyrhizobium japonicum* + VAM (T_{10} : 80.67 and 62.05 days, at (30-60) DAS and 60 DAS – harvest, respectively) as compared to all other treatments.

Application of NPK + FYM + $ZnSO_4$ + borax + *Bradyrhizobium japonicum* (T_6 : 71.09 and 53.27 days, respectively), NPK + FYM + $ZnSO_4$ + VAM (T_8 : 68.51 and 51.49 days, respectively) and NPK + FYM + borax + *Rhizobium* (T_7 : 63.97 and 49.19 days, respectively) were found to be the next best treatments with respect to leaf area duration and were found on par with each other. Significantly shorter LAD was observed with application of NPK + FYM (T_1) at (30-60) DAS (34.85 days) and 60 DAS – harvest (24.74 days) (Table 4.8.5 and Fig. 49).

4.8.1.5.2 Number of branches

At 60 DAS, application of NPK + FYM + $ZnSO_4$ + borax + *Bradyrhizobium japonicum* + VAM (T_{10}) recorded significantly higher

Table 4.8.5: Leaf area duration and number of branches per plant of soybean at different growth stages as influenced by zinc, boron and microbial inoculants application in finger millet- soybean based cropping system

Treatment	Leaf area duration (days)						Number of branches					
	30- 60 DAS			60 DAS - harvest			60 DAS			At harvest		
	2005	2006	Pooled	2005	2006	Pooled	2005	2006	Pooled	2005	2006	Pooled
T_1 : Control(NPK + FYM only)	36.75	32.95	34.85	26.29	23.20	24.74	2.00	1.68	1.84	2.95	2.60	2.78
T_2 : NPK+ FYM + $ZnSO_4$	62.78	59.58	61.18	48.65	45.93	47.29	3.50	3.20	3.35	4.80	4.48	4.64
T_3 : NPK+ FYM + Borax	53.25	49.85	51.55	39.38	36.55	37.96	3.35	3.05	3.20	4.30	4.28	4.29
T_4 : NPK + FYM + *B.japonicum*	51.75	48.25	50.00	38.01	35.15	36.58	3.00	2.69	2.85	4.10	3.78	3.94
T_5 : NPK + FYM + VAM	49.65	46.05	47.85	36.37	33.35	34.86	2.50	2.21	2.36	3.80	3.50	3.65
T_6 : NPK+ FYM + $ZnSO_4$+ *B.japonicum*	72.54	69.64	71.09	54.55	51.99	53.27	4.50	4.22	4.36	6.00	5.69	5.85
T_7 : NPK+ FYM + Borax + *B.japonicum*	65.52	62.42	63.97	50.52	47.86	49.19	3.70	3.40	3.55	5.20	4.87	5.04
T_8 : NPK + FYM + $ZnSO_4$ + VAM	70.01	67.01	68.51	52.79	50.19	51.49	4.00	3.72	3.86	5.50	5.17	5.34
T_9 : NPK + FYM + Borax + VAM	54.55	51.25	52.90	41.54	38.80	40.17	3.20	2.93	3.07	4.70	4.38	4.54
T_{10} : NPK + FYM + $ZnSO_4$ + Borax + *B.japonicum* + VAM	82.07	79.27	80.67	63.29	60.80	62.05	5.00	4.73	4.87	6.30	6.00	6.15
F test	*	*	*	*	*	*	*	*	*	*	*	*
S.Em ±	**3.71**	**4.04**	**2.68**	**3.40**	**4.01**	**2.59**	**0.28**	**0.16**	**0.17**	**0.31**	**0.20**	**0.18**
CD at 5 %	**11.02**	**12.02**	**7.67**	**10.10**	**11.90**	**7.40**	**0.83**	**0.47**	**0.49**	**0.91**	**0.60**	**0.51**
CV (%)	**10.73**	**12.37**	**11.27**	**13.05**	**16.37**	**14.48**	**13.93**	**8.55**	**12.67**	**11.13**	**7.87**	**9.48**

DAS-Days after sowing, NPK @ 25:60:25 kg/ha and FYM @ 6.25 t/ha, $ZnSO_4$@ 12.5 kg/ha, Borax @10 kg/ha, *B*: *Bradyrhizobium*
Crop rotation: Finger millet (2005)- Soybean (2006), Soybean (2005)- Finger millet (2006)

number of branches (4.87) as compared to rest of the treatments, whereas application of NPK + FYM + $ZnSO_4$ + *Bradyrhizobium japonicum* (T_6 : 4.36) was found to be the next best treatment with respect to number of branches at 60 DAS and was significantly superior over other treatments (Table 4.8.5 and Fig. 49).

Significantly higher number of branches were recorded with application of NPK + FYM + $ZnSO_4$ + borax + *Bradyrhizobium japonicum* + VAM (T_{10}) at harvest (6.15) as compared to other treatments. However, it was found on par with application of NPK + FYM + $ZnSO_4$ + *Bradyrhizobium japonicum* (T_6 : 5.85) at harvest. Significantly lower number of branches were recorded in NPK + FYM (T_1) at 60 DAS (1.84) and at harvest (2.78).

4.8.1.6 Dry matter accumulation and its distribution (g/plant)

4.8.1.6.1 Dry matter accumulation (DMA) in leaf, stem and total dry matter accumulation (TDMA) at 30 DAS (g/plant)

Application of NPK + FYM + $ZnSO_4$ + borax + *Bradyrhizobium japonicum* + VAM (T_{10}) recorded significantly higher leaf dry matter (2.52 g/plant) as compared to rest of the treatments. Application of NPK + FYM + $ZnSO_4$ + *Bradyrhizobium japonicum* (T_6 :2.20 g/plant) and NPK + FYM + $ZnSO_4$ + VAM (T_8 : 1.99) were found on par with each other (Table 4.8.6).

Significantly higher stem dry matter accumulation was recorded with application of NPK + FYM + $ZnSO_4$ + borax + *Bradyrhizobium japonicum* + VAM (T_{10} : 2.10 g/plant) as compared to other treatments but was found on par with application of NPK + FYM + $ZnSO_4$ + *Bradyrhizobium japonicum* (T_6 : 1.90 g/plant).

Table 4.8.6: Dry matter accumulation in leaf, stem and total dry matter accumulation (TDMA) of soybean at 30 DAS as influenced by zinc, boron and microbial inoculants application in finger millet- soybean based cropping system

Treatment	Leaf dry matter (g/plant)			Stem dry matter (g/plant)			TDMA (g/plant)		
	2005	2006	Pooled	2005	2006	Pooled	2005	2006	Pooled
T_1 : Control(NPK + FYM only)	0.95	0.75	0.85	0.60	0.40	0.50	1.55	1.15	1.35
T_2 : NPK+ FYM + $ZnSO_4$	1.85	1.56	1.71	1.43	1.20	1.32	3.28	2.76	3.02
T_3 : NPK+ FYM + Borax	1.57	1.20	1.39	1.30	1.08	1.19	2.87	2.28	2.58
T_4 : NPK + FYM + *B.japonicum*	1.40	1.15	1.28	1.15	0.93	1.04	2.55	2.08	2.32
T_5 : NPK + FYM + VAM	1.35	1.00	1.18	1.10	0.80	0.95	2.45	1.80	2.13
T_6 : NPK+ FYM + $ZnSO_4$+ *B.japonicum*	2.40	2.00	2.20	2.00	1.79	1.90	4.40	3.79	4.10
T_7 : NPK+ FYM + Borax + *B.japonicum*	1.98	1.65	1.82	1.50	1.29	1.40	3.48	2.94	3.21
T_8 : NPK + FYM + $ZnSO_4$ + VAM	2.20	1.78	1.99	1.80	1.59	1.70	4.00	3.37	3.69
T_9 : NPK + FYM + Borax + VAM	1.75	1.35	1.55	1.32	1.10	1.21	3.07	2.45	2.76
T_{10} : NPK + FYM + $ZnSO_4$ + Borax + *B.japonicum* + VAM	2.63	2.41	2.52	2.20	2.00	2.10	4.83	4.41	4.62
F test	*	*	*	*	*	*	*	*	*
S.Em ±	**0.18**	**0.13**	**0.11**	**0.11**	**0.07**	**0.07**	**0.30**	**0.25**	**0.19**
CD at 5 %	**0.53**	**0.40**	**0.31**	**0.32**	**0.21**	**0.19**	**0.89**	**0.73**	**0.55**
CV (%)	**16.95**	**15.56**	**16.10**	**12.81**	**10.14**	**12.43**	**16.05**	**15.85**	**15.75**

DAS: Days after sowing, NPK @ 25:60:25 kg/ha and FYM @ 6.25 t/ha, $ZnSO_4$ @ 12.5 kg/ha, Borax @ 10 kg/ha, *B*: *Bradyrhizobium*
Crop rotation: Finger millet (2005)- Soybean (2006), Soybean (2005)- Finger millet (2006)

The TDMA was significantly higher with application of NPK + FYM + $ZnSO_4$ + borax + *Bradyrhizobium japonicum* + VAM (T_{10} : 4.62 g/ha) as compared to rest of the treatments. However, it was found on par with application of NPK + FYM + $ZnSO_4$ + *Bradyrhizobium japonicum* (T_6 : 4.10 g/ha). Significantly lower leaf, stem and TDMA (0.85, 0.50 and 1.35 g/plant, respectively) was recorded in NPK + FYM (T_1), while the rest of the treatments were found intermediate.

4.8.1.6.2 Dry matter accumulation in leaf, stem, pods and TDMA (g/plant) at 60 DAS

Application of NPK + FYM + $ZnSO_4$ + borax + *Bradyrhizobium japonicum* + VAM (T_{10}) recorded significantly higher leaf dry matter (6.52 g/plant) as compared to rest of the treatments, but was found on par with application of NPK + FYM + $ZnSO_4$ + *Bradyrhizobium japonicum* (T_6 : 6.22 g/plant) (Table 4.8.7).

Significantly higher stem, pod and TDMA (4.85, 5.35 and 16.71 g/plant, respectively) was recorded with application of NPK + FYM + $ZnSO_4$ + borax + *Bradyrhizobium japonicum* + VAM (T_{10}) followed by application of NPK + FYM + $ZnSO_4$ + *Bradyrhizobium japonicum* (T_6 : 4.64, 5.24 and 16.10 g/plant, respetively) and NPK + FYM + $ZnSO_4$ + VAM (T_8 : 4.45, 5.09 and 15.24 g/plant, respectively).

Application of NPK + FYM (T_1) recorded significantly lower DMA in leaf, stem, pods and TDMA (2.53, 2.00, 2.20 and 6.73 g/plant, respectively) as compared to rest of the treatments. However, it was found on par with application of NPK + FYM + VAM (T_5) with respect to leaf dry matter (3.09 g/plant) accumulation.

Table 4.8.7: Dry matter accumulation in leaf, stem, pod and total dry matter accumulation (TDMA) of soybean at 60 DAS as influenced by zinc, boron and microbial inoculants application in finger millet- soybean based cropping system

Treatment	Leaf dry matter (g/plant)			Stem dry matter (g/plant)			Pod dry matter (g/plant)			TDMA (g/plant)		
	2005	2006	Pooled	2005	2006	Pooled	2005	2006	Pooled	2005	2006	Pooled
T_1 : Control(NPK + FYM only)	2.65	2.40	2.53	2.15	1.85	2.00	2.30	2.10	2.20	7.10	6.35	6.73
T_2 : NPK+ FYM + $ZnSO_4$	5.20	4.98	5.09	4.10	3.80	3.95	4.15	4.00	4.08	13.45	12.78	13.12
T_3 : NPK+ FYM + Borax	3.97	3.77	3.87	3.60	3.30	3.45	3.80	3.63	3.72	11.37	10.70	11.04
T_4 : NPK + FYM + *B.japonicum*	3.50	3.28	3.39	3.50	3.20	3.35	3.55	3.37	3.46	10.55	9.85	10.20
T_5 : NPK + FYM + VAM	3.20	2.98	3.09	3.45	3.15	3.30	3.50	3.31	3.41	10.15	9.44	9.80
T_6 : NPK+ FYM + $ZnSO_4$+ *B.japonicum*	6.30	6.13	6.22	4.80	4.48	4.64	5.30	5.18	5.24	16.40	15.79	16.10
T_7 : NPK+ FYM + Borax + *B.japonicum*	5.30	5.10	5.20	4.25	3.95	4.10	4.35	4.21	4.28	13.90	13.26	13.58
T_8 : NPK + FYM + $ZnSO_4$+VAM	5.80	5.61	5.71	4.60	4.30	4.45	5.15	5.02	5.09	15.55	14.93	15.24
T_9 : NPK + FYM + Borax + VAM	4.05	3.88	3.97	4.05	3.75	3.90	4.20	3.94	4.07	12.30	11.57	11.94
T_{10} : NPK + FYM + $ZnSO_4$ + Borax + *B.japonicum* + VAM	6.60	6.43	6.52	5.00	4.70	4.85	5.40	5.29	5.35	17.00	16.42	16.71
F test	*	*	*	*	*	*	*	*	*	*	*	*
S.Em ±	**0.40**	**0.31**	**0.25**	**0.23**	**0.22**	**0.18**	**0.31**	**0.28**	**0.21**	**1.02**	**1.04**	**0.72**
CD at 5 %	**1.17**	**0.91**	**0.72**	**0.69**	**0.66**	**0.50**	**0.91**	**0.84**	**0.60**	**3.02**	**3.09**	**2.05**
CV (%)	**14.70**	**11.93**	**13.58**	**10.16**	**10.52**	**11.33**	**12.79**	**12.21**	**12.55**	**13.77**	**14.88**	**14.12**

DAS: Days after sowing, NPK @ 25:60:25 kg/ha and FYM @ 6.25 t/ha, $ZnSO_4$ @ 12.5 kg/ha, Borax @10 kg/ha, *B*: *Bradyrhizobium*

Crop rotation: Finger millet (2005)- Soybean (2006), Soybean (2005)- Finger millet (2006)

4.8.1.6.3 Dry matter accumulation in leaf, stem, pods and TDMA (g/plant) at harvest

Significantly higher dry matter accumulation in leaves and stem was registered with application of NPK + FYM + $ZnSO_4$ + borax + *Bradyrhizobium japonicum* + VAM (T_{10} : 2.20 and 6.56 g/plant, respectively) as compared to rest of the treatments. However, it was found at par with application of NPK + FYM + $ZnSO_4$ + *Bradyrhizobium japonicum* (T_6 : 6.19 g/plant) and NPK + FYM + $ZnSO_4$ VAM (T_8 : 5.89 g/plant) with respect to DMA in stem (Table 4.8.8 and Fig. 48).

Application of NPK + FYM + $ZnSO_4$ + borax + *Bradyrhizobium japonicum* + VAM (T_{10}) recorded significantly higher DMA in pods and TDMA (12.37 and 21.12 g/plant, respectively) as compared to rest of the treatments. However, it was comparable with application of NPK + FYM + $ZnSO_4$ + *Bradyrhizobium japonicum* (T_6 :11.61 and 19.79 g/plant, respectively) and NPK + FYM + $ZnSO_4$ + VAM (T_8 : 11.36 and 19.06 g/plant, respectively).

Significantly lower DMA in leaf, stem, pods and TDMA was noticed in NPK + FYM (T_1 : 0.97, 3.35, 5.55 and 9.87 g/plant, respectively) as compared to other treatments, but was on par with application of NPK + FYM + VAM (T_5 : 1.18, 6.36 and 11.64 g/plant in leaf, pods and TDMA, respectively).

4.8.1.7 Nodule number per plant and nodule dry weight (g/plant)

4.8.1.7.1 Nodule number per plant

At 45 DAS, application of NPK + FYM + $ZnSO_4$ + borax + *Bradyrhizobium japonicum* + VAM (T_{10}) recorded significantly higher number of nodules per plant (43.95) followed by NPK + FYM + $ZnSO_4$ + *Bradyrhizobium japonicum* (T_6 : 39.55) which were found on par with each other (Table 4.8.9).

Table 4.8.8: Dry matter accumulation in leaf, stem, pod and total dry matter accumulation (TDMA) of soybean at harvest as influenced by zinc, boron and microbial inoculants application in finger millet- soybean based cropping system

Treatment	Leaf dry matter (g/plant)			Stem dry matter (g/plant)			Pod dry matter (g/plant)			Tdma (g/plant)		
	2005	2006	Pooled	2005	2006	Pooled	2005	2006	Pooled	2005	2006	Pooled
T_1 : Control(NPK + FYM only)	1.12	0.82	0.97	3.50	3.20	3.35	5.70	5.40	5.55	10.32	9.42	9.87
T_2 : NPK+ FYM + $ZnSO_4$	1.70	1.45	1.58	5.00	4.75	4.88	9.20	8.91	9.06	15.90	15.11	15.51
T_3 : NPK+ FYM + Borax	1.55	1.28	1.42	4.75	4.48	4.62	8.25	7.96	8.11	14.55	13.72	14.14
T_4 : NPK + FYM + *B.japonicum*	1.45	1.17	1.31	4.50	4.22	4.36	7.35	7.06	7.21	13.30	12.45	12.88
T_5 : NPK + FYM + VAM	1.32	1.03	1.18	4.25	3.96	4.11	6.50	6.21	6.36	12.07	11.20	11.64
T_6 : NPK+ FYM + $ZnSO_4$+ *B.japonicum*	2.10	1.88	1.99	6.30	6.08	6.19	11.75	11.47	11.61	20.15	19.43	19.79
T_7 : NPK+ FYM + Borax + *B.japonicum*	1.85	1.61	1.73	5.50	5.26	5.38	10.20	9.92	10.06	17.55	16.79	17.17
T_8 : NPK + FYM + $ZnSO_4$ + VAM	1.93	1.70	1.82	6.00	5.77	5.89	11.50	11.22	11.36	19.43	18.69	19.06
T_9 : NPK + FYM + Borax + VAM	1.60	1.34	1.47	4.90	4.47	4.69	8.70	8.42	8.56	15.20	14.23	14.72
T_{10} : NPK + FYM + $ZnSO_4$ + Borax + *B.japonicum* + VAM	2.30	2.09	2.20	6.83	6.29	6.56	12.50	12.23	12.37	21.63	20.61	21.12
F test	*	*	*	*	*	*	*	*	*	*	*	*
S.Em ±	**0.13**	**0.13**	**0.10**	**0.34**	**0.32**	**0.26**	**0.64**	**0.69**	**0.50**	**1.28**	**1.07**	**0.84**
CD at 5 %	**0.39**	**0.40**	**0.27**	**1.02**	**0.96**	**0.75**	**1.90**	**2.05**	**1.42**	**3.79**	**3.18**	**2.41**
CV (%)	**13.61**	**16.13**	**14.88**	**11.55**	**11.55**	**12.75**	**12.09**	**13.45**	**13.48**	**13.81**	**12.24**	**13.25**

NPK @ 25:60:25 kg/ha and FYM @ 6.25 t/ha, $ZnSO_4$ @ 12.5 kg/ha, Borax @10 kg/ha, *B*: *Bradyrhizobium*

Crop rotation: Finger millet (2005)- Soybean (2006), Soybean (2005)- Finger millet (2006)

Table 4.8.9: Nodule number in soybean at 45, 60 and 75 DAS as influenced by zinc, boron and microbial inoculants application in finger millet- soybean based cropping system

Treatment	Nodule number								
	45 DAS			60 DAS			75 DAS		
	2005	2006	Pooled	2005	2006	Pooled	2005	2006	Pooled
T_1 : Control(NPK + FYM only)	18.00	16.00	17.00	35.20	31.20	33.20	24.30	22.00	23.15
T_2 : NPK+ FYM + $ZnSO_4$	30.50	29.00	29.75	53.00	49.50	51.25	43.00	40.75	41.88
T_3 : NPK+ FYM + Borax	28.50	26.80	27.65	48.50	44.80	46.65	39.00	36.75	37.88
T_4 : NPK + FYM + *B.japonicum*	26.50	24.70	25.60	44.20	40.40	42.30	37.00	34.72	35.86
T_5 : NPK + FYM + VAM	24.90	23.00	23.95	40.30	36.40	38.35	30.00	29.70	29.85
T_6 : NPK+ FYM + $ZnSO_4$+ *B.japonicum*	40.15	38.95	39.55	64.50	61.30	62.90	55.00	52.75	53.88
T_7 : NPK+ FYM + Borax + *B.japonicum*	34.25	32.85	33.55	55.00	51.60	53.30	45.00	42.73	43.87
T_8 : NPK + FYM + $ZnSO_4$ + VAM	38.75	37.25	38.00	60.00	56.70	58.35	50.00	47.73	48.87
T_9 : NPK + FYM + Borax + VAM	29.80	28.20	29.00	50.25	46.65	48.45	41.00	38.74	39.87
T_{10} : NPK + FYM + $ZnSO_4$ + Borax + *B. japonicum* + VAM	44.50	43.40	43.95	68.50	65.40	66.95	59.50	57.25	58.38
F test	*	*	*	*	*	*	*	*	*
S.Em ±	**2.49**	**2.77**	**1.85**	**3.20**	**3.05**	**2.17**	**3.25**	**3.19**	**2.31**
CD at 5 %	**7.40**	**8.22**	**5.29**	**9.50**	**9.06**	**6.22**	**9.65**	**9.48**	**6.60**
CV (%)	**13.66**	**15.96**	**14.70**	**10.66**	**10.91**	**10.62**	**13.28**	**13.71**	**13.67**

DAS-Days after sowing, NPK @ 25:60:25 kg/ha and FYM @ 6.25 t/ha, $ZnSO_4$ @ 12.5 kg/ha, Borax @ 10 kg/ha, *B*: *Bradyrhizobium*
Crop rotation: Finger millet (2005)- Soybean (2006), Soybean (2005)- Finger millet (2006)

Application of NPK + FYM + $ZnSO_4$ + borax + *Bradyrhizobium japonicum* + VAM (T_{10}) and NPK + FYM + $ZnSO_4$ + *Bradyrhizobium japonicum* (T_6) recorded significantly higher number of nodules at 60 (66.95 and 62.90, respectively) and 75 DAS (58.38 and 53.88, respectively) as compared to NPK + FYM (T_1). However, they were found on par with each other. Significantly lower number of nodules were recorded with application of NPK + FYM (T_1 : 33.20 and 23.15, respectively).

4.8.1.7.2 Nodule dry weight (g/plant)

Micronutrients and microbial inoculants application significantly influenced the nodule dry weight at 45, 60 and 75 DAS (Table 4.8.10).

Significant increase in nodule dry weight was observed with application of NPK + FYM + $ZnSO_4$ + borax + *Bradyrhizobium japonicum* + VAM (T_{10} : 1.02 g/plant) which was on par with application of NPK + FYM + $ZnSO_4$ + *Bradyrhizobium japonicum* (T_6 : 0.94 g/plant).

At 60 and 75 DAS, application of NPK + FYM + $ZnSO_4$ + borax + *Bradyrhizobium japonicum* + VAM (T_{10}) recorded significantly maximum nodule dry weight (1.39 and 1.20 g/plant, respectively) as compared to rest of the treatments and was on par with application of NPK + FYM + $ZnSO_4$ + *Bradyrhizobium japonicum* (T_6 : 1.27 and 1.23 g/plant, respectively). However, significantly lower nodule dry weight was recorded with application of NPK + FYM (T_1 : 0.32, 0.52 and 0.41 g/plant, respectively) as compared to rest of the treatments except with application of NPK + FYM + VAM (T_5 : 0.34 and 0.59 g/plant at 45 and 60 DAS, respectively).

Table 4.8.10: Nodule dry weight (g/plant) in soybean at 45, 60 and 75 DAS as influenced by zinc, boron and microbial inoculants application in finger millet- soybean based cropping system

Treatment	Nodule dry weight (g/plant)								
	45 DAS			60 DAS			75 DAS		
	2005	2006	Pooled	2005	2006	Pooled	2005	2006	Pooled
T_1 : Control(NPK + FYM only)	0.36	0.28	0.32	0.58	0.45	0.52	0.54	0.28	0.41
T_2 : NPK+ FYM + $ZnSO_4$	0.63	0.56	0.60	0.98	0.90	0.94	0.92	0.65	0.79
T_3 : NPK+ FYM + Borax	0.53	0.47	0.50	0.86	0.77	0.82	0.87	0.62	0.75
T_4 : NPK + FYM + *B. japonicum*	0.43	0.36	0.40	0.78	0.70	0.74	0.80	0.55	0.68
T_5 : NPK + FYM + VAM	0.38	0.30	0.34	0.63	0.54	0.59	0.75	0.50	0.63
T_6 : NPK+ FYM + $ZnSO_4$+ *B. japonicum*	0.98	0.90	0.94	1.33	1.20	1.27	1.25	1.20	1.23
T_7 : NPK+ FYM + Borax + *B. japonicum*	0.66	0.59	0.63	1.03	0.94	0.99	0.95	0.72	0.84
T_8 : NPK + FYM + $ZnSO_4$ + VAM	0.91	0.85	0.88	1.13	1.05	1.09	1.20	1.00	1.10
T_9 : NPK + FYM + Borax + VAM	0.56	0.50	0.53	0.93	0.85	0.89	0.88	0.67	0.78
T_{10} : NPK + FYM + $ZnSO_4$ + Borax + *B. japonicum* + VAM	1.03	1.00	1.02	1.43	1.35	1.39	1.30	1.10	1.20
F test	*	*	*	*	*	*	*	*	*
S.Em ±	**0.03**	**0.05**	**0.03**	**0.08**	**0.06**	**0.05**	**0.06**	**0.08**	**0.05**
CD at 5 %	**0.10**	**0.14**	**0.08**	**0.23**	**0.17**	**0.15**	**0.17**	**0.25**	**0.14**
CV (%)	**8.57**	**14.17**	**11.44**	**14.03**	**11.02**	**14.18**	**10.68**	**19.64**	**14.67**

DAS-Days after sowing, NPK @ 25:60:25 kg/ha and FYM @ 6.25 t/ha, $ZnSO_4$ @ 12.5 kg/ha, Borax @ 10 kg/ha, *B*: *Bradyrhizobium*
Crop rotation: Finger millet (2005)- Soybean (2006), Soybean (2005)- Finger millet (2006)

4.8.2 YIELD PARAMETERS OF SOYBEAN AS INFLUENCED BY ZINC, BORON AND MICROBIAL INOCULANTS APPLICATION

The data on yield parameters of soybean viz., number of pods per plant, number of seeds per pod, pod length, pod yield per plant, seed yield per plant and test weight are presented in Table 4.8.11 to 4.8.12.

4.8.2.1 Number of pods per plant

Micronutrients (zinc and boron) and microbial inoculants application caused significant variations in number of pods per plant (Table 4.8.11 and Fig. 50).

Application of NPK + FYM + $ZnSO_4$ + borax + *Bradyrhizobium japonicum* + VAM (T_{10}) recorded significantly higher number of pods per plant (25.90) as compared to rest of the treatments, but was found at par with application of NPK + FYM + $ZnSO_4$ + *Bradyrhizobium japonicum* (T_6 : 23.65). However, significantly lower number of pods per plant was recorded in control (T_1: NPK + FYM; 11.33) as compared to all treatments except with application of NPK + FYM + VAM (T_5 14.13). Application of NPK + FYM + $ZnSO_4$ + borax + *Bradyrhizobium japonicum* + VAM (T_{10}) and NPK + FYM + $ZnSO_4$ + *Bradyrhizobium japonicum* (T_6) recorded 128.6 and 108.74 per cent higher number of pods per plant over control (NPK + FYM).

4.8.2.2 Number of seeds per pod

Significantly higher number of seeds per pod was recorded with application of NPK + FYM + $ZnSO_4$ + borax + *Bradyrhizobium japonicum* + VAM (T_{10} : 3.15) as compared to rest of the treatments. Application of NPK + FYM + $ZnSO_4$ + *Bradyrhizobium japonicum* (T_6 : 2.95) and NPK + FYM + $ZnSO_4$ + VAM (T_8 : 2.95) were found on par with each other and recorded significantly higher number of seeds per pod as compared to other treatments. However, lower number of seeds per pod (2.10) was

Table 4.8.11: Number of pods per plant, number of seeds per pod and pod length of soybean as influenced by zinc, boron and microbial inoculants application in finger millet-soybean based cropping system

Treatment	Number of pods per plant			Number of seeds per pod			Pod length (cm)		
	2005	2006	Pooled	2005	2006	Pooled	2005	2006	Pooled
T_1 : Control(NPK + FYM only)	12.50	10.15	11.33	2.20	2.00	2.10	2.50	1.00	1.75
T_2 : NPK+ FYM + $ZnSO_4$	20.00	18.75	19.38	2.80	2.70	2.75	4.40	4.25	4.33
T_3 : NPK+ FYM + Borax	18.00	15.50	16.75	2.60	2.50	2.55	4.05	3.88	3.97
T_4 : NPK + FYM + *B. japonicum*	16.50	14.20	15.35	2.53	2.40	2.47	3.90	3.73	3.82
T_5 : NPK + FYM + VAM	15.25	13.00	14.13	2.40	2.30	2.35	3.75	3.58	3.67
T_6 : NPK+ FYM + $ZnSO_4$+ *B. japonicum*	24.30	23.00	23.65	3.00	2.90	2.95	5.80	5.64	5.72
T_7 : NPK+ FYM + Borax + *B. japonicum*	21.00	19.80	20.40	2.90	2.78	2.84	4.55	4.39	4.47
T_8 : NPK + FYM + $ZnSO_4$ + VAM	22.43	20.90	21.67	3.00	2.90	2.95	5.60	5.45	5.53
T_9 : NPK + FYM + Borax + VAM	19.00	17.50	18.25	2.70	2.60	2.65	4.28	4.13	4.21
T_{10} : NPK + FYM + $ZnSO_4$ + Borax + *B. japonicum* + VAM	26.50	25.30	25.90	3.20	3.10	3.15	6.10	5.95	6.03
F test	*	*	*	*	*	*	*	*	*
S.Em ±	**1.47**	**1.60**	**1.06**	**0.07**	**0.10**	**0.06**	**0.35**	**0.21**	**0.20**
CD at 5 %	**4.37**	**4.75**	**3.04**	**0.20**	**0.28**	**0.17**	**1.05**	**0.61**	**0.57**
CV (%)	**13.04**	**15.54**	**13.92**	**4.30**	**6.32**	**5.28**	**13.65**	**8.48**	**11.28**

DAS-Days after sowing, NPK @ 25:60:25 kg/ha and FYM @ 6.25 t/ha, $ZnSO_4$ @ 12.5 kg/ha, Borax @ 10 kg/ha, *B*: *Bradyrhizobium*
Crop rotation: Finger millet (2005)- Soybean (2006), Soybean (2005)- Finger millet (2006)

recorded in control (T_1 : NPK + FYM). The increase in number of seeds per plant due to application of NPK + FYM + $ZnSO_4$ + borax + *Bradyrhizobium japonicum* + VAM was 50 per cent higher over control (Table 4.8.11 and Fig. 50).

4.8.2.3 Pod length (cm)

Significantly higher pod length (6.03 cm) was obtained with application of NPK + FYM + $ZnSO_4$ + borax + *Bradyrhizobium japonicum* + VAM (T_{10}) which was on par with application of NPK + FYM + $ZnSO_4$ + *Bradyrhizobium japonicum* (T_6 : 5.72) and NPK + FYM + $ZnSO_4$ + VAM (T_8 : 5.53). However, significantly lower pod length (1.75 cm) was recorded in control (T_1 : NPK + FYM) as compared to other treatments (Table 4.8.11 and Fig. 51).

4.8.2.4 Pod yield per plant (g/plant)

Data on pod yield per plant differed significantly due to micronutrients and microbial inoculants application (Table 4.8.12 and Fig. 51).

Conjunctive use of zinc sulphate, borax, *Bradyrhizobium japonicum* and VAM along with recommended NPK and FYM (T_{10}) recorded significantly higher pod yield per plant (12.37 g/plant) as compared to other treatments but it was found on par with application of NPK + FYM + $ZnSO_4$ + VAM (T_8 : 11.36 g/plant) and NPK + FYM + $ZnSO_4$ + *Bradyrhizobium japonicum* (T_6 : 11.61 g/plant). Significantly lower pod yield per plant (5.55 g/plant) was recorded in control (T_1 : NPK + FYM).

Application of NPK + FYM + $ZnSO_4$ + borax + *Bradyrhizobium japonicum* + VAM (T_{10}), NPK + FYM + $ZnSO_4$ + *Bradyrhizobium japonicum* (T_6) and NPK + FYM + $ZnSO_4$ + VAM (T_8) recorded 122.88, 109.19 and

104.68 per cent increase in pod yield per plant over control (NPK + FYM) (Table 4.8.12).

4.8.2.5 Seed yield per plant (g/plant)

Significantly higher seed yield per plant was recorded with application of NPK + FYM + $ZnSO_4$ + borax + *Bradyrhizobium japonicum* + VAM (T_{10} : 5.78 g/plant) as compared to other treatments. However, it was found on par with application of NPK + FYM + $ZnSO_4$ + *Bradyrhizobium japonicum* (T_6 : 5.62 g/plant) and NPK + FYM + $ZnSO_4$ + VAM (T_8 : 5.56 g/plant). Whereas, significantly lower seed yield per plant (3.94 g/plant) was recorded in control (T_1 : NPK + FYM) (Table 4.8.12 and Fig. 52).

4.8.2.6 Test weight (g)

The test weight of soybean seed was not influenced due to conjunctive use of macro- micro and microbial inoculants (Table 4.8.12 and Fig. 52).

4.8.3 SEED YIELD, HAULM YIELD AND HARVEST INDEX OF SOYBEAN AS INFLUENCED BY ZINC, BORON AND MICROBIAL INOCULANTS APPLICATION

4.8.3.1 Seed yield (kg/ha)

The micronutrients and microbial inoculants application caused significant variation in seed yield.

Among the various treatments, application of NPK + FYM + $ZnSO_4$ + borax + *Bradyrhizobium japonicum* + VAM (T_{10}) recorded significantly higher seed yield (2081 kg/ha) as compared to other treatments. However, it was found on par with application of NPK + FYM + $ZnSO_4$ + *Bradyrhizobium japonicum* (T_6 :2029 kg/ha) and NPK + FYM + $ZnSO_4$ + VAM (T_8 :2017 kg/ha). Application of NPK + FYM + borax +

Table 4.8.12: Pod yield, seed yield and test weight (100-seed weight) of soybean as influenced by zinc, boron and microbial inoculants application in finger millet- soybean based cropping system

Treatment	Pod yield per plant (g/plant))			Seed yield per plant (g/ plant)			Test weight (g)		
	2005	**2006**	**Pooled**	**2005**	**2006**	**Pooled**	**2005**	**2006**	**Pooled**
T_1 : Control(NPK + FYM only)	5.70	5.40	5.55	4.00	3.88	3.94	13.40	13.10	13.25
T_2 : NPK+ FYM + $ZnSO_4$	9.20	8.91	9.06	4.94	4.39	4.67	14.20	14.10	14.15
T_3 : NPK+ FYM + Borax	8.25	7.96	8.11	4.76	4.16	4.46	13.90	13.80	13.85
T_4 : NPK + FYM + *B. japonicum*	7.35	7.06	7.21	4.69	4.09	4.39	13.70	13.60	13.65
T_5 : NPK + FYM + VAM	6.50	6.21	6.36	4.65	4.05	4.35	13.60	13.40	13.50
T_6 : NPK+ FYM + $ZnSO_4$+ *B. japonicum*	11.75	11.47	11.61	5.98	5.27	5.62	14.80	14.37	14.58
T_7 : NPK+ FYM + Borax + *B. japonicum*	10.20	9.92	10.06	5.00	4.43	4.72	14.40	14.30	14.35
T_8 : NPK + FYM + $ZnSO_4$ + VAM	11.50	11.22	11.36	5.93	5.18	5.56	14.60	14.50	14.55
T_9 : NPK + FYM + Borax + VAM	8.70	8.42	8.56	4.74	4.25	4.50	14.10	14.00	14.05
T_{10} : NPK + FYM + $ZnSO_4$ + Borax + *B. japonicum* + VAM	12.50	12.23	12.37	6.13	5.42	5.78	14.90	14.80	14.85
F test	*	*	*	*	*	*			
S.Em ±	**0.64**	**0.69**	**0.50**	**0.22**	**0.14**	**0.13**	**0.93**	**0.73**	**0.58**
CD at 5 %	**1.90**	**2.05**	**1.42**	**0.66**	**0.42**	**0.37**	**NS**	**NS**	**NS**
CV (%)	**12.09**	**13.45**	**13.48**	**7.57**	**5.48**	**6.69**	**11.40**	**9.01**	**10.03**

NPK @ 25:60:25 kg/ha, $ZnSO_4$ @ 12.5 kg/ha and FYM @ 6.25 t/ha, Borax @ 10 kg/ha, NS: Non significant, *B*: *Bradyrhizobium*
Crop rotation: Finger millet (2005)- Soybean (2006), Soybean (2005)- Finger millet (2006)

Bradyrhizobium japonicum (T_7 :1711 kg/ha), NPK + FYM + $ZnSO_4$ (T_2 :1687 kg/ha), NPK + FYM + borax (T_3 :1634 kg/ha), NPK + FYM + borax + VAM (T_9 :1631 kg/ha), NPK + FYM + *Bradyrhizobium japonicum* (T_4 :1619 kg/ha) and NPK + FYM + VAM (T_5 :1609 kg/ha) recorded significantly higher seed yield as compared to control (T_1 :1420 kg/ha). However, they were found on par with each other. The magnitude of increase in the seed yield due to application of NPK + FYM + $ZnSO_4$ + borax + *Bradyrhizobium japonicum* + VAM (T_{10}), NPK + FYM + $ZnSO_4$ + *Bradyrhizobium japonicum* (T_6) and NPK + FYM + $ZnSO_4$ + VAM (T_8) was 46.55, 42.89 and 42.04 per cent over control (NPK + FYM) (Table 4.8.13 and Fig. 53).

4.8.3.2 Haulm yield (kg/ha)

The data on haulm yield of soybean differed significantly due to micronutrients and microbial inoculants application (Table 4.8.13 and Fig. 53). Application of NPK + FYM + $ZnSO_4$ + borax + *Bradyrhizobium japonicum* + VAM (T_{10}) recorded significantly higher haulm yield (3304 kg/ha) as compared to other treatments. However, it was found on par with application of NPK + FYM + $ZnSO_4$ + *Bradyrhizobium japonicum* (T_6 : 3174 kg/ha) and NPK + FYM + $ZnSO_4$ + VAM (T_8 : 3154 kg/ha). Haulm yield was lower in control (NPK + FYM : 2496 kg/ha) and was on par with remaining treatments.

4.8.3.3 Harvest index (HI)

Data on HI of soybean did not differ significantly due to micronutrients and microbial inoculants application (Table 4.8.13 and Fig. 53).

Table 4.8.13 : Seed yield, haulm yield and harvest index of soybean as influenced by zinc, boron and microbial inoculants application in finger millet- soybean based cropping system

Treatment	Seed yield (kg/ ha)			Haulm yield (kg/ha)			Harvest index		
	2005	2006	Pooled	2005	2006	Pooled	2005	2006	Pooled
T_1 : Control(NPK + FYM only)	1550	1290	1420	2626	2365	2496	0.37	0.37	0.37
T_2 : NPK+ FYM + $ZnSO_4$	1817	1557	1687	2895	2642	2769	0.39	0.37	0.38
T_3 : NPK+ FYM + Borax	1764	1504	1634	2770	2518	2644	0.39	0.37	0.38
T_4 : NPK + FYM + *B. japonicum*	1744	1494	1619	2666	2478	2572	0.39	0.38	0.39
T_5 : NPK + FYM + VAM	1734	1484	1609	2646	2468	2557	0.39	0.38	0.38
T_6 : NPK+ FYM + $ZnSO_4$+ *B. japonicum*	2154	1904	2029	3320	3028	3174	0.39	0.39	0.39
T_7 : NPK+ FYM + Borax + *B. japonicum*	1835	1587	1711	2920	2672	2796	0.39	0.37	0.38
T_8 : NPK + FYM + $ZnSO_4$ + VAM	2142	1892	2017	3300	3008	3154	0.39	0.39	0.39
T_9 : NPK + FYM + Borax + VAM	1756	1506	1631	2865	2538	2702	0.38	0.37	0.38
T_{10} : NPK + FYM + $ZnSO_4$ + Borax + *B. japonicum* + VAM	2206	1956	2081	3450	3158	3304	0.39	0.38	0.39
F test	*	*	*	*	*	*		*	*
S.Em ±	**74.06**	**63.69**	**49.43**	**135.32**	**161.95**	**115.07**	**0.02**	**0.02**	**0.02**
CD at 5 %	**220.06**	**189.25**	**141.48**	**402.08**	**481.18**	**329.37**	**NS**	**NS**	**NS**
CV (%)	**6.86**	**6.82**	**6.94**	**7.96**	**10.44**	**10.01**	**9.83**	**8.85**	**10.06**

NPK @ 25:60:25 kg/ha, $ZnSO_4$ @ 12.5 kg/ha and FYM @ 6.25 t/ha, Borax @ 10 kg/ha, NS: Non significant, *B*: *Bradyrhizobium*
Crop rotation: Finger millet (2005)- Soybean (2006), Soybean (2005)- Finger millet (2006)

4.8.4 SEED QUALITY PARAMETERS OF SOYBEAN

4.8.4.1 Protein content (%) and protein yield (kg/ha)

The protein content of soybean did not differ significantly due to micronutrients and microbial inoculants application (Table 4.8.14).

Significant differences in protein yield was recorded due to application of micronutrients and microbial inoculants. Application of NPK + FYM + $ZnSO_4$ + borax + *Bradyrhizobium japonicum* + VAM (T_{10}) registered significantly higher protein yield (870.10 kg/ha) over rest of the treatments. However, it was found on par with application of NPK + FYM + $ZnSO_4$ + *Bradyrhizobium japonicum* (T_6 : 839.58 kg/ha) and NPK + FYM + $ZnSO_4$ + VAM (T_8 : 823.07 kg/ha) (Table 4.8.14 and Fig. 54).

4.8.4.2 Oil content (%) and oil yield (kg/ha)

Data on oil content did not differ significantly due to zinc, boron and microbial inoculants application (Table 4.8.14).

Oil yield differed significantly due to zinc, boron and microbial inoculants application. Oil yield was significantly higher with application of NPK + FYM + $ZnSO_4$ + borax + *Bradyrhizobium japonicum* + VAM (T_{10} : 396.05 kg/ha) as compared to rest of the treatments. However, application of NPK + FYM + $ZnSO_4$ + *Bradyrhizobium japonicum* (T_6 : 382.09 kg/ha) and NPK + FYM + $ZnSO_4$ + VAM (T_8 : 379.36 kg/ha) were found on par with each other and with the former treatment. Significantly lower oil yield (259.91 kg/ha) was recorded in control (T_1 : NPK + FYM) (Table 4.8.14 and Fig. 54).

4.8.4.3 Germination (%), dry weight of root and shoot (mg) and seed vigour index

Significantly higher germination (97%) and shoot and root dry weight of soybean seed (24.90 mg) was observed with application of NPK

Table 4.8.14: Protein content, protein yield, oil content and oil yield of soybean as influenced by zinc, boron and microbial inoculants application in finger millet- soybean based cropping system

Treatment	Protein content (%)			Protein yield (kg/ ha)			Oil content (%)			Oil yield (kg/ha)		
	2005	2006	Pooled	2005	2006	Pooled	2005	2006	Pooled	2005	2006	Pooled
T_1 : Control(NPK + FYM only)	39.38	39.13	39.25	610.21	505.00	557.61	18.30	18.24	18.27	284.54	235.29	259.91
T_2 : NPK+ FYM + $ZnSO_4$	40.63	40.44	40.53	739.33	630.75	685.04	18.65	18.58	18.62	338.78	289.63	314.21
T_3 : NPK+ FYM + Borax	40.00	39.81	39.91	705.95	600.17	653.06	18.46	18.39	18.43	325.59	276.67	301.13
T_4 : NPK + FYM + *B. japonicum*	39.75	39.69	39.72	693.42	591.96	642.69	18.37	18.32	18.35	320.37	273.70	297.03
T_5 : NPK + FYM + VAM	39.69	39.56	39.62	689.91	588.05	638.98	18.35	18.29	18.32	318.23	271.27	294.75
T_6 : NPK+ FYM + $ZnSO_4$+ *B. japonicum*	41.50	41.31	41.41	892.51	786.66	839.58	18.85	18.80	18.83	405.92	358.26	382.09
T_7 : NPK+ FYM + Borax + *B. japonicum*	40.81	40.56	40.69	749.15	643.97	696.56	18.70	18.66	18.68	343.18	296.15	319.67
T_8 : NPK + FYM + $ZnSO_4$ + VAM	40.88	40.63	40.75	875.44	770.70	823.07	18.80	18.74	18.77	402.62	356.10	379.36
T_9 : NPK + FYM + Borax + VAM	40.31	40.06	40.19	716.86	603.80	660.33	18.55	18.48	18.52	324.64	277.99	301.31
T_{10} : NPK + FYM + $ZnSO_4$ + Borax + *B. japonicum* + VAM	41.88	41.75	41.81	923.34	816.87	870.10	19.05	19.00	19.03	420.63	371.47	396.05
F test	**-**	**-**	**-**	*****	*****	*****	-	-	-	*****	*****	*****
S.Em ±	**1.99**	**1.17**	**1.13**	**30.78**	**30.84**	**21.32**	**0.57**	**0.60**	**0.41**	**12.90**	**13.41**	**9.07**
CD at 5 %	**NS**	**NS**	**NS**	**91.45**	**91.62**	**61.02**	**NS**	**NS**	**NS**	**38.34**	**39.84**	**25.97**
CV (%)	**8.50**	**5.03**	**6.88**	**7.02**	**8.17**	**7.39**	**5.31**	**5.58**	**5.35**	**6.41**	**7.72**	**6.85**

NS: Non significant, NPK @ 25:60:25 kg/ha and FYM @ 6.25 t/ha, $ZnSO_4$ @ 12.5 kg/ha, Borax @ 10 kg/ha, *B*: *Bradyrhizobium*
Crop rotation: Finger millet (2005)- Soybean (2006), Soybean (2005)- Finger millet (2006)

Table 4.8.15: Germination, dry weight of root and shoot and seed vigour index of soybean as influenced by zinc, boron microbial inoculants application in finger millet- soybean based cropping system

Treatment	Germination (%)			Dry weight of root and shoot (mg)			Seed vigour index		
	2005	2006	Pooled	2005	2006	Pooled	2005	2006	Pooled
T_1 : Control(NPK + FYM only)	84	83	84	17.45	16.20	16.83	1467	1345	1406
T_2 : NPK+ FYM + $ZnSO_4$	92	90	91	21.70	19.36	20.53	1998	1744	1871
T_3 : NPK+ FYM + Borax	90	89	90	20.20	18.74	19.47	1819	1671	1745
T_4 : NPK + FYM + *B. japonicum*	89	88	89	19.48	18.50	18.99	1736	1629	1682
T_5 : NPK + FYM + VAM	88	87	88	18.50	18.38	18.44	1630	1601	1615
T_6 : NPK+ FYM + $ZnSO_4$+ *B. japonicum*	97	96	97	25.30	22.20	23.75	2456	2130	2293
T_7 : NPK+ FYM + Borax + *B. japonicum*	93	91	92	22.19	19.50	20.85	2067	1776	1922
T_8 : NPK + FYM + $ZnSO_4$ + VAM	96	95	96	24.20	20.76	22.48	2325	1975	2150
T_9 : NPK + FYM + Borax + VAM	91	89	90	20.40	19.00	19.70	1851	1693	1772
T_{10} : NPK + FYM + $ZnSO_4$ + Borax + *B. japonicum* + VAM	97	97	97	26.79	23.00	24.90	2601	2233	2417
F test	*	*	*	*	*	*	*	*	*
S.Em ±	**1.29**	**1.87**	**1.11**	**0.76**	**0.66**	**0.50**	**85.13**	**87.22**	**60.49**
CD at 5 %	**3.82**	**5.57**	**3.18**	**2.25**	**1.98**	**1.44**	**252.94**	**259.14**	**173.16**
CV (%)	**2.43**	**3.59**	**2.99**	**6.06**	**5.89**	**5.99**	**7.39**	**8.49**	**7.85**

NPK @ 25:60:25 kg/ha and FYM @ 6.25 t/ha, $ZnSO_4$ @ 12.5 kg/ha, Borax @ 10 kg/ha, *B*: *Bradyrhizobium*
Crop rotation: Finger millet (2005)- Soybean (2006), Soybean (2005)- Finger millet (2006)

+ FYM + $ZnSO_4$ + borax + *Bradyrhizobium japonicum* + VAM (T_{10}) as compared to rest of the treatments. This was found to be on par with application of NPK + FYM + $ZnSO_4$ + *Bradyrhizobium japonicum* (T_6 :97 % and 23.75 mg, respectively) (Table 4.8.15 and Fig. 55).

Application of NPK + FYM + $ZnSO_4$ + borax + *Bradyrhizobium japonicum* + VAM (T_{10}) recorded significantly higher seed vigour index (2417) as compared to rest of the treatments. While application of NPK + FYM + $ZnSO_4$ + *Bradyrhizobium japonicum* (T_6 : 2293) was found to be the next best treatment with respect to seed vigour index which recorded significantly higher seed vigour index over control and was at par with application of NPK + FYM + $ZnSO_4$ + borax + *Bradyrhizobium japonicum* + VAM (T_{10}) (Table 4.8.15 and Fig. 55).

4.8.5 NUTRIENTS UPTAKE STUDIES

4.8.5.1 Nitrogen uptake by soybean seed, haulm and total plant uptake (kg/ha)

Significant differences were observed in nitrogen uptake by seeds of soybean due to micronutrients and microbial inoculants application (Table 4.8.16).

Application of NPK + FYM + $ZnSO_4$ + borax + *Bradyrhizobium japonicum* + VAM (T_{10}) recorded significantly higher nitrogen by soybean seed (139.23 kg/ha) as compared to rest of the treatments. However, it was found on par with application of NPK + FYM + $ZnSO_4$ + *Bradyrhizobium japonicum* (T_6 : 134.44 kg/ha) and NPK + FYM + $ZnSO_4$ + VAM (T_8 : 131.54 kg/ha). Significantly lower nitrogen uptake in seed was recorded in control (T_1 : NPK + FYM; 89.20 kg/ha) as compared to all other treatments.

Significantly higher nitrogen uptake by soybean haulm and total nitrogen uptake was recorded with application of NPK + FYM + $ZnSO_4$ +

Table 4.8.16: Nitrogen uptake by seed, haulm and total nitrogen uptake of soybean as influenced by zinc, boron and microbial inoculants application in finger millet- soybean based cropping system

Treatment	Nitrogen uptake (kg/ha)								
	Seed (kg/ha)			Haulm (kg/ha)			Total uptake (kg/ha)		
	2005	2006	Pooled	2005	2006	Pooled	2005	2006	Pooled
T_1 : Control(NPK + FYM only)	97.65 (6.30)	80.75 (6.26)	89.20 (6.28)	26.85 (1.02)	25.05 (1.06)	25.95 (1.04)	124.50 (7.32)	105.80 (7.32)	115.15 (7.32)
T_2 : NPK+ FYM + $ZnSO_4$	118.11 (6.50)	100.74 (6.47)	109.43 (6.49)	32.13 (1.11)	29.19 (1.11)	30.66 (1.11)	150.24 (7.61)	129.93 (7.58)	140.09 (7.59)
T_3 : NPK+ FYM + Borax	112.90 (6.40)	95.80 (6.37)	104.35 (6.39)	29.67 (1.07)	26.06 (1.04)	27.87 (1.05)	142.57 (7.47)	121.86 (7.41)	132.22 (7.44)
T_4 : NPK + FYM + *B. japonicum*	110.92 (6.36)	94.87 (6.35)	102.90 (6.36)	27.46 (1.03)	25.42 (1.03)	26.44 (1.03)	138.38 (7.39)	120.29 (7.38)	129.34 (7.38)
T_5 : NPK + FYM + VAM	110.11 (6.35)	93.94 (6.33)	102.03 (6.34)	27.12 (1.03)	25.20 (1.02)	26.16 (1.02)	137.23 (7.38)	119.14 (7.35)	128.19 (7.36)
T_6 : NPK+ FYM + $ZnSO_4$+ *B. japonicum*	143.03 (6.64)	125.85 (6.61)	134.44 (6.63)	37.68 (1.14)	34.22 (1.13)	35.95 (1.13)	180.71 (7.78)	160.07 (7.74)	170.39 (7.76)
T_7 : NPK+ FYM + Borax + *B. japonicum*	119.83 (6.53)	103.00 (6.49)	111.42 (6.51)	32.70 (1.12)	29.82 (1.12)	31.26 (1.12)	152.53 (7.65)	132.82 (7.61)	142.68 (7.63)
T_8 : NPK + FYM + $ZnSO_4$ + VAM	140.09 (6.54)	122.98 (6.50)	131.54 (6.52)	37.29 (1.13)	33.90 (1.13)	35.60 (1.13)	177.38 (7.67)	156.88 (7.63)	167.13 (7.65)
T_9 : NPK + FYM + Borax + VAM	113.26 (6.45)	96.53 (6.41)	104.90 (6.43)	31.52 (1.10)	27.82 (1.10)	29.67 (1.10)	144.78 (7.55)	124.35 (7.51)	134.57 (7.53)
T_{10} : NPK + FYM + $ZnSO_4$ + Borax + *B. japonicum* + VAM	147.80 (6.70)	130.66 (6.68)	139.23 (6.69)	39.33 (1.14)	35.84 (1.14)	37.59 (1.14)	187.13 (7.84)	166.50 (7.82)	176.82 (7.83)
F test	*	*	*	*	*	*	*	*	*
S.Em ±	**4.58**	**4.03**	**2.98**	**1.73**	**1.26**	**1.06**	**5.49**	**4.36**	**3.44**
CD at 5 %	**13.61**	**11.98**	**8.54**	**5.13**	**3.76**	**3.03**	**16.32**	**12.97**	**9.85**
CV (%)	**6.54**	**6.68**	**6.47**	**9.29**	**7.48**	**8.45**	**6.20**	**5.65**	**5.87**

NPK @ 25:60:25 kg/ha and FYM @ 6.25 t/ha, $ZnSO_4$ @ 12.5 kg/ha, Borax@10 kg/ha, *B*: *Bradyrhizobium,* Figures in parenthesis indicates actual concentration of nitrogen in per cent, **Crop rotation**: Finger millet (2005)- Soybean (2006), Soybean (2005)- Finger millet (2006)

borax + *Bradyrhizobium japonicum* + VAM (T_{10} : 37.59 and 176.82 kg/ha, respectively) as compared to rest of the treatments, but was found on par with application of NPK + FYM + $ZnSO_4$ + *Bradyrhizobium japonicum* (T_6 : 35.95 and 170.39 kg/ha, respectively) and NPK + FYM + $ZnSO_4$ + VAM (T_8 : 35.60 and 167.13 kg/ha, respectively). Significantly lower nitrogen uptake by soybean haulm (25.95 kg/ha) and total nitrogen uptake by soybean plant (115.15 kg/ha) was recorded in control (T_1 : NPK + FYM). However, application of NPK + FYM + $ZnSO_4$ + borax (T_3 : 27.87 kg/ha), NPK + FYM + *Bradyrhizobium japonicum* (T_4 : 26.44 kg/ha) and NPK + FYM + VAM (T_5 : 26.16 kg/ha) were found on par with each other and with control (T_1) with respect to nitrogen uptake by soybean haulm (Table 4.8.16 and Fig. 56).

4.8.5.2 Phosphorus uptake by soybean seed, haulm and total plant uptake (kg/ha)

Phosphorus uptake by soybean seed ranged from 2.10 to 4.42 kg per ha due to application of micronutrients and microbial inoculants. Phosphorus uptake was significantly higher with application of NPK + FYM + $ZnSO_4$ + borax + *Bradyrhizobium japonicum* + VAM (T_{10}) in soybean seed (4.42 kg/ha), haulm (4.56 kg/ha) and total (8.98 kg/ha) as compared to all other treatments, whereas application of NPK + FYM + $ZnSO_4$ + *Bradyrhizobium japonicum* (T_6 : 3.87, 4.25 and 8.12 kg/ha, respectively) and NPK + FYM + $ZnSO_4$ + VAM (T_8 : 3.68, 4.12 and 7.80 kg/ha, respectively) were found on par with each other and recorded significantly higher phosphorus uptake as compared to rest of the treatments (Table 4.8.17 and Fig.56).

4.8.5.3 Potassium uptake by soybean seed, haulm and total plant uptake (kg/ha)

Potassium uptake in seed, haulm and total plant uptake was significantly influenced among the treatments. Application of NPK + FYM

Table 4.8.17: Phosphorus uptake by seed, haulm and total phosphorus uptake of soybean as influenced by zinc, boron and microbial inoculants application in finger millet- soybean based cropping system

Treatment	Phosphorus uptake (kg/ha)								
	Seed (kg/ha)			Haulm (kg/ha)			Total uptake(kg/ha)		
	2005	2006	Pooled	2005	2006	Pooled	2005	2006	Pooled
T_1 : Control(NPK + FYM only)	2.33 (0.150)	1.87 (0.145)	2.10 (0.148)	2.94 (0.112)	2.67 (0.113)	2.81 (0.113)	5.27 (0.262)	4.54 (0.258)	4.91 (0.260)
T_2 : NPK+ FYM + $ZnSO_4$	3.02 (0.166)	2.55 (0.164)	2.79 (0.165)	3.65 (0.126)	3.14 (0.119)	3.40 (0.123)	6.67 (0.292)	5.69 (0.283)	6.18 (0.288)
T_3 : NPK+ FYM + Borax	2.82 (0.160)	2.44 (0.162)	2.63 (0.161)	3.35 (0.121)	2.90 (0.115)	3.13 (0.118)	6.17 (0.281)	5.34 (0.277)	5.76 (0.279)
T_4 : NPK + FYM + *B. japonicum*	2.69 (0.154)	2.24 (0.150)	2.47 (0.152)	3.12 (0.117)	2.73 (0.110)	2.93 (0.114)	5.81 (0.271)	4.97 (0.260)	5.39 (0.266)
T_5 : NPK + FYM + VAM	3.23 (0.186)	2.66 (0.179)	2.95 (0.183)	3.44 (0.130)	3.04 (0.123)	3.24 (0.127)	6.67 (0.316)	5.70 (0.302)	6.19 (0.309)
T_6 : NPK+ FYM + $ZnSO_4$+ *B. japonicum*	4.07 (0.189)	3.67 (0.193)	3.87 (0.191)	4.52 (0.136)	3.97 (0.131)	4.25 (0.134)	8.59 (0.325)	7.64 (0.324)	8.12 (0.325)
T_7 : NPK+ FYM + Borax + *B. japonicum*	3.20 (0.175)	2.76 (0.174)	2.98 (0.175)	3.74 (0.128)	3.21 (0.120)	3.48 (0.124)	6.94 (0.303)	5.97 (0.294)	6.46 (0.299)
T_8 : NPK + FYM + $ZnSO_4$ + VAM	3.77 (0.176)	3.58 (0.189)	3.68 (0.183)	4.39 (0.133)	3.85 (0.128)	4.12 (0.131)	8.16 (0.309)	7.43 (0.317)	7.80 (0.313)
T_9 : NPK + FYM + Borax + VAM	3.34 (0.190)	2.77 (0.184)	3.06 (0.187)	3.78 (0.132)	3.20 (0.126)	3.49 (0.129)	7.12 (0.322)	5.97 (0.310)	6.55 (0.316)
T_{10} : NPK + FYM + $ZnSO_4$ + Borax + *B. japonicum* + VAM	4.74 (0.215)	4.09 (0.209)	4.42 (0.212)	4.83 (0.140)	4.29 (0.136)	4.56 (0.138)	9.57 (0.355)	8.38 (0.345)	8.98 (0.350)
F test	*	*	*	*	*	*	*	*	*
S.Em +	**0.15**	**0.17**	**0.12**	**0.13**	**0.15**	**0.10**	**0.21**	**0.25**	**0.17**
CD at 5 %	**0.44**	**0.50**	**0.34**	**0.38**	**0.45**	**0.30**	**0.64**	**0.74**	**0.48**
CV (%)	**7.74**	**10.13**	**9.30**	**5.91**	**7.92**	**7.22**	**5.23**	**7.00**	**6.24**

NPK @ 25:60:25 kg/ha and FYM @ 6.25 t/ha, $ZnSO_4$ @ 12.5 kg/ha, Borax @ 10 kg/ha, *B*: *Bradyrhizobium,* Figures in parenthesis indicate actual concentration of Phosphorus in per cent, **Crop rotation**: Finger millet (2005)- Soybean (2006), Soybean (2005)- Finger millet (2006)

+ $ZnSO_4$ + borax + *Bradyrhizobium japonicum* + VAM (T_{10}) recorded significantly higher potassium uptake in seed (10.45 kg/ha) and haulm (49.77 kg/ha) over all other treatments except with application of NPK + FYM + $ZnSO_4$ + *Bradyrhizobium japonicum* (T_6 : 10 and 48.33 kg/ha, respectively) (Table 4.8.18).

Total potassium uptake (60.22 kg/ha) by soybean plant was significantly higher with application of NPK + FYM + $ZnSO_4$ + borax + *Bradyrhizobium japonicum* + VAM (T_{10}) over rest of the treatments. However, it was found on par with application of NPK + FYM + $ZnSO_4$ + *Bradyrhizobium japonicum* (T_6 : 58.33 kg/ha). Significantly lower potassium uptake by soybean seed (6.59 kg/ha) was recorded in control (T_1 : NPK + FYM). However, application of NPK + FYM + VAM (T_5) was found on par with application of NPK + FYM (T_1) with respect to potassium uptake by soybean haulm (37.75 kg/ha) and total potassium uptake (45.56 kg/ha) (Table 4.8.18 and Fig. 56).

4.8.5.4 Zinc uptake by soybean seed, haulm and total plant uptake (g/ha)

Zinc uptake by soybean seed and haulm differed significantly due to application of zinc, boron and microbial inoculants application. Significantly higher zinc uptake by soybean seed and haulm (134.39 and 70.47 g/ha, respectively) was recorded with application of NPK + FYM + $ZnSO_4$ + borax + *Bradyrhizobium japonicum* + VAM (T_{10}) as compared to rest of the treatments. Application of NPK + FYM + $ZnSO_4$ + *Bradyrhizobium japonicum* (T_6 : 114.30 and 60.36 g/ha, respectively) and NPK + FYM + $ZnSO_4$ + VAM (T_8 : 109.17 and 57.97 g/ha, respectively) were found on par with each other and recorded significantly higher uptake of zinc by soybean seed and haulm as compared to remaining treatments (Table 4.8.19).

Table 4.8.18: Potassium uptake by seed, haulm and total potassium uptake of soybean as influenced by zinc, boron and microbial inoculants application in finger millet- soybean based cropping system

Treatment	Potassium uptake (kg/ha)								
	Seed(kg/ha)			Haulm (kg/ha)			Total uptake(kg/ha)		
	2005	2006	Pooled	2005	2006	Pooled	2005	2006	Pooled
T_1 : Control(NPK + FYM only)	7.25 (0.468)	5.93 (0.460)	6.59 (0.464)	38.73 (1.475)	34.74 (1.469)	36.74 (1.472)	45.98 (1.943)	40.67 (1.929)	43.33 (1.936)
T_2 : NPK+ FYM + $ZnSO_4$	8.85 (0.487)	7.50 (0.482)	8.18 (0.485)	43.45 (1.501)	39.50 (1.495)	41.48 (1.498)	52.30 (1.988)	47.00 (1.977)	49.65 (1.983)
T_3 : NPK+ FYM + Borax	8.38 (0.478)	7.14 (0.475)	7.76 (0.477)	41.19 (1.487)	37.44 (1.487)	39.32 (1.487)	49.57 (1.965)	44.58 (1.962)	47.08 (1.964)
T_4 : NPK + FYM + *B. japonicum*	8.21 (0.475)	7.05 (0.472)	7.63 (0.474)	39.51 (1.482)	36.60 (1.477)	38.06 (1.480)	47.72 (1.957)	43.65 (1.949)	45.69 (1.953)
T_5 : NPK + FYM + VAM	8.67 (0.471)	6.95 (0.468)	7.81 (0.470)	39.11 (1.478)	36.38 (1.474)	37.75 (1.476)	47.78 (1.949)	43.33 (1.942)	45.56 (1.946)
T_6 : NPK+ FYM + $ZnSO_4$+ *B. japonicum*	10.58 (0.500)	9.42 (0.495)	10.00 (0.498)	50.63 (1.525)	46.03 (1.520)	48.33 (1.523)	61.21 (2.025)	55.45 (2.015)	58.33 (2.020)
T_7 : NPK+ FYM + Borax + *B. japonicum*	9.08 (0.491)	7.73 (0.487)	8.41 (0.489)	43.89 (1.503)	40.03 (1.498)	41.96 (1.501)	52.97 (1.994)	47.76 (1.985)	50.37 (1.990)
T_8 : NPK + FYM + $ZnSO_4$ + VAM	10.32 (0.495)	9.27 (0.490)	9.80 (0.493)	49.80 (1.509)	45.18 (1.502)	47.49 (1.506)	60.12 (2.004)	54.45 (1.992)	57.29 (1.998)
T_9 : NPK + FYM + Borax + VAM	8.89 (0.482)	7.20 (0.478)	8.05 (0.480)	42.77 (1.493)	37.84 (1.491)	40.31 (1.492)	51.66 (1.975)	45.04 (1.969)	48.35 (1.972)
T_{10} : NPK + FYM + $ZnSO_4$ + Borax + *B. japonicum* + VAM	11.16 (0.506)	9.74 (0.498)	10.45 (0.502)	52.13 (1.511)	47.40 (1.501)	49.77 (1.506)	63.29 (2.017)	57.14 (1.999)	60.22 (2.008)
F test	*	*	*	*	*	*	*	*	*
S.Em +	**0.31**	**0.30**	**0.22**	**1.85**	**1.56**	**1.24**	**1.93**	**1.56**	**1.29**
CD at 5 %	**0.91**	**0.91**	**0.63**	**5.48**	**4.62**	**3.54**	**5.74**	**4.63**	**3.68**
CV (%)	**5.80**	**6.78**	**6.33**	**7.24**	**6.72**	**7.19**	**6.28**	**5.63**	**6.23**

NPK @ 25:60:25 kg/ha and FYM @ 6.25 t/ha, $ZnSO_4$ @ 12.5 kg/ha, Borax @ 10 kg/ha, *B*: *Bradyrhizobium,* Figures in parenthesis indicate actual concentration of Potassium in per cent, **Crop rotation**: Finger millet (2005)-Soybean (2006), Soybean (2005)- Finger millet (2006)

The total zinc uptake by soybean plant was significantly higher with application of NPK + FYM + $ZnSO_4$ + borax + *Bradyrhizobium japonicum* + VAM (T_{10} : 204.86 g/ha) as compared to all other treatments. Application of NPK + FYM + $ZnSO_4$ + *Bradyrhizobium japonicum* (T_6 : 174.65 g/ha) and NPK + FYM + $ZnSO_4$ + VAM (T_8 : 167.14 g/ha) were found next best treatments with respect to total zinc uptake by soybean plant and recorded significantly higher total Zn uptake over other treatments. However, these two treatments were found on par with each other. Significantly lower zinc uptake by seed, haulm and total zinc uptake (69.97, 39.87 and 109.84 g/ha, respectively) was registered in control (T_1 : NPK + FYM) (Table 4.8.19 and Fig. 57).

4.8.5.5 Boron uptake by soybean seed, haulm and total plant uptake (g/ha)

Significant difference was observed in boron uptake by soybean seed, haulm and total plant uptake due to zinc, boron and microbial inoculants application. Significantly higher boron uptake by soybean seed, haulm and total boron uptake (28.35, 41.22 and 69.57 g/ha, respectively) was recorded with application of NPK + FYM + $ZnSO_4$ + borax + *Bradyrhizobium japonicum* + VAM (T_{10}) as compared to rest of the treatments. Application of NPK + FYM + $ZnSO_4$ + *Bradyrhizobium japonicum* (T_6 : 22.32, 31.70 and 54.02 g/ha, respectively), NPK + FYM + borax + *Bradyrhizobium japonicum* (T_8 : 21.71, 30.68 and 52.39 g/ha, respectively) were found on par with each other and recorded significantly higher boron uptake as compared to control (T_1 : 13.01, 20.28 and 33.29 g/ha, respectively) (Table 4.8.20 and Fig. 57).

Table 4.8.19: Zinc uptake by seed, haulm and total zinc uptake of soybean as influenced by zinc, boron and microbial inoculants application in finger millet- soybean based cropping system

Treatment	Zinc uptake (g/ha)								
	Seed (g/ha)			Haulm (g/ha)			Total uptake(g/ha)		
	2005	2006	Pooled	2005	2006	Pooled	2005	2006	Pooled
T_1 : Control(NPK + FYM only)	77.30 (49.87)	62.64 (48.56)	69.97 (49.22)	43.50 (16.57)	36.23 (15.32)	39.87 (15.95)	120.80 (66.44)	98.87 (63.88)	109.84 (65.16)
T_2 : NPK+ FYM + $ZnSO_4$	109.11 (60.05)	93.22 (59.87)	101.17 (59.96)	59.72 (20.63)	52.39 (19.83)	56.06 (20.23)	168.83 (80.68)	145.61 (79.70)	157.22 (80.19)
T_3 : NPK+ FYM + Borax	93.53 (53.02)	78.21 (52.00)	85.87 (52.51)	49.68 (17.93)	42.35 (16.82)	46.02 (17.38)	143.21 (70.95)	120.56 (68.82)	131.89 (69.89)
T_4 : NPK + FYM + *B. japonicum*	88.97 (51.02)	74.77 (50.05)	81.87 (50.54)	49.23 (18.46)	43.02 (17.36)	46.13 (17.91)	138.20 (69.48)	117.79 (67.41)	128.00 (68.45)
T_5 : NPK + FYM + VAM	86.79 (50.05)	74.17 (49.98)	80.48 (50.02)	48.46 (18.31)	42.57 (17.25)	45.52 (17.78)	135.25 (68.36)	116.74 (67.23)	126.00 (67.80)
T_6 : NPK+ FYM + $ZnSO_4$+ *B. japonicum*	122.33 (56.79)	106.26 (55.81)	114.30 (56.30)	65.03 (19.59)	55.68 (18.39)	60.36 (18.99)	187.36 (76.38)	161.94 (74.20)	174.65 (75.29)
T_7 : NPK+ FYM + Borax + *B. japonicum*	101.71 (55.43)	86.05 (54.22)	93.88 (54.83)	53.93 (18.47)	46.36 (17.35)	50.15 (17.91)	155.64 (73.90)	132.41 (71.57)	144.03 (72.74)
T_8 : NPK + FYM + $ZnSO_4$ + VAM	116.89 (54.57)	101.45 (53.62)	109.17 (54.10)	62.39 (18.91)	53.54 (17.80)	57.97 (18.36)	179.28 (73.48)	154.99 (71.42)	167.14 (72.45)
T_9 : NPK + FYM + Borax + VAM	97.17 (55.33)	81.75 (54.28)	89.46 (54.81)	51.13 (17.85)	42.64 (16.80)	46.89 (17.33)	148.30 (73.18)	124.39 (71.08)	136.35 (72.13)
T_{10} : NPK + FYM + $ZnSO_4$ + Borax + *B. japonicum* + VAM	143.53 (65.06)	125.24 (64.03)	134.39 (64.55)	75.06 (21.76)	65.88 (20.86)	70.47 (21.31)	218.59 (86.82)	191.12 (84.89)	204.86 (85.86)
F test	*	*	*	*	*	*	*	*	*
S.Em ±	**4.26**	**3.97**	**2.84**	**1.97**	**1.91**	**1.35**	**5.75**	**5.47**	**3.87**
CD at 5 %	**12.66**	**11.81**	**8.13**	**5.87**	**5.67**	**3.86**	**17.09**	**16.26**	**11.07**
CV (%)	**7.11**	**7.79**	**7.25**	**6.13**	**6.88**	**6.37**	**6.24**	**6.95**	**6.40**

NPK @ 25:60:25 kg/ha and FYM @ 6.25 t/ha, $ZnSO_4$ @ 12.5 kg/ha, Borax @ 10 kg/ha, *B*: *Bradyrhizobium,* Figures in parenthesis indicate actual concentration of Zinc in ppm, **Crop rotation**: Finger millet (2005)- Soybean (2006), Soybean (2005)- Finger millet (2006)

Table 4.8.20: Boron uptake by seed, haulm and total boron uptake of soybean as influenced by zinc, boron and microbial inoculants application in finger millet- soybean based cropping system

Treatment	Boron uptake (g/ha)								
	Seed (g/ha)			Haulm (g/ha)			Total uptake (g/ha)		
	2005	2006	Pooled	2005	2006	Pooled	2005	2006	Pooled
T_1 : Control(NPK + FYM only)	14.91 (9.62)	11.10 (8.61)	13.01 (9.12)	22.59 (8.60)	17.97 (7.60)	20.28 (8.10)	37.50 (18.22)	29.07 (16.21)	33.29 (17.22)
T_2 : NPK+ FYM + $ZnSO_4$	19.63 (10.80)	15.26 (9.80)	17.45 (10.30)	27.98 (9.67)	22.85 (8.65)	25.42 (9.16)	47.61 (20.47)	38.11 (18.45)	42.86 (19.46)
T_3 : NPK+ FYM + Borax	20.88 (11.84)	16.27 (10.82)	18.58 (11.33)	29.70 (10.72)	24.21 (9.62)	26.96 (10.17)	50.58 (22.56)	40.48 (20.44)	45.53 (21.50)
T_4 : NPK + FYM + *B. japonicum*	18.11 (10.39)	13.86 (9.28)	15.99 (9.83)	24.52 (9.20)	20.26 (8.18)	22.39 (8.69)	42.63 (19.58)	34.12 (17.46)	38.38 (18.52)
T_5 : NPK + FYM + VAM	17.39 (10.03)	13.77 (9.28)	15.58 (9.65)	24.14 (9.12)	20.03 (8.12)	22.09 (8.62)	41.53 (19.15)	33.80 (17.40)	37.67 (18.27)
T_6 : NPK+ FYM + $ZnSO_4$+ *B. japonicum*	24.74 (11.49)	19.90 (10.45)	22.32 (10.97)	34.76 (10.47)	28.64 (9.46)	31.70 (9.97)	59.50 (21.96)	48.54 (19.91)	54.02 (20.93)
T_7 : NPK+ FYM + Borax + *B. japonicum*	24.46 (13.33)	19.89 (12.53)	22.18 (12.93)	35.55 (12.18)	31.13 (11.65)	33.34 (11.91)	60.01 (25.51)	51.02 (24.18)	55.52 (24.84)
T_8 : NPK + FYM + $ZnSO_4$ + VAM	24.12 (11.26)	19.30 (10.20)	21.71 (10.73)	33.74 (10.22)	27.61 (9.18)	30.68 (9.70)	57.86 (21.48)	46.91 (19.38)	52.39 (20.43)
T_9 : NPK + FYM + Borax + VAM	21.43 (12.20)	16.82 (11.17)	19.13 (11.69)	31.22 (10.90)	24.85 (9.79)	28.04 (10.34)	52.65 (23.10)	41.67 (20.96)	47.16 (22.03)
T_{10} : NPK + FYM + $ZnSO_4$ + Borax + *B. japonicum* + VAM	31.12 (14.11)	25.58 (13.08)	28.35 (13.59)	43.27 (12.54)	39.16 (12.40)	41.22 (12.47)	74.39 (26.65)	64.74 (25.48)	69.57 (26.06)
F test	*	*	*	*	*	*	*	*	*
S.Em +	**1.01**	**0.80**	**0.69**	**1.10**	**1.11**	**0.76**	**1.60**	**1.50**	**1.14**
CD at 5 %	**3.01**	**2.38**	**1.98**	**3.27**	**3.29**	**2.18**	**4.76**	**4.45**	**3.26**
CV (%)	**8.08**	**8.07**	**8.72**	**6.20**	**7.48**	**6.62**	**5.29**	**6.06**	**5.86**

NPK @ 25:60:25 kg/ha and FYM @ 6.25 t/ha, $ZnSO_4$ @ 12.5 kg/ha, Borax @ 10 kg/ha, *B*: *Bradyrhizobium,* Figures in parenthesis indicate actual concentration of boron in ppm, **Crop rotation**: Finger millet (2005)- Soybean (2006), Soybean (2005)- Finger millet (2006)

4.8.6 CORRELATION AND REGRESSION ANALYSIS FOR GROWTH, YIELD PARAMETERS AND TOTAL UPTAKE OF NUTRIENTS IN SOYBEAN

The seed yield was significantly and positively correlated with growth parameters viz., TDM at harvest (r = 0.723), leaf area at harvest (r = 0.851), nodule number at 60 DAS (r = 0.769), nodule dry weight at 60 DAS (r = 0.698), number of branches at harvest (r = 0.796). Besides this, the seed yield had a positive and significant correlation with yield components viz., number of pods per plant (r = 0.753), number of seeds per plant (r = 0.750), pod length (r = 0.722), pod yield plant (r = 0.699), seed yield per plant (r = 0.803) and test weight (r = 0.282). The quality parameters viz., protein yield (r = 0.953) were oil yield (r = 0.946) are also significantly and positively correlated with seed yield (Table 4.8.21).

Similarly, the seed yield had a positive and significant correlation with total uptake of nutrients at maturity viz., uptake of nitrogen, phosphorus, potassium, zinc and boron (r = 0.892, 0.854, 0.849, 0.851 and 0.807, respectively) in soybean.

The multiple linear regression equations for soybean seed yield with growth, yield parameters and total uptake of nutrients as influenced by zinc, boron and microbial inoculants are presented in Table 4.8.21.

Variation in the seed yield of soybean due to growth, yield parameters and total uptake of nutrients was about 95 per cent as explained by the multiple linear regression equation.

Table 4.8.21: Correlation and regression equation for pooled data of soybean as influenced by zinc, boron and microbial inoculants in finger millet-soybean based cropping system

Sl. No.	Parameters (X)	Regression equation Y{Grain yield(kg/ha))}	Correlation coefficient (r)	R^2
1	TDM at harvest (g/plant)	Y= 974.631+49.344 X	0.723**	0.523
2	Leaf area (cm^2)at harvest	Y= 742.823+11.870 X	0.851**	0.724
3	Nodule number at 60 DAS	Y= 838.480+18.045 X	0.769**	0.592
4	Nodule dry weight (g/plant) at 60 DAS	Y= -375.944+787.028 X	0.698**	0.487
5	No. of branches at harvest	Y= 1153.987+640.058 X	0.796**	0.634
6	No. of pods per plant	Y= 815.787+200.869 X	0.753**	0.567
7	No. of seeds per plant	Y= 994.857+40.095 X	0.750**	0.563
8	Pod length (cm)	Y= 125.058+606.444 X	0.722**	0.522
9	Pod yield per plant (g/plant)	Y= 1091.114+150.164 X	0.699**	0.489
10	Seed yield per plant (g/plant)	Y= 1048.571+77.055 X	0.803**	0.644
11	Test weight (g)	Y= 336.558+293.369 X	0.282**	0.079
12	Protein yield (kg/ha)	Y = 1015.874+51.407 X	0.953**	0.909
13	Oil Yield (kg/ha)	Y= 254.788 +2.107 X	0.946**	0.894
14	Total N uptake(kg/ha)	Y= 276.752+10.212 X	0.892**	0.796
15	Total P_2O_5 uptake (kg/ha)	Y= 639.267+166.592 X	0.854**	0.729
16	Total K_2O uptake (kg/ha)	Y= 62.814+33.232 X	0.849**	0.721
17	Total Zn uptake (g/ha)	Y = 637.495+7.475 X	0.851**	0.724
18	Total B uptake (g/ha)	Y= 855.692+18.644 X	0.807**	0.651
$Y= - 68.613+7.078X_1- 0.455 X_2 - 2.015 X_3- 116.543 X_4+17.681 X_5 +1.474 X_6+74.388 X_7 +9.174 X_8 -22.281 X_9 -2.551 X_{10}+ 4.182 X_{11}+1.270 X_{12}+ 1.921 X_{13}+ 2.134 X_{14} – 22.600 X_{15}+0.848 X_{16}- 0.153 X_{17}+1.197 X_{18}$			0.976	0.953

** Correlation is significant at the 0.01 level (2-tailed)

Note: The dependent variables X_1, X_2, X_3….. X_{18} refers to the parameters listed in serial number 1, 2, 3…..18, respectively

4.9 SOIL MICROBIOLOGICAL STUDIES

4.9.1 POPULATION OF SOIL MICRO-ORGANISMS AT 50 PER CENT FLOWERING (X 10^n cfu/g soil)

4.9.1.1 Finger millet-soybean based cropping system

Significantly higher population of bacteria and fungi was observed in NPK + FYM + $ZnSO_4$ + borax + *A.brasilense*/*Bradyrhizobium japonicum* + VAM (T_{10}) at 50 per cent flowering in finger millet (55 x 10^5 and 33 x 10^4 cfu/g soil, respectively) and soybean (56.30 x 10^5 and 33 x 10^4 cfu/g soil, respectively) as compared to other treatments. However, it was found on par with application of NPK + FYM + $ZnSO_4$ + *A.brasilense* (T_6). Application of NPK + FYM + borax + *A.brasilense* (T_7) recorded significantly higher population of bacteria and fungi as compared to control at 50 per cent flowering in both finger millet and soybean crops (Table 4.9.1; Fig. 58 and 59).

The population of actinomycetes was higher with application of NPK + FYM + $ZnSO_4$ + borax + *A.brasilense* /*Bradyrhizobium japonicum* + VAM (T_{10}) in finger millet (22 x 10^3 cfu/g soil) and soybean (22 x 10^3 cfu/g soil) followed by NPK + FYM + $ZnSO_4$ + *A.brasilense* (T_6) in finger millet and soybean (21 x 10^3 cfu/g soil), while significantly lower population of actinomycetes was observed in control (T_1 : 8 and 9 x 10^3 cfu/g soil in finger millet and soybean, respectively) (Table 4.9.1 and Fig. 60).

4.9.1.2 Soybean-finger millet based cropping system

At 50 per cent flowering, significantly higher population of bacteria and fungi was observed with application of NPK + FYM + $ZnSO_4$ + borax + *A.brasilense*/*Bradyrhizobium japonicum* + VAM (T_{10}) in soybean (54.20 x 10^5 and 35 x 10^4 cfu/g soil, respectively) and finger millet (58.00 x 10^5 and 30 x 10^4 cfu/g soil, respectively) as compared to other treatments.

Table 4.9.1: Population of soil microorganisms at 50 per cent flowering of crops as influenced by zinc boron and microbial inoculants application in finger millet- soybean and soybean- finger millet based cropping system

Treatment	Population of soil microorganisms (x 10 ^{n} cfu /g soil) at 50% flowering											
	Bacteria (x10^{5})				Fungi (x10^{4})				Actinomycetes (x10^{3})			
	Finger millet	Soybean	Soybean	Finger millet	Finger millet	Soybean	Soybean	Finger millet	Finger millet	Soybean	Soybean	Finger millet
	2005	2006	2005	2006	2005	2006	2005	2006	2005	2006	2005	2006
T_1: Control (NPK+ FYM)	16.50	36.00	26.00	19.00	11.30	12.00	15.00	10.00	8.00	9.00	12.00	8.00
T_2:NPK + FYM + $ZnSO_4$	28.00	42.00	35.00	29.00	16.00	17.00	22.00	16.00	10.50	12.00	15.00	11.00
T_3:NPK + FYM + Borax	22.00	41.00	33.00	23.00	14.00	16.00	20.00	15.00	10.00	11.00	14.00	10.00
T_4:NPK + FYM + *A brasilense*	46.30	50.50	49.00	50.00	27.50	27.50	28.00	26.50	17.00	18.00	19.00	17.00
T_5: NPK + FYM + VAM	33.00	43.00	37.00	35.00	20.00	18.00	24.00	19.00	13.00	13.20	17.00	12.00
T_6:NPK+FYM+$ZnSO_4$+*A brasilense*	52.33	54.00	52.00	56.00	32.00	31.50	33.00	28.00	21.00	21.00	22.00	19.00
T_7:NPK+FYM+ Borax +*A brasilense*	49.00	51.00	50.00	53.00	28.00	29.30	31.00	27.30	19.50	20.50	20.00	18.50
T_8:NPK + FYM + $ZnSO_4$ + VAM	39.50	46.00	45.00	38.00	26.00	23.50	27.50	22.00	16.00	15.20	18.00	14.00
T_9:NPK + FYM + Borax + VAM	34.00	44.00	43.00	36.00	24.00	19.50	26.00	20.00	14.00	14.30	16.00	13.00
T_{10}:NPK + FYM + $ZnSO_4$ + Borax + *A brasilense* + VAM	55.00	56.30	54.20	58.00	33.00	33.00	35.00	30.00	22.00	22.00	23.00	20.50
F test	*	*	*	*	*	*	*	*	*	*	*	*
S.Em ±	**1.71**	**1.52**	**1.24**	**1.33**	**0.86**	**1.01**	**1.33**	**0.89**	**0.55**	**0.46**	**0.54**	**0.59**
CD at 5 %	**5.08**	**4.51**	**3.70**	**3.97**	**2.54**	**3.00**	**3.95**	**2.63**	**1.64**	**1.38**	**1.61**	**1.76**
CV (%)	**7.88**	**5.67**	**5.08**	**5.82**	**6.39**	**7.69**	**8.82**	**7.17**	**6.33**	**5.14**	**5.32**	**7.16**

$ZnSO_4$@ 12.50 kg/ha, Borax @ 10 kg/ha

Crop rotation: Finger millet (2005)- Soybean (2006), Soybean (2005)- Finger millet (2006)

Note: For Soybean crop seed treatment was carried out with *Bradyrhizobium* inoculant

For Finger millet – NPK @ 50:40:25 kg/ha and FYM @ 7.5 t/ha; Soybean – NPK @ 25:60:25 kg/ha and FYM @ 6.25 t/ha

However, it was found on par with application of NPK + FYM + $ZnSO_4$ + *Bradyrhizobium japonicum/A.brasilense* (T_6 : 52 x 10^5 and 33 x 10^4 cfu/g soil and 56 x 10^5 and 28 x 10^4 cfu/g soil in soybean and finger millet, respectively), whereas application of NPK + FYM + borax + *Bradyrhizobium japonicum* / *A.brasilense* (T_7) and NPK + FYM + *Bradyrhizobium japonicum / A.brasilense* were found at par with each other and recorded significantly higher population of bacteria and fungi over control in soybean and finger millet (Table 4.9.1; Fig. 58 and 59).

Among the different treatments, application of NPK + FYM + $ZnSO_4$ + borax + *Bradyrhizobium japonicum* / *A.brasilense* + VAM (T_{10}) registered significantly higher population of actinomycetes in soybean (23 x 10^3 cfu/g soil) and finger millet (20.50 cfu/g soil) followed by NPK + FYM + $ZnSO_4$ + *Bradyrhizobium japonicum* / *A.brasilense* (T_6) in soybean (22 x 10^3 cfu/g soil) and finger millet (19 x 10^3 cfu/g soil). These two treatments were found on par with each other but recorded significantly higher population over other treatments. Significantly lower population of actinomycetes was observed in control (T_1) in soybean (12 x 10^3) and finger millet (8 x 10^3 cfu/g soil) (Table 4.9.1 and Fig. 60).

4.9.2 POPULATION OF SOIL MICROORGANISMS AT HARVEST (x 10^n cfu/g soil)

The population of soil micro-organisms differed significantly due to application of zinc, boron and microbial inoculants and there was a marked decline in the population of soil microorganisms at harvest (Table 4.9.2).

4.9.2.1 Finger millet-soybean based cropping system

Application of NPK + FYM + $ZnSO_4$ + borax + *A.brasilense* / *Bradyrhizobium japonicum* + VAM (T_{10}) recorded significantly higher population of bacteria (38.50 and 37 x 10^5 cfu/g soil, respectively), fungi

Table 4.9.2: Population of soil microorganisms at harvest of crops as influenced by zinc boron and microbial inoculants application in finger millet- soybean and soybean- finger millet based cropping system

Treatment	Population of soil microorganisms (x 10 ^{n} cfu /g soil) at harvest											
	Bacteria (x10^{5})				Fungi (x10^{4})				Actinomycetes (x10^{3})			
	Finger millet	Soybean	Soybean	Finger millet	Finger millet	Soybean	Soybean	Finger millet	Finger millet	Soybean	Soybean	Finger millet
	2005	2006	2005	2006	2005	2006	2005	2006	2005	2006	2005	2006
T_1: Control (NPK+ FYM)	10.50	20.00	14.50	18.00	6.50	9.00	8.00	7.00	3.00	6.80	6.00	5.30
T_2:NPK + FYM + $ZnSO_4$	19.00	25.00	22.00	23.00	13.00	12.00	15.00	9.00	6.50	10.00	7.00	9.00
T_3:NPK + FYM + Borax	17.00	24.00	19.00	22.00	11.00	11.00	13.00	8.00	5.00	9.00	6.50	8.00
T_4:NPK + FYM + *A brasilense*	30.00	31.00	35.00	29.00	23.00	14.00	25.00	14.00	12.00	15.00	13.00	14.00
T_5: NPK + FYM + VAM	20.00	26.00	26.00	24.00	16.00	11.00	18.00	10.00	8.00	11.00	8.50	10.10
T_6:NPK+FYM+$ZnSO_4$+*A brasilense*	36.00	35.00	38.00	34.00	22.00	18.33	30.00	17.00	15.00	17.00	17.00	15.00
T_7:NPK+FYM+ Borax + *A brasilense*	33.00	32.00	36.00	30.00	20.00	17.00	28.00	16.00	13.00	16.00	15.00	15.00
T_8:NPK + FYM + $ZnSO_4$ + VAM	27.00	30.00	33.00	28.00	18.00	13.00	23.00	12.00	10.00	13.00	10.00	12.00
T_9:NPK + FYM + Borax + VAM	23.00	28.00	30.00	26.00	17.00	12.00	20.00	11.00	9.50	12.10	9.00	11.10
T_{10}:NPK + FYM + $ZnSO_4$ + Borax + *A brasilense* + VAM	38.50	37.00	40.60	35.00	25.00	19.33	33.00	18.00	17.00	18.00	19.00	16.00
F test	*	*	*	*	*	*	*	*	*	*	*	*
S.Em ±	**1.18**	**1.23**	**1.37**	**1.08**	**1.19**	**0.66**	**1.56**	**0.62**	**0.93**	**0.63**	**1.02**	**0.66**
CD at 5 %	**3.50**	**3.65**	**4.07**	**3.22**	**3.52**	**1.98**	**4.65**	**1.84**	**2.77**	**1.87**	**3.04**	**1.96**
CV (%)	**8.03**	**7.38**	**8.06**	**6.98**	**11.98**	**8.43**	**12.72**	**8.81**	**16.29**	**8.52**	**15.98**	**9.87**

$ZnSO_4$@ 12.50 kg/ha, Borax @ 10 kg/ha

Crop rotation: Finger millet (2005)- Soybean (2006), Soybean (2005)- Finger millet (2006)

Note: For Soybean crop seed treatment was carried out with *Bradyrhizobium* inoculant

For Finger millet – NPK @ 50:40:25 kg/ha and FYM @ 7.5 t/ha; Soybean – NPK @ 25:60:25 kg/ha and FYM @ 6.25 t/ha

(25 and 19.33 x 10^4 cfu/g soil, respectively) and actinomycetes (17 and 18 x 10^3 cfu/g soil, respectively) at harvest in finger millet and soybean, respectively as compared to other treatments. However, it was found on par with application of NPK + FYM + $ZnSO_4$ + *A.brasilense* / *Bradyrhizobium japonicum* (T_6 : 36 and 35 x 10^5, 22 and 18.33 x 10^4, 15 and 17 x 10^3 cfu/g, soil, respectively). Least activity of bacteria, fungi and actinomycetes (10.50 and 20 x 10^5, 6.50 and 9 x 10^4, 3 and 6.80 x 10^3 cfu/g soil, respectively) was observed in control (T_1) (Table 4.9.2; Fig. 58, 59 and 60).

4.9.2.2 Soybean-finger millet based cropping system

Significantly maximum population of bacteria, fungi and actinomycetes (40.60 and 35 x 10^5, 33 and 18 x 10^4 and 19 and 16 x 10^3 cfu/g soil, respectively) was observed with application of NPK + FYM + $ZnSO_4$ + borax + *Bradyrhizobium japonicum* / *A.brasilense* + VAM (T_{10}) at harvest in soybean and finger millet crops as compared to rest of the treatments. However, it was found on par with application of NPK + FYM + $ZnSO_4$ + *Bradyrhizobium japonicum* / *A.brasilense* (T_6 : 38 and 34 x 10^5, 30 and 17.00 x 10^4 and 17 and 15 x 10^3 cfu/g soil, respectively) in soybean and finger millet crops at harvest. Least activity of all the microorganisms were observed in control (T_1 : 14.50 and 18 x 10^5, 8 and 7 x 10^4 and 6 and 5.30 x 10^3 cfu/g soil, respectively) (Table 4.9.2; Fig. 58, 59 and 60).

4.9.3 SOIL ENZYMES ACTIVITY AT 50 PER CENT FLOWERING

4.9.3.1 Finger millet-soybean based cropping system

The activity of dehydrogenase was significantly higher (188 and 190 µg TPF/g soil/24 h at 50% flowering in finger millet and soybean, respectively) with application of NPK + FYM + $ZnSO_4$ + borax + *A.brasilense* / *Bradyrhizobium japonicum* + VAM (T_{10}) as compared to

other treatments. However, it was found on par with application of NPK + FYM + $ZnSO_4$ + *A. brasilense* / *Bradyrhizobium japonicum* (T_6 : 170 and 180 µg TPF/g soil/24 h at 50% flowering in finger millet and soybean, respectively) (Fig. 61)..

The urease, acid and alkaline phosphatase activity was found to be higher with the application of NPK + FYM + $ZnSO_4$ + borax + *A.brasilense* / *Bradyrhizobium japonicum* + VAM(T_{10} :57 and 59 µg NH_4N/g soil/2 h, 175 and 190 µg PNP/g soil/h, 65 and 80 µg PNP/g soil/h, in finger millet and soybean, respectively). However, it was found on par with application of NPK + FYM + $ZnSO_4$ + *A.brasilense* / *Bradyrhizobium japonicum* (T_6 : 51 and 55 µg NH_4N/g soil/2 h, respectively) with regard to urease activity and NPK + FYM + $ZnSO_4$ + VAM (T_8) with respect to acid (165 and 180 µg PNP/g soil/h, respectively) and alkaline (61 and 75 µg PNP/g soil/h, respectively) phosphatase activity in finger millet and soybean crops. Indeed, least activity of dehydrogenase, urease, acid and alkaline phosphatase was observed in control (T_1 : 78 and 87 µg/TPF/g soil/24 h, 20 and 30 µg NH_4 N/g soil/2 h, 95 and 100 µg PNP/g soil h; 25 and 24 µg PNP/g soil/h in finger millet and soybean, respectively) (Table 4.9.3; Fig. 62, 63 and 64).

4.9.3.2 Soybean-finger millet based cropping system

The activity of dehydrogenase and urease was significantly higher (193 and 183 µg TPF/g soil/24 h; 56 and 60 µg NH_4 N/g soil/2 h, respectively) with application of NPK + FYM + $ZnSO_4$ + borax + *Bradyrhizobium japonicum* / *A.brasilense* + VAM (T_{10}) in soybean and finger millet crops as compared to rest of the treatments. However, it was found on par with application of NPK + FYM + $ZnSO_4$ + *Bradyrhizobium japonicum* + *A.brasilense* + VAM (T_6) with regard to dehydrogenase activity in soybean (185 µg TPF/g soil/24 h) and urease activity (53 and 55 µg NH_4N/g soil/2 h, respectively) in soybean and

Table 4.9.3: Dehydrogenase, urease, acid phosphatase and alkaline phosphatase enzymes activity in soil at 50 % flowering of crops as influenced by zinc boron andmicrobial inoculants application in finger millet- soybean and soybean- finger millet based cropping system

Treatment	Soil enzymes activity at 50 % flowering															
	Dehydrogenase (µg TPF/g soil /24 h)				Urease (µg NH_4N/g soil /2h)				Acid phosphatase (µg PNP/g soil / h)				Alkaline phosphatase (µg PNP/g soil / h)			
	Finger millet	Soybean	Soybean	Finger millet	Finger millet	Soybean	Soybean	Finger millet	Finger millet	Soybean	Soybean	Finger millet	Finger millet	Soybean	Soybean	Finger millet
	2005	2006	2005	2006	2005	2006	2005	2006	2005	2006	2005	2006	2005	2006	2005	2006
T_1	78	87	95	60	20	30	27	26	95	100	100	98	25	24	20	30
T_2	113	115	140	108	27	40	37	30	124	130	127	130	38	54	50	45
T_3	105	100	112	100	24	36	34	27	117	120	118	122	35	28	24	40
T_4	141	145	160	129	33	48	45	38	107	113	110	115	30	26	22	35
T_5	134	130	150	125	30	45	42	35	153	170	165	155	50	65	58	53
T_6	170	180	185	166	51	55	53	55	137	150	148	143	45	62	56	50
T_7	145	175	179	138	41	54	48	46	130	140	138	135	40	58	52	48
T_8	156	177	183	150	46	53	50	50	165	180	178	170	61	75	70	65
T_9	143	167	172	133	37	50	45	42	155	176	173	160	56	73	67	60
T_{10}	188	190	193	183	57	59	56	60	175	190	185	180	65	80	76	68
F test	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
S.Em ±	**6.23**	**4.31**	**4.34**	**4.75**	**2.14**	**1.62**	**2.32**	**2.51**	**5.01**	**6.59**	**5.85**	**5.22**	**2.57**	**3.41**	**3.01**	**3.07**
CD at 5 %	**18.51**	**12.79**	**12.89**	**14.10**	**6.34**	**4.82**	**6.90**	**7.45**	**14.90**	**19.58**	**17.38**	**15.50**	**7.64**	**10.14**	**8.93**	**9.14**
CV (%)	**7.86**	**5.09**	**4.79**	**6.36**	**10.10**	**5.98**	**9.20**	**10.62**	**6.39**	**7.77**	**7.03**	**6.42**	**10.00**	**10.85**	**10.52**	**10.78**

T_1: Control (NPK+ FYM), T_2:NPK + FYM + $ZnSO_4$, T_3:NPK + FYM + Borax, T_4:NPK + FYM + *A brasilense,* T_5: NPK + FYM + VAM, T_6:NPK+FYM+$ZnSO_4$+ *A brasilense* ,T_7:NPK+FYM+ Borax + *A brasilense* , T_8: NPK +FYM + $ZnSO_4$ + VAM, T_9:NPK + FYM + Borax + VAM, T_{10}:NPK + FYM + $ZnSO_4$ + Borax + *A brasilense* + VAM

$ZnSO_4$@ 12.50 kg/ha, Borax @ 10 kg/ha

Crop rotation: Finger millet (2005)- Soybean (2006), Soybean (2005)- Finger millet (2006)

Note: For Soybean crop seed treatment was carried out with *Bradyrhizobium* inoculant

For Finger millet – NPK @ 50:40:25 kg/ha and FYM @ 7.5 t/ha; Soybean – NPK @ 25:60:25 kg/ha and FYM @ 6.25 t/ha

finger millet, respectively. Least activity of dehydrogenase and urease was found in control (T_1).

Significantly higher activity of acid and alkaline phosphatase was observed with application of NPK + FYM + $ZnSO_4$ + borax + *Bradyrhizobium japonicum / A.brasilense* + VAM (T_{10} : 185 and 180; 76 and 68 µg PNP/g soil/h in soybean and finger millet crops, respectively) as compared to all other treatments, but was found on par with application of NPK + FYM + $ZnSO_4$ + VAM (T_8 : 178 and 170; 70 and 65 µg PNP/g soil/h in finger millet and soybean crops, respectively) and NPK + FYM + borax + VAM (T_9) with regard to acid phosphatase activity in soybean (173 µg PNP/g soil/h) and alkaline phosphatase activity in finger millet (60 µg PNP/g soil/h). Least activity of acid and alkaline phosphatase activity was observed in control (T_1) (Table 4.9.3; Fig. 61 and 62).

4.9.4 SOIL ENZYMATIC ACTIVITY AT HARVEST

4.9.4.1 Finger millet-soybean based cropping system

Application of NPK + FYM + $ZnSO_4$ + borax + *A.brasilense / Bradyrhizobium japonicum* + VAM (T_{10}) supported higher activity of dehydrogenase (137 and 153 µg TPF/g soil/24 h), urease (44 and 46 µg NH_4N/g soil/2 h) as compared to rest of the treatments in finger millet and soybean crops. However, it was found on par with application of NPK + FYM + $ZnSO_4$ + *A.brasilense* / *Bradyrhizobium japonicum* (T_6 : 130 and 140 µg TPF/g soil/24 h; 40 and 41 µg NH_4N/g soil/2 h, respectively). The least activity of dehydrogenase and urease was observed in control (T_1) (Table 4.9.4; Fig. 61 and 62).

The activity of acid and alkaline phosphatase was encouraged significantly to a maximum extent by application of NPK + FYM + $ZnSO_4$ + borax + *A.brasilense / Bradyrhizobium japonicum* + VAM (T_{10} : 133

Table 4.9.4: Dehydrogenase, urease, acid phosphatase and alkaline phosphatase enzymes activity in soil at harvest of crops as influenced by zinc boron andmicrobial inoculants application in finger millet- soybean and soybean- finger millet based cropping system

Treatment	Soil enzymes activity at harvest															
	Dehydrogenase (µg TPF/g soil /24 h)				Urease (µg NH_4N/g soil /2h)				Acid phosphatase (µg PNP/g soil / h)				Alkaline phosphatase (µg PNP/g soil / h)			
	Finger millet	Soybean	Soybean	Finger millet	Finger millet	Soybean	Soybean	Finger millet	Finger millet	Soybean	Soybean	Finger millet	Finger millet	Soybean	Soybean	Finger millet
	2005	2006	2005	2006	2005	2006	2005	2006	2005	2006	2005	2006	2005	2006	2005	2006
T_1	44	60	55	50	14	18	17	14	75	98	94	80	15	20	18	19
T_2	80	95	91	85	19	20	22	16	90	125	120	95	25	35	33	27
T_3	66	90	85	70	16	18	18	15	86	120	115	91	19	30	27	24
T_4	91	108	105	95	25	26	27	21	80	113	108	85	16	24	21	20
T_5	84	101	97	90	23	23	25	18	110	150	140	115	33	45	41	37
T_6	130	140	137	135	40	41	42	36	102	140	130	108	29	42	36	32
T_7	110	120	113	115	31	32	33	28	97	132	127	103	27	38	35	30
T_8	116	120	117	120	36	35	38	32	118	175	170	125	40	48	45	45
T_9	91	118	108	100	28	28	30	24	115	165	160	122	35	47	43	40
T_{10}	137	153	147	140	44	46	45	44	133	196	194	130	45	52	48	48
F test	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
S.Em ±	**6.29**	**6.02**	**5.70**	**6.41**	**1.96**	**1.96**	**3.71**	**1.61**	**3.21**	**6.98**	**5.86**	**3.49**	**1.19**	**1.66**	**2.05**	**1.68**
CD at 5 %	**18.68**	**17.88**	**16.95**	**19.05**	**5.83**	**5.81**	**11.02**	**4.77**	**9.53**	**20.74**	**17.40**	**10.36**	**3.54**	**4.92**	**6.08**	**4.98**
CV (%)	**11.47**	**9.43**	**9.36**	**11.11**	**12.29**	**11.80**	**21.64**	**11.21**	**5.52**	**8.55**	**7.47**	**5.73**	**7.26**	**7.53**	**10.22**	**9.02**

T_1: Control (NPK+ FYM), T_2:NPK + FYM + $ZnSO_4$, T_3:NPK + FYM + Borax, T_4:NPK + FYM + *A brasilense,* T_5: NPK + FYM + VAM, T_6:NPK+FYM+$ZnSO_4$+ *A brasilense,* T_7:NPK+FYM+ Borax + *A brasilense* , T_8: NPK +FYM + $ZnSO_4$ + VAM, T_9:NPK + FYM + Borax + VAM, T_{10}:NPK + FYM + $ZnSO_4$ + Borax + *A brasilense* + VAM

$ZnSO_4$@ 12.50 kg/ha, Borax @ 10 kg/ha

Crop rotation: Finger millet (2005)- Soybean (2006), Soybean (2005)- Finger millet (2006)

Note: For Soybean crop seed treatment was carried out with *Bradyrhizobium* inoculant

For Finger millet – NPK @ 50:40:25 kg/ha and FYM @ 7.5 t/ha; Soybean – NPK @ 25:60:25 kg/ha and FYM @ 6.25 t/ha

aand 196; 45 and 52 µg PNP/g soil/h in finger millet and soybean, respectively) as compared to all other treatments except in soybean (48 µg PNP/g soil/h) with regard to alkaline phosphatase activity. The activity of acid and alkaline phosphatase was least in control (T_1 : 75 and 98; 15 and 20 µg PNP/g soil/h in finger millet and soybean, respectively) (Fig.63 and 64).

4.9.4.2 Soybean-finger millet based cropping system

The activity of dehydrogenase and urease enzymes was encouraged significantly to a maximum extent by application of NPK + FYM + $ZnSO_4$ + borax + *Bradyrhizobium japonicum* / *Bradyrhizobium japonicum* (T_{10} : 147 and 140 µg TPF/g soil/24 h; 45 and 44 µg NH_4N/g soil/2 h, in soybean and finger millet, respectively) as compared to rest of the treatments. However, it was found on par with application of NPK + FYM + $ZnSO_4$ + *Bradyrhizobium japonicum / A.brasilense* (T_6) with regard to dehydrogenase activity (137 and 135 µg soil/24 h; in soybean and finger millet, respectively) and urease activity (42 µg NH_4N/g soil/2 h) in soybean (Table 4.9.4; Fig. 61 and 62).

Application of NPK + FYM + $ZnSO_4$ + borax + *Bradyrhizobium japonicum* / *A.brasilense* + VAM (T_{10}) supported maximum activity of acid and alkaline phosphatase in soybean (194 and 48 µg PNP/g soil/h, respectively) and finger millet (130 and 48 µg PNP/g soil/h, respectively) as compared to rest of the treatments. However, application of NPK + FYM + $ZnSO_4$ + VAM (T_8) was found on par with regard to acid phosphatase activity in finger millet (125 µg PNP/g soil/h) and alkaline phosphatase activity in soybean (45 µg PNP/g soil/h) and finger millet (45 µg PNP/g soil/h) and finger millet (45 µg PNP/g soil/h). Application of NPK + FYM + borax + VAM (T_9) was found on par with above said treatments with regard to acid phosphatase activity in finger millet (122

µg PNP/g soil/h) and alkaline phosphatase activity in soybean (43 µg PNP/g soil/h) (Table 4.9.4; Fig. 63 and 64).

4.10 AVAILABLE NUTRIENTS STATUS OF SOIL

4.10.1 AVAILABLE NITROGEN (kg/ha)

4.10.1.1 Finger millet-soybean based cropping system

Significantly higher available nitrogen after harvest of finger millet was recorded in control (T_1 : NPK + FYM; 225.55 kg/ha). However, it was found on par with all other treatments except with application of NPK + FYM + $ZnSO_4$ + *A.brasilense* (T_6 : 182.93 kg/ha), NPK + FYM + $ZnSO_4$ + VAM (T_8 : 186.02 kg/ha) and NPK + FYM + $ZnSO_4$ + borax + *A.brasilense* + VAM (T_{10} : 176.79 kg/ha) (Table 4.10.1).

Application of NPK + FYM (T_1 : 199.46 kg/ha) recorded significantly higher available nitrogen after harvest of soybean as compared to other treatments. However, it was found on par with application of NPK + FYM + *Bradyrhizobium japonicum* (T_4 : 196.79 kg/ha), NPK + FYM + VAM (T_5 : 185.05 kg/ha) and NPK + FYM + borax + VAM (T_9 : 187.99 kg/ha) (Table 4.10.1 and Fig. 65).

4.10.1.2 Soybean-finger millet based cropping system

Application of NPK + FYM + $ZnSO_4$ + borax + *Bradyrhizobium japonicum* + VAM (T_{10}) recorded significantly lower available nitrogen (175.85 kg/ha) after harvest of soybean as compared to other treatments. However, it was found on par with application of NPK + FYM + $ZnSO_4$ + VAM (T_8 : 183.02 kg/ha) and NPK + FYM + $ZnSO_4$ + *Bradyrhizobium japonicum* (T_6 : 176.89 kg/ha) (Table 4.10.1 and Fig. 65).

Significantly lower available nitrogen was recorded after harvest of finger millet with application of NPK + FYM + $ZnSO_4$ + borax + *A.brasilense* + VAM (T_{10} : 156.16 kg/ha) as compared to other treatments

Table 4.10.1: Available nitrogen, phosphorus and potassium status in soil after harvest of crops as influenced by zinc, boron and microbial inoculants application in finger millet- soybean and soybean- finger millet based cropping system

Treatment	Available nitrogen (kg/ha)				Available phosphorus (kg/ha)				Available potassium (kg/ha)			
	Finger millet	Soybean	Soybean	Finger millet	Finger millet	Soybean	Soybean	Finger millet	Finger millet	Soybean	Soybean	Finger millet
	2005	2006	2005	2006	2005	2006	2005	2006	2005	2006	2005	2006
T_1: Control (NPK+ FYM)	225.55	199.46	207.94	211.93	96.02	128.39	129.35	133.96	149.88	168.35	175.20	180.34
T_2:NPK + FYM + $ZnSO_4$	202.35	171.02	201.19	192.25	97.09	131.54	131.27	139.96	134.46	150.60	169.35	175.30
T_3:NPK + FYM + Borax	208.94	176.46	199.56	197.92	96.27	130.02	130.96	137.62	138.69	165.80	172.30	169.20
T_4:NPK + FYM + *A brasilense*	213.15	196.79	218.60	212.84	95.81	127.91	129.21	139.06	144.20	155.80	174.20	173.30
T_5: NPK + FYM + VAM	215.80	185.05	205.35	205.74	107.51	151.55	131.24	150.01	148.81	165.20	175.80	176.20
T_6:NPK+FYM+$ZnSO_4$+ *A brasilense*	182.93	128.59	176.89	159.85	96.95	127.93	132.03	140.67	132.03	158.35	163.20	180.20
T_7:NPK+FYM+ Borax + *A brasilense*	199.82	172.60	206.07	196.45	98.78	127.62	128.72	142.27	135.34	155.68	166.30	176.30
T_8:NPK + FYM + $ZnSO_4$ + VAM	186.02	136.54	183.02	170.35	100.85	142.93	131.50	139.88	117.14	167.53	179.30	179.30
T_9:NPK + FYM + Borax + VAM	207.94	187.99	205.80	201.12	105.85	151.77	131.74	144.33	137.77	163.21	182.30	172.30
T_{10}:NPK + FYM + $ZnSO_4$ + Borax + *A brasilense* + VAM	176.79	119.04	175.85	156.16	96.75	137.65	128.83	132.78	114.73	172.68	185.60	185.30
F test	*	*	*	*	*	*	*	*	*	*	*	*
S.Em +	**8.68**	**6.94**	**7.39**	**8.48**	**4.35**	**5.60**	**5.65**	**6.06**	**6.00**	**5.79**	**7.84**	**5.76**
CD at 5 %	**25.79**	**20.62**	**21.96**	**25.19**	**NS**	**16.64**	**NS**	**NS**	**17.82**	**17.20**	**NS**	**NS**
CV (%)	**7.44**	**7.18**	**6.47**	**7.71**	**7.59**	**7.15**	**7.50**	**7.49**	**7.68**	**6.18**	**7.78**	**5.65**

$ZnSO_4$@ 12.50 kg/ha, Borax @ 10 kg/ha, **NS:** Non significant

Crop rotation: Finger millet (2005)- Soybean (2006), Soybean (2005)- Finger millet (2006)

Note: For Soybean crop seed treatment was carried out with *Bradyrhizobium* inoculant

For Finger millet – NPK @ 50:40:25 kg/ha and FYM @ 7.5 t/ha; Soybean – NPK @ 25:60:25 kg/ha and FYM @ 6.25 t/ha

while, it was found on par with application of NPK + FYM + $ZnSO_4$ + *A.brasilense* (T_6 : 159.85 kg/ha) and NPK + FYM + $ZnSO_4$ + VAM (T_8 : 170.35 kg/ha).

4.10.2 AVAILABLE PHOSPHORUS (kg/ha)

4.10.2.1 Finger millet-soybean based cropping system

The available phosphorus in soil after harvest of finger millet did not differ significantly due to different treatments (Table 4.10.1 and Fig. 66).

Significantly higher available phosphorus after harvest of soybean was recorded with application of NPK + FYM + borax + VAM (T_9 : 151.77 kg/ha) as compared to other treatments. However, it was found on par with application of NPK + FYM + VAM (T_5 : 151.55 kg/ha), NPK + FYM + $ZnSO_4$ + VAM (T_8 : 142.93 kg/ha) and NPK + FYM + $ZnSO_4$ + borax + *Bradyrhizobium japonicum* + VAM (T_{10} : 137.65 kg/ha).

4.10.2.2 Soybean-finger millet based cropping system

The available phosphorus status in soil after harvest of soybean and finger millet crops did not differ significantly due to different treatments (Table 4.10.1 and Fig. 66).

4.10.3 AVAILABLE POTASSIUM (kg/ha)

4.10.3.1 Finger millet-soybean based cropping system

Significantly lower available potassium in soil after harvest of finger millet was recorded with application of NPK + FYM + $ZnSO_4$ + borax + *A.brasilense* + VAM (T_{10} : 114.73 kg/ha) as compared to other treatments. Nevertheless, it was found on par with application of NPK + FYM + $ZnSO_4$ + *A.brasilense* (T_6 : 132.03 kg/ha) and NPK + FYM + $ZnSO_4$ + VAM (T_8 : 117.14 kg/ha) (Table 4.10.1 and Fig. 67).

The available potassium status in soil after harvest of soybean did not differ significantly due to different treatments. However, application of NPK + FYM + $ZnSO_4$ + borax + *Bradyrhizobium japonicum* + VAM (T_{10}) recorded slightly higher available potassium (172.68 kg/ha).

4.10.3.2 Soybean-finger millet based cropping system

The available potassium status in soil did not differ significantly due to zinc, boron and microbial inoculants application. However, application of NPK + FYM + $ZnSO_4$ + borax + *A.brasilense* (*Bradyrhizobium japonicum* for soybean) + VAM (T_{10}) recorded slightly higher available potassium of 185.60 and 185.30 kg per ha after harvest of soybean and finger millet, respectively (Table 4.10.1 and Fig. 67).

4.10.4 AVAILABLE ZINC (ppm)

4.10.4.1 Finger millet-soybean based cropping system

Significantly higher available zinc status in soil after harvest of finger millet was registered with application of NPK + FYM + $ZnSO_4$ + borax + *A.brasilense* + VAM (T_{10} : 1.25 ppm) as compared to other treatments. However, it was found on par with application of NPK + FYM + $ZnSO_4$ + borax + *A.brasilense* (T_6 : 1.20 ppm) and NPK + FYM + $ZnSO_4$ + VAM (T_8 : 1.18 ppm) (Table 4.10.2 and Fig. 68).

Application of NPK + FYM + $ZnSO_4$ + borax + *Bradyrhizobium japonicum* + VAM (T_{10}) recorded significantly higher available zinc (1.80 ppm) followed by NPK + FYM + $ZnSO_4$ + *Bradyrhizobium japonicum* (T_6 : 1.75 ppm), NPK + FYM + $ZnSO_4$ + VAM (T_8 : 1.72 ppm) and NPK + FYM + $ZnSO_4$ (T_2 : 1.69 ppm) as compared to other treatments. However, all these treatments were found on par with each other.

Table 4.10.2: Available zinc and boron status in soil after harvest of crops as influenced by zinc, boron and microbial inoculants application in finger millet- soybean and soybean- finger millet based cropping system

Treatment	Available zinc (ppm)				Available boron (ppm)			
	Finger millet	Soybean	Soybean	Finger millet	Finger millet	Soybean	Soybean	Finger millet
	2005	2006	2005	2006	2005	2006	2005	2006
T_1: Control (NPK+ FYM)	0.44	0.45	0.45	0.46	0.37	0.34	0.38	0.34
T_2:NPK + FYM + $ZnSO_4$	1.10	1.69	1.26	1.72	0.38	0.33	0.37	0.33
T_3:NPK + FYM + Borax	0.46	0.43	0.45	0.45	0.71	0.98	0.71	1.00
T_4:NPK + FYM + *A brasilense*	0.45	0.44	0.47	0.46	0.37	0.33	0.37	0.32
T_5: NPK + FYM + VAM	0.44	0.42	0.45	0.44	0.36	0.32	0.38	0.32
T_6:NPK+ FYM+$ZnSO_4$+ *A brasilense*	1.20	1.75	1.29	1.77	0.37	0.32	0.37	0.33
T_7:NPK+FYM+ Borax + *A brasilense*	0.43	0.40	0.44	0.43	0.70	0.99	0.71	1.10
T_8:NPK + FYM + $ZnSO_4$ + VAM	1.18	1.72	1.30	1.74	0.37	0.30	0.36	0.31
T_9:NPK + FYM + Borax + VAM	0.41	0.38	0.45	0.41	0.68	0.98	0.71	0.98
T_{10}:NPK + FYM + $ZnSO_4$ + Borax + *A brasilense* + VAM	1.25	1.80	1.32	1.82	0.71	0.98	0.72	1.00
F test	*	*	*	*	*	*	*	*
S.Em ±	**0.04**	**0.05**	**0.04**	**0.06**	**0.02**	**0.03**	**0.02**	**0.04**
CD at 5 %	**0.11**	**0.15**	**0.13**	**0.17**	**0.07**	**0.09**	**0.06**	**0.11**
CV (%)	**8.54**	**9.07**	**9.46**	**10.03**	**7.66**	**9.37**	**7.19**	**10.34**

$ZnSO_4$@ 12.50 kg/ha, Borax @ 10 kg/ha

Crop rotation: Finger millet (2005)- Soybean (2006), Soybean (2005)- Finger millet (2006)

Note: For Soybean crop seed treatment was carried out with *Bradyrhizobium* inoculant

For Finger millet – NPK @ 50:40:25 kg/ha and FYM @ 7.5 t/ha; Soybean – NPK @ 25:60:25 kg/ha and FYM @ 6.25 t/ha

4.10.4.2 Soybean-finger millet based cropping system

Application of NPK + FYM + $ZnSO_4$ + borax + *Bradyrhizobium japonicum* (*A.brasilense* for finger millet crop) + VAM (T_{10}) recorded significantly higher available zinc status in soil after harvest of soybean-finger millet crops (1.32 and 1.82 ppm, respectively) as compared to other treatments. However, it was found on par with application of NPK + FYM + $ZnSO_4$ + VAM (T_8 : 1.30 and 1.74 ppm, respectively), NPK + FYM + $ZnSO_4$ + *Bradyrhizobium japonicum*/*A.brasilense* (T_6 : 1.29 and 1.77 ppm, respectively) and NPK + FYM + $ZnSO_4$ (T_2 : 1.26 and 1.72 ppm, respectively) (Table 4.10.2 and Fig. 68).

4.10.5 AVAILABLE BORON (ppm)

4.10.5.1 Finger millet-soybean based cropping system

Significantly higher available boron status in soil was recorded with application of NPK + FYM + $ZnSO_4$ + borax + *A.brasilense* (*Bradyrhizobium japonicum* for soybean) + VAM (T_{10} : 0.71 and 0.98 ppm, respectively), NPK + FYM + borax (T_3 : 0.71 and 0.98 ppm, respectively), NPK + FYM + borax + *A.brasilense / Bradyrhizobium japonicum* (T_7 : 0.70 and 0.99 ppm, respectively) after harvest of finger millet and soybean as compared to other treatments. However, all these treatments were found on par with each other (Table 4.10.2 and Fig. 69).

4.10.5.2 Soybean-finger millet based cropping system

Application of NPK + FYM + $ZnSO_4$ + borax + *Bradyrhizobium japonicum / A.brasilense* + VAM (T_{10} : 0.72 and 1.0 ppm, respectively), NPK + FYM + borax + VAM (T_9 : 0.71 and 0.98 ppm, respectively), NPK + FYM + borax + *Bradyrhizobium japonicum / A.brasilense* (T_7 :0.71 and 1.10 ppm, respectively) and NPK + FYM + borax (T_3 :0.71 and 1ppm, respectively) recorded significantly higher available boron in soil after

harvest of soybean and finger millet, respectively as compared to other treatments (Table 4.10.2 and Fig. 69).

4.11 BALANCE SHEET OF NITROGEN, PHOSPHORUS, POTASSIUM, ZINC AND BORON STATUS IN SOIL AS INFLUENCED BY ZINC, BORON AND MICROBIAL INOCULANTS APPLICATION IN FINGER MILLET-SOYBEAN AND SOYBEAN-FINGER MILLET BASED CROPPING SYSTEM

4.11.1 NITROGEN BALANCE STUDIES IN SOIL

The data pertaining to nitrogen balance as influenced by different treatments in finger millet-soybean and soybean-finger millet cropping system are presented in Table 4.11.1 to 4.11.2.

4.11.1.1 Finger millet-soybean based cropping system

The initial available nitrogen status in soil was 238.0 kg per ha (Table 4.11.1). The addition of nitrogen through organic manure and fertilizers was 90.50 kg per ha. Maximum uptake of nitrogen by finger millet was observed with application of NPK + FYM + $ZnSO_4$ + borax + *A.brasilense* + VAM (T_{10} :116.18 kg/ha), while application of NPK + FYM (T_1) recorded lower uptake of nitrogen (62.0 kg/ha). There was a negative balance of nitrogen observed in all the treatments. Application of NPK + FYM (T_1) recorded higher negative balance of nitrogen (40.95 kg/ha) (Table 4.11.1).

The actual N balance after harvest of finger millet (2005) would be the initial soil available N during 2006. The initial status of soil available nitrogen was higher on NPK + FYM treatment (T_1 : 225.55 kg/ha). The addition of nitrogen through fertilizer and manures was 58.75 kg/ha which was same to all the treatments. Total nitrogen removed by soybean crop was higher with application of NPK + FYM + $ZnSO_4$ + borax + *Bradyrhizobium japonicum* + VAM (T_{10} : 166.50 kg/ha) followed by NPK

Table 4.11.1: Nitrogen balance in soil as influenced by zinc, boron and microbial inoculants application in finger millet –soybean based cropping system

Treatments	Finger millet (2005)							Soybean (2006)						
	Initial soil available N (kg/ha)	Addition of N through fertilizers and manures (kg/ha	Total N (kg/ha)	Crop uptake of N (kg/ha)	Expected N balance (kg/ha)	Actual N balance (kg/ha	Net gain (+) or Net loss (-) (kg/ha)	Initial soil available N (kg/ha)	Addition of N through fertilizers and manures (kg/ha	Total N (kg/ha)	Crop uptake of N (kg/ha)	Expected N balance (kg/ha)	Actual N balance (kg/ha	Net gain (+) or Net loss (-) (kg/ha)
	(1)	(2)	3=(1+2)	(4)	5=(3-4)	(6)	7=(6-5)	(1)	(2)	3=(1+2)	(4)	5=(3-4)	(6)	7=(6-5)
T_1	238.00	90.50	328.50	62.00	266.50	225.55	-40.95	225.55	58.75	284.30	105.80	178.50	199.46	20.96
T_2	238.00	90.50	328.50	87.78	240.72	202.35	-38.37	202.35	58.75	261.10	129.93	131.17	171.02	39.85
T_3	238.00	90.50	328.50	80.45	248.05	208.94	-39.11	208.94	58.75	267.69	121.86	145.83	176.46	30.63
T_4	238.00	90.50	328.50	75.78	252.72	213.15	-39.57	213.15	58.75	271.90	120.29	151.61	196.79	45.18
T_5	238.00	90.50	328.50	72.83	255.67	215.80	-39.87	215.80	58.75	274.55	119.14	155.41	185.05	29.64
T_6	238.00	90.50	328.50	109.36	219.14	182.93	-36.21	182.93	58.75	241.68	160.07	81.61	128.59	46.98
T_7	238.00	90.50	328.50	90.59	237.91	199.82	38.09	199.82	58.75	258.57	132.82	125.75	172.60	46.85
T_8	238.00	90.50	328.50	105.84	222.66	186.02	-36.64	186.02	58.75	244.77	156.88	87.69	136.54	48.65
T_9	238.00	90.50	328.50	81.57	246.93	207.94	-38.99	207.94	58.75	266.69	124.35	142.34	180.99	38.65
T_{10}	238.00	90.50	328.50	116.18	212.32	176.79	-35.53	176.79	58.75	235.54	166.50	69.04	119.04	50.00

T_1: Control (NPK+FYM),T_2: NPK + FYM+ $ZnSO_4$ @ 12.50 kg/ha,T_3: NPK + FYM+ Borax @ 10.00 kg/ha,T_4: NPK + FYM+ *Azospirillum* , T_5 : NPK + FYM+ VAM , T_6 : NPK + FYM+ $ZnSO_4$ @ 12.50 kg/ha + *Azospirillum* ,T_7 : NPK + FYM+ Borax @ 10 kg/ha + *Azospirillum,* T_8 : NPK + FYM+ $ZnSO_4$ @ 12.50 kg/ha + VAM ,T_9:NPK+ FYM+ Borax @ 10 kg/ha + VAM,T_{10} : NPK + FYM+ $ZnSO_4$ @ 12.50 kg/ha + Borax @10 kg/ha + *Azospirillum* + VAM

Crop rotation: Finger millet (2005)- Soybean (2006), Soybean (2005)- Finger millet (2006)

Note: For Soybean crop seed treatment was carried out with *Bradyrhizobium* inoculant

For Finger millet – NPK @ 50:40:25 kg/ha and FYM @ 7.5 t/ha; Soybean – NPK @ 25:60:25 kg/ha and FYM @ 6.25 t/ha (0.54 % N)

+ FYM + $ZnSO_4$ + *Bradyrhizobium japonicum* (T_6 : 160.07 kg/ha). There was a positive balance of nitrogen in all the treatments. The higher positive nitrogen balance was recorded with application of NPK + FYM + $ZnSO_4$ + borax + *Bradyrhizobium japonicum* + VAM (T_{10} : 50 kg/ha) while lower in control treatment (T_1 : 20.96 kg/ha).

4.11.1.2 Soybean-finger millet based cropping system

The initial available nitrogen status of the experimental site was 238 kg per ha (Table 4.11.2). The addition of nitrogen through fertilizers and manures was 58.75 kg per ha which was same to all the treatments. Total nitrogen removed by the soybean crop was higher with application of NPK + FYM + $ZnSO_4$ + borax + *Bradyrhizobium japonicum* + VAM (T_{10} : 187.13 kg/ha). This was followed by NPK + FYM + $ZnSO_4$ + *Bradyrhizobium japonicum*. A net gain of nitrogen was observed in all the treatments. A higher amount of nitrogen was observed with application of NPK + FYM + $ZnSO_4$ + borax + *Bradyrhizobium japonicum* + VAM(T_{10} : 66.23 kg/ha), whereas, lower amount of nitrogen was observed in control (T_1 : NPK + FYM; 35.69 kg/ha) (Table 4.11.2).

The actual balance of nitrogen during 2005 would be the initial balance of nitrogen during 2006, and it was higher with application of NPK + FYM + *Bradyrhizobium japonicum* (T_4 : 218.60 kg/ha). Total nitrogen removed by finger millet crop was higher with application of NPK + FYM + $ZnSO_4$ + borax + *A.brasilense* + VAM (T_{10} : 104.99 kg/ha). On the contrary, a lower amount of nitrogen was removed by the finger millet crop in control (T_1 :60.21 kg/ha). A net loss of nitrogen was observed in all the treatments, while a higher loss of nitrogen was observed in control (T_1 :26.30 kg/ha) followed by NPK + FYM + *A.brasilense* (T_4 :25.60 kg/ha).

Table 4.11.2: Nitrogen balance in soil as influenced by zinc, boron and microbial inoculants application in soybean– finger millet based cropping system

Treatments	Soybean (2005)							Finger millet (2006)						
	Initial soil available N (kg/ha)	Addition of N through fertilizers and manures (kg/ha	Total N (kg/ha)	Crop uptake of N (kg/ha)	Expected balance (kg/ha)	Actual balance (kg/ha	Net gain (+) or Net loss (-) (kg/ha)	Initial soil available N (kg/ha)	Addition of N through fertilizers and manures (kg/ha	Total N (kg/ha)	Crop uptake of N (kg/ha)	Expected balance (kg/ha)	Actual balance (kg/ha	Net gain (+) or Net loss (-) (kg/ha)
	(1)	(2)	3=(1+2)	(4)	5=(3-4)	(6)	7=(6-5)	(1)	(2)	3=(1+2)	(4)	5=(3-4)	(6)	7=(6-5)
T_1	238.00	58.75	296.75	124.50	172.25	207.94	35.69	207.94	90.50	298.44	60.21	238.23	211.93	-26.30
T_2	238.00	58.75	296.75	150.24	146.51	201.19	54.68	201.19	90.50	291.69	79.25	212.44	192.25	-20.19
T_3	238.00	58.75	296.75	142.57	154.18	199.56	45.38	199.56	90.50	290.06	72.79	217.27	197.92	-19.35
T_4	238.00	58.75	296.75	138.38	158.37	218.60	60.23	218.60	90.50	309.10	70.66	238.44	212.84	-25.60
T_5	238.00	58.75	296.75	137.23	159.52	205.35	45.83	205.35	90.50	295.85	69.38	226.47	205.74	-20.73
T_6	238.00	58.75	296.75	180.71	116.04	176.89	60.85	176.89	90.50	267.85	98.44	168.95	159.85	-9.10
T_7	238.00	58.75	296.75	152.53	144.22	206.07	61.85	206.07	90.50	296.39	81.73	214.84	196.45	-18.39
T_8	238.00	58.75	296.75	177.38	119.37	183.02	63.65	183.02	90.50	273.52	94.87	178.65	170.35	-8.30
T_9	238.00	58.75	296.75	144.78	151.97	205.80	53.83	205.80	90.50	296.30	77.86	218.44	201.12	-17.32
T_{10}	238.00	58.75	296.75	187.13	109.62	175.85	66.23	175.85	90.50	266.35	104.99	161.36	156.16	-5.20

T_1: Control (NPK+FYM),T_2: NPK + FYM+ $ZnSO_4$ @ 12.50 kg/ha,T_3: NPK + FYM+ Borax @ 10.00 kg/ha,T_4: NPK + FYM+ *Azospirillum* , T_5 : NPK + FYM+ VAM , T_6 : NPK + FYM+ $ZnSO_4$ @ 12.50 kg/ha + *Azospirillum* ,T_7 : NPK + FYM+ Borax @ 10 kg/ha + *Azospirillum,* T_8 : NPK + FYM+ $ZnSO_4$ @ 12.50 kg/ha + VAM ,T_9:NPK+ FYM+ Borax @ 10 kg/ha + VAM,T_{10} : NPK + FYM+ $ZnSO_4$ @ 12.50 kg/ha + Borax @10 kg/ha + Azospirillum + VAM

Crop rotation: Finger millet (2005)- Soybean (2006), Soybean (2005)- Finger millet (2006)

Note: For Soybean crop seed treatment was carried out with *Bradyrhizobium* inoculant

For Finger millet – NPK @ 50:40:25 kg/ha and FYM @ 7.5 t/ha; Soybean – NPK @ 25:60:25 kg/ha and FYM @ 6.25 t/ha (0.54 % N)

4.11.2 PHOSPHORUS BALANCE STUDIES IN SOIL

4.11.2.1 Finger millet-soybean based cropping system

Initial status of phosphorus of the experimental site was 106.0 kg per ha (Table 4.11.3). The addition of phosphorus through organic manure and fertilizer was 57.25 kg per ha which was same to all the treatments. The higher uptake of phosphorus by finger millet was registered with application of NPK + FYM + $ZnSO_4$ + borax + *A.brasilense* + VAM (T_{10} :51.25 kg/ha) followed by NPK + FYM + $ZnSO_4$ + *A.brasilense* (T_6 :45.46 kg/ha). There was a negative balance in P_2O_5 noticed in all treatments. The higher negative P_2O_5 balance was noticed with application of NPK + FYM (T_1 :39.86 kg/ha) followed by NPK + FYM + *A.brasilense* (T_4 :35.84 kg/ha) (Table 4.11.3).

The actual P_2O_5 balance after harvest of finger millet crop (2005) would be the initial soil available P_2O_5 during 2006. The addition of phosphorus through organic manure and fertilizer was same (74.37 kg/ha) to all the treatments. The higher uptake of phosphorus through organic manure and fertilizer was recorded with application of NPK + FYM + $ZnSO_4$ + borax + *Bradyrhizobium japonicum* + VAM (T_{10} : 19.19 kg/ha) followed by NPK + FYM + $ZnSO_4$ + *Bradyrhizobium japonicum* (T_6 : 17.50 kg/ha). After harvest of soybean all the treatments showed a negative balance of P_2O_5 in all the treatments. The higher negative P_2O_5 balance was recorded with application of NPK + FYM + borax + *Bradyrhizobium japonicum* (T_7 :31.86 kg/ha) followed by NPK + FYM (T_1 :31.60 kg/ha).

4.11.2.2 Soybean-finger millet based cropping system

The initial available phosphorus of the experimental site was 106.0 kg per ha (Table 4.11.4). Addition of P_2O_5 through fertilizer and manure was same (74.37 kg/ha) to all the treatments. Total P_2O_5 removed by

Table 4.11.3: Phosphorus balance in soil as influenced by zinc, boron and microbial inoculants application in finger millet - soybean based cropping system

Treatments	Finger millet (2005)							Soybean (2006)						
	Initial soil available P_2O_5 (kg/ha)	Addition of P_2O_5 through fertilizers and manures (kg/ha	Total P_2O_5 (kg/ha)	Crop uptake of P_2O_5 (kg/ha) {P x2.29}	Expected P_2O_5 balance (kg/ha)	Actual P_2O_5 balance (kg/ha	Net gain (+) or Net loss (-) (kg/ha)	Initial soil available P_2O_5 (kg/ha)	Addition of P_2O_5 through fertilizers and manures (kg/ha	Total P_2O_5 (kg/ha)	Crop uptake of P_2O_5 (kg/ha) {P x2.29}	Expected P_2O_5 balance (kg/ha)	Actual P_2O_5 balance (kg/ha	Net gain (+) or Net loss (-) (kg/ha)
	(1)	(2)	3=(1+2)	(4)	5=(3-4)	(6)	7=(6-5)	(1)	(2)	3=(1+2)	(4)	5=(3-4)	(6)	7=(6-5)
T_1	106.00	57.25	163.25	27.37	135.88	96.02	-39.86	96.02	74.37	170.39	10.40	159.99	128.39	-31.60
T_2	106.00	57.25	163.25	35.98	127.27	97.09	-30.18	97.09	74.37	171.46	13.03	158.43	131.54	-26.89
T_3	106.00	57.25	163.25	33.34	129.91	96.27	-33.64	96.27	74.37	170.64	12.23	158.41	130.02	-28.39
T_4	106.00	57.25	163.25	31.60	131.65	95.81	-35.84	95.81	74.37	170.18	11.38	158.80	127.91	-30.89
T_5	106.00	57.25	163.25	32.56	130.69	107.51	-23.18	107.51	74.37	181.88	13.05	168.83	151.55	-17.28
T_6	106.00	57.25	163.25	45.46	117.79	96.95	-20.84	96.95	74.37	171.32	17.50	153.82	127.93	-25.89
T_7	106.00	57.25	163.25	38.79	124.46	98.78	-25.68	98.78	74.37	173.15	13.67	159.48	127.62	-31.86
T_8	106.00	57.25	163.25	44.86	117.39	100.85	-17.54	100.85	74.37	175.22	17.01	158.21	142.93	-15.28
T_9	106.00	57.25	163.25	36.57	126.68	105.85	-20.83	105.85	74.37	180.22	13.67	166.55	151.77	-16.78
T_{10}	106.00	57.25	163.25	51.25	112.00	96.75	-15.25	96.75	74.37	171.12	19.19	151.93	137.65	-14.28

T_1: Control (NPK+FYM),T_2: NPK + FYM+ $ZnSO_4$ @ 12.50 kg/ha,T_3: NPK + FYM+ Borax @ 10.00 kg/ha,T_4: NPK + FYM+ *Azospirillum* , T_5 : NPK + FYM+ VAM , T_6 : NPK + FYM+ $ZnSO_4$ @ 12.50 kg/ha + *Azospirillum* ,T_7 : NPK + FYM+ Borax @ 10 kg/ha + *Azospirillum,* T_8 : NPK + FYM+ $ZnSO_4$ @ 12.50 kg/ha + VAM ,T_9:NPK+ FYM+ Borax @ 10 kg/ha + VAM,T_{10} : NPK + FYM+ $ZnSO_4$ @ 12.50 kg/ha + Borax @10 kg/ha + *Azospirillum* + VAM

Crop rotation: Finger millet (2005)- Soybean (2006), Soybean (2005)- Finger millet (2006)

Note: For Soybean crop seed treatment was carried out with *Bradyrhizobium* inoculant

For Finger millet – NPK @ 50:40:25 kg/ha and FYM @ 7.5 t/ha; Soybean – NPK @ 25:60:25 kg/ha and FYM @ 6.25 t/ha (0.23% P_2O_5)

Table 4.11.4: Phosphorus balance in soil as influenced by zinc, boron and microbial inoculants application in soybean– finger millet based cropping system

Treatments	Soybean (2005)							Finger millet (2006)						
	Initial soil available P_2O_5 (kg/ha)	Addition of P_2O_5 through fertilizers and manures (kg/ha	Total P_2O_5 (kg/ha)	Crop uptake of P_2O_5 (kg/ha) {P x2.29}	Expected P_2O_5 balance (kg/ha)	Actual P_2O_5 balance (kg/ha	Net gain (+) or Net loss (-) (kg/ha)	Initial soil available P_2O_5 (kg/ha)	Addition of P_2O_5 through fertilizers and manures (kg/ha	Total P_2O_5 (kg/ha)	Crop uptake of P_2O_5 (kg/ha) {P x2.29}	Expected P_2O_5 balance (kg/ha)	Actual P_2O_5 balance (kg/ha	Net gain (+) or Net loss (-) (kg/ha)
	(1)	(2)	3=(1+2)	(4)	5=(3-4)	(6)	7=(6-5)	(1)	(2)	3=(1+2)	(4)	5=(3-4)	(6)	7=(6-5)
T_1	106.00	74.37	180.37	12.07	168.30	129.35	-38.95	129.35	57.25	186.60	26.77	159.83	133.96	-25.87
T_2	106.00	74.37	180.37	15.27	165.10	131.27	-33.83	131.27	57.25	188.52	32.70	155.82	139.96	-15.86
T_3	106.00	74.37	180.37	14.13	166.24	130.96	-35.28	130.96	57.25	188.21	29.91	158.30	137.62	-20.68
T_4	106.00	74.37	180.37	13.30	167.07	129.21	-37.86	129.21	57.25	186.46	28.51	157.95	139.06	-18.89
T_5	106.00	74.37	180.37	15.28	165.09	131.24	-33.85	131.24	57.25	188.49	30.23	158.26	150.01	-8.25
T_6	106.00	74.37	180.37	19.67	160.70	132.03	-28.67	132.03	57.25	189.28	43.26	146.02	140.67	-5.35
T_7	106.00	74.37	180.37	15.89	164.48	128.72	-35.76	128.72	57.25	185.97	34.42	151.55	142.27	-9.28
T_8	106.00	74.37	180.37	18.69	161.68	131.50	-30.18	131.50	57.25	188.75	40.01	148.74	139.88	-8.86
T_9	106.00	74.37	180.37	16.30	164.07	131.74	-32.33	131.74	57.25	188.99	33.94	155.05	144.33	-10.72
T_{10}	106.00	74.37	180.37	21.92	158.45	128.83	-29.62	128.83	57.25	186.08	47.43	138.65	132.78	-5.87

T_1: Control (NPK+FYM),T_2: NPK + FYM+ $ZnSO_4$ @ 12.50 kg/ha,T_3: NPK + FYM+ Borax @ 10.00 kg/ha,T_4: NPK + FYM+ *Azospirillum* , T_5 : NPK + FYM+ VAM , T_6 : NPK + FYM+ $ZnSO_4$ @ 12.50 kg/ha + *Azospirillum* ,T_7 : NPK + FYM+ Borax @ 10 kg/ha + *Azospirillum,* T_8 : NPK + FYM+ $ZnSO_4$ @ 12.50 kg/ha + VAM ,T_9:NPK+ FYM+ Borax @ 10 kg/ha + VAM,T_{10} : NPK + FYM+ $ZnSO_4$ @ 12.50 kg/ha + Borax @10 kg/ha + *Azospirillum* + VAM

Crop rotation: Finger millet (2005)- Soybean (2006), Soybean (2005)- Finger millet (2006)

Note: For Soybean crop seed treatment was carried out with *Bradyrhizobium* inoculant

For Finger millet – NPK @ 50:40:25 kg/ha and FYM @ 7.5 t/ha; Soybean – NPK @ 25:60:25 kg/ha and FYM @ 6.25 t/ha (0.23% P_2O_5)

soybean crop was higher in NPK + FYM + $ZnSO_4$ + borax + *Bradyrhizobium japonicum* + VAM (T_{10} : 21.92 kg/ha) followed by NPK + FYM + $ZnSO_4$ + *Bradyrhizobium japonicum* (T_6 :19.67 kg/ha). Lower amount of P_2O_5 was removed by soybean crop in control (T_1 :12.07 kg/ha). However, a net loss of phosphorus was observed in all the treatments. On the contrary, a higher loss of phosphorus was observed with application of NPK + FYM (T_1 :38.95 kg/ha) followed by NPK + FYM + *Bradyrhizobium japonicum* (T_4 :37.86 kg/ha).

The actual P_2O_5 balance after harvest of soybean would be the initial soil available P_2O_5 before sowing of finger millet. The initial soil available P_2O_5 was higher in NPK + FYM + $ZnSO_4$ + *A.brasilense* treatments (T_6 : 132.03 kg/ha).

The addition of P_2O_5 through fertilizer and manure was same (57.25 kg/ha) to all the treatments. A higher uptake of P_2O_5 by finger millet crop was noticed in NPK + FYM + $ZnSO_4$ + borax + *A.brasilense* + VAM (T_{10} : 47.43 kg/ha) treatment, followed by NPK + FYM + $ZnSO_4$ + *A.brasilense* (T_6 : 43.26 kg/ha). After the harvest of finger millet all the treatments showed a negative balance of P_2O_5. The higher negative balance of 25.87 kg per ha was noticed in NPK + FYM (T_1) treatment followed by NPK + FYM + borax (T_3 : 20.68 kg/ha).

4.11.3 POTASSIUM BALANCE STUDIES IN SOIL

4.11.3.1 Finger millet-soybean based cropping system

The initial status of potassium of the experimental site was 168.0 kg per ha (Table 4.11.5). The addition of potassium through organic manure and fertilizer was same (64 kg/ha) to all the treatments. An higher uptake of potassium by finger millet crop was noticed in NPK + FYM + $ZnSO_4$ + borax + *A.brasilense* + VAM (T_{10} : 109.42 kg/ha) treatment followed by application of NPK + FYM + $ZnSO_4$ + *A.brasilense*

Table 4.11.5: Potassium balance in soil as influenced by zinc, boron and microbial inoculants application in finger millet –soybean based cropping system

Treatments	Finger millet (2005)							Soybean (2006)						
	Initial soil available K_2O (kg/ha)	Addition of K_2O through fertilizers and manures (kg/ha)	Total K_2O (kg/ha)	Crop uptake of K_2O (kg/ha) {K x 1.2}	Expected K_2O balance (kg/ha)	Actual K_2O balance (kg/ha)	Net gain (+) or Net loss (-) (kg/ha)	Initial soil available K_2O (kg/ha)	Addition of K_2O through fertilizers and manures (kg/ha)	Total K_2O (kg/ha)	Crop uptake of K_2O (kg/ha) {K x 1.2}	Expected K_2O balance (kg/ha)	Actual K_2O balance (kg/ha)	Net gain (+) or Net loss (-) (kg/ha)
	(1)	(2)	3=(1+2)	(4)	5=(3-4)	(6)	7=(6-5)	(1)	(2)	3=(1+2)	(4)	5=(3-4)	(6)	7=(6-5)
T_1	168.00	64.00	232.00	61.44	170.56	149.88	-20.68	149.88	57.50	207.38	48.80	158.58	168.35	9.77
T_2	168.00	64.00	232.00	87.26	144.74	134.46	-10.28	134.46	57.50	191.96	56.40	135.56	150.60	15.04
T_3	168.00	64.00	232.00	80.08	151.92	138.69	-13.23	138.69	57.50	196.16	53.50	142.66	165.80	23.14
T_4	168.00	64.00	232.00	73.00	159.00	144.20	-14.80	144.20	57.50	201.70	52.38	149.32	155.80	6.48
T_5	168.00	64.00	232.00	68.16	163.84	148.81	-15.03	148.81	57.50	206.31	52.00	154.31	165.20	10.89
T_6	168.00	64.00	232.00	90.39	141.61	132.03	-9.58	132.03	57.50	189.53	66.54	122.99	158.35	35.36
T_7	168.00	64.00	232.00	85.36	146.64	135.34	-11.30	135.34	57.50	192.84	57.31	135.53	155.68	20.15
T_8	168.00	64.00	232.00	106.67	125.33	117.14	-8.19	117.14	57.50	174.64	65.34	109.30	167.53	58.23
T_9	168.00	64.00	232.00	81.43	150.57	137.77	-12.80	137.77	57.50	195.27	54.05	141.22	163.21	21.99
T_{10}	168.00	64.00	232.00	109.42	122.58	114.73	-7.85	114.73	57.50	172.23	68.57	103.66	172.68	57.63

T_1: Control (NPK+FYM),T_2: NPK + FYM+ $ZnSO_4$ @ 12.50 kg/ha,T_3: NPK + FYM+ Borax @ 10.00 kg/ha,T_4: NPK + FYM+ *Azospirillum* , T_5 : NPK + FYM+ VAM , T_6 : NPK + FYM+ $ZnSO_4$ @ 12.50 kg/ha + *Azospirillum* ,T_7 : NPK + FYM+ Borax @ 10 kg/ha + *Azospirillum,* T_8 : NPK + FYM+ $ZnSO_4$ @ 12.50 kg/ha + VAM ,T_9:NPK+ FYM+ Borax @ 10 kg/ha + VAM,T_{10} : NPK + FYM+ $ZnSO_4$ @ 12.50 kg/ha + Borax @10 kg/ha + Azospirillum + VAM

Crop rotation: Finger millet (2005)- Soybean (2006), Soybean (2005)- Finger millet (2006)

Note: For Soybean crop seed treatment was carried out with *Bradyrhizobium* inoculant

For Finger millet – NPK @ 50:40:25 kg/ha and FYM @ 7.5 t/ha; Soybean – NPK @ 25:60:25 kg/ha and FYM @ 6.25 t/ha (0.52 % K_2O)

(T_6 : 90.39 kg/ha). There was a negative balance of potassium in all the treatments. An higher negative K_2O balance was recorded in control treatment (T_1 :20.68 kg/ha) followed by NPK + FYM + VAM (T_5 :15.03 kg/ha).

The actual K_2O balance during 2005 (after harvest of finger millet) would be the initial soil available K_2O during 2006. The initial available K_2O was higher in NPK + FYM (T_1 :149.88 kg/ha) followed by NPK + FYM + VAM (T_5 :148.81 kg/ha). Addition of K_2O through fertilizer and manure was same (57.50 kg/ha) to all the treatments. Indeed, an higher uptake of K_2O was noticed in NPK + FYM + $ZnSO_4$ + borax + *Bradyrhizobium japonicum* + VAM (T_{10} :68.57 kg/ha) followed by NPK + FYM + $ZnSO_4$ + *Bradyrhizobium japonicum* (T_6 : 66.54 kg/ha). It is noteworthy to state that a positive balance of K_2O was noticed in all the treatments. The higher net gain of 58.23 kg per ha of K_2O was noticed in NPK + FYM + $ZnSO_4$ + VAM (T_8) followed by NPK + FYM + $ZnSO_4$ + borax + *Bradyrhizobium japonicum* + VAM (T_{10} :57.63 kg/ha) (Table 4.11.5).

4.11.3.2 Soybean-finger millet cropping system

The initial available K_2O of experimental site was 168 kg per ha. The addition of K_2O through fertilizers and manures was same (57.50 kg/ha) to all the treatments. Total K_2O removed by the soybean crop was higher with application of NPK + FYM + $ZnSO_4$ + borax + *Bradyrhizobium japonicum* + VAM (T_{10} : 75.95 kg/ha) followed by NPK + FYM + $ZnSO_4$ + *Bradyrhizobium japonicum* (T_6 : 73.45 kg/ha). A lower uptake of 55.18 kg per ha was recorded in control (T_1). A net gain of potassium was observed in all the treatments. It is very important to state that an higher gain of potassium was observed with application of NPK + FYM + $ZnSO_4$ + borax + *Bradyrhizobium japonicum* + VAM (T_{10} : 36.05 kg/ha) followed by NPK + FYM + $ZnSO_4$ + VAM (T_8 : 25.94 kg/ha).

Table 4.11.6: Potassium balance in soil as influenced by zinc, boron and microbial inoculants application in soybean– finger millet based cropping system

Treatments	Soybean (2005)							Finger millet (2006)						
	Initial soil available K_2O (kg/ha)	Addition of K_2O through fertilizers and manures (kg/ha)	Total K_2O (kg/ha)	Crop uptake of K_2O (kg/ha) {K x 1.2}	Expected K_2O balance (kg/ha)	Actual K_2O balance (kg/ha)	Net gain (+) or Net loss (-) (kg/ha)	Initial soil available K_2O (kg/ha)	Addition of K_2O through fertilizers and manures (kg/ha)	Total K_2O (kg/ha)	Crop uptake of K_2O (kg/ha) {K x 1.2}	Expected K_2O balance (kg/ha)	Actual K_2O balance (kg/ha)	Net gain (+) or Net loss (-) (kg/ha)
	(1)	(2)	3=(1+2)	(4)	5=(3-4)	(6)	7=(6-5)	(1)	(2)	3=(1+2)	(4)	5=(3-4)	(6)	7=(6-5)
T_1	168.00	57.50	225.50	55.18	170.32	175.20	4.88	175.20	64.00	239.20	61.52	177.68	180.30	2.62
T_2	168.00	57.50	225.50	62.76	162.74	169.35	6.61	169.35	64.00	233.35	82.38	150.97	175.30	24.33
T_3	168.00	57.50	225.50	59.48	166.02	172.30	6.28	172.30	64.00	236.30	75.11	161.19	169.20	8.01
T_4	168.00	57.50	225.50	57.26	168.24	174.20	5.96	174.20	64.00	238.20	72.13	166.07	173.30	7.23
T_5	168.00	57.50	225.50	57.34	168.16	175.80	7.64	175.80	64.00	238.80	66.10	172.70	176.20	3.50
T_6	168.00	57.50	225.50	73.45	152.05	163.20	11.15	163.20	64.00	227.20	86.69	140.51	180.20	39.69
T_7	168.00	57.50	225.50	63.56	161.94	166.30	4.36	166.30	64.00	230.30	80.11	150.19	176.30	26.11
T_8	168.00	57.50	225.50	72.14	153.36	179.30	25.94	179.30	64.00	243.30	100.16	143.14	179.30	36.16
T_9	168.00	57.50	225.50	61.99	163.51	182.30	18.79	182.30	64.00	246.30	81.02	165.28	172.30	7.02
T_{10}	168.00	57.50	225.50	75.95	149.55	185.60	36.05	185.60	64.00	249.60	103.38	146.22	185.30	39.08

T_1: Control (NPK+FYM),T_2: NPK + FYM+ $ZnSO_4$ @ 12.50 kg/ha,T_3: NPK + FYM+ Borax @ 10.00 kg/ha,T_4: NPK + FYM+ *Azospirillum* , T_5 : NPK + FYM+ VAM , T_6 : NPK + FYM+ $ZnSO_4$ @ 12.50 kg/ha + *Azospirillum* ,T_7 : NPK + FYM+ Borax @ 10 kg/ha + *Azospirillum,* T_8 : NPK + FYM+ $ZnSO_4$ @ 12.50 kg/ha + VAM ,T_9:NPK+ FYM+ Borax @ 10 kg/ha + VAM,T_{10} : NPK + FYM+ $ZnSO_4$ @ 12.50 kg/ha + Borax @10 kg/ha + Azospirillum + VAM

Crop rotation: Finger millet (2005)- Soybean (2006), Soybean (2005)- Finger millet (2006)

Note: For Soybean crop seed treatment was carried out with *Bradyrhizobium* inoculant

For Finger millet – NPK @ 50:40:25 kg/ha and FYM @ 7.5 t/ha; Soybean – NPK @ 25:60:25 kg/ha and FYM @ 6.25 t/ha (0.52 % K_2O)

Lower gain of K_2O was noticed in NPK + FYM + borax + *Bradyrhizobium japonicum* (T_7 : 4.36 kg/ha).

The actual K_2O balance after harvest of soybean would be the initial available K_2O in soil during 2006 which was higher in NPK + FYM + $ZnSO_4$ + borax + *Bradyrhizobium japonicum* + VAM (T_{10}) treatment. The higher K_2O uptake by finger millet crop was also noticed in the same treatment (103.38 kg/ha) followed by NPK + FYM + $ZnSO_4$ + VAM (T_8 : 100.16 kg/ha). A net gain of potassium was observed in all the treatments. It is very important to note that an higher gain of potassium was observed with application of NPK + FYM + $ZnSO_4$ + *A.brasilense* (T_6 :39.69 kg/ha) followed by NPK + FYM + $ZnSO_4$ + borax + *A.brasilense* + VAM (T_{10} :39.08 kg/ha) (Table 4.11.6).

4.11.4 ZINC BALANCE STUDIES IN SOIL

4.11.4.1 Finger millet-soybean based cropping system

The initial soil available zinc status of experimental site was 0.54 ppm. The addition of zinc through organic manures and fertilizers was higher (1.24 ppm) with application of NPK + FYM + $ZnSO_4$ + borax + *A.brasilense* + VAM (T_{10}), NPK + FYM + $ZnSO_4$ + VAM (T_8), NPK + FYM + $ZnSO_4$ + *A.brasilense* (T_6) and NPK + FYM + $ZnSO_4$ (T_2). The uptake of zinc by finger millet crop was higher (0.08 ppm) with application of NPK + FYM + $ZnSO_4$ + borax + *A.brasilense* + VAM (T_{10}) followed by NPK + FYM + $ZnSO_4$ + VAM (T_8 : 0.07 ppm) and NPK + FYM + $ZnSO_4$ + *A.brasilense* (T_6 : 0.07 ppm). There was a negative balance of zinc noticed in all the treatments. The higher negative balance of 0.62 ppm was noticed in NPK + FYM + $ZnSO_4$ (T_2) treatment followed by NPK + FYM + $ZnSO_4$ + VAM (T_8 :0.53 ppm) treatment (Table 4.11.7).

The actual zinc balance after harvest of finger millet (2005) would be the initial soil available zinc during 2006 and it was higher with

Table 4.11.7: Zinc balance in soil as influenced by zinc, boron and microbial inoculants application in finger millet –soybean based cropping system

Treatments	Finger millet (2005)							Soybean (2006)						
	Initial soil available Zn (ppm)	Addition of Zn through fertilizers and manures (ppm)	Total Zn (ppm)	Crop uptake of Zn (ppm)	Expected Zn balance (ppm)	Actual Zn balance (ppm)	Net gain (+) or Net loss (-) (ppm)	Initial soil available Zn (ppm)	Addition of Zn through fertilizers and manures (ppm)	Total Zn (ppm)	Crop uptake of Zn (ppm)	Expected Zn balance (ppm)	Actual Zn balance (ppm)	Net gain (+) or Net loss (-) (ppm)
	(1)	(2)	3=(1+2)	(4)	5=(3-4)	(6)	7=(6-5)	(1)	(2)	3=(1+2)	(4)	5=(3-4)	(6)	7=(6-5)
T_1	0.54	0.07	0.61	0.04	0.57	0.44	-0.13	0.44	0.06	0.50	0.04	0.46	0.45	-0.01
T_2	0.54	1.24	1.78	0.06	1.72	1.10	-0.62	1.10	1.23	2.33	0.07	2.26	1.69	-0.57
T_3	0.54	0.07	0.61	0.05	0.56	0.46	-0.10	0.46	0.06	0.50	0.05	0.45	0.43	-0.02
T_4	0.54	0.07	0.61	0.05	0.56	0.45	-0.11	0.45	0.06	0.51	0.05	0.46	0.44	-0.02
T_5	0.54	0.07	0.61	0.05	0.56	0.44	-0.12	0.44	0.06	0.50	0.05	0.45	0.42	-0.03
T_6	0.54	1.24	1.78	0.07	1.71	1.20	-0.51	1.20	1.23	2.43	0.07	2.36	1.75	-0.61
T_7	0.54	0.07	0.61	0.06	0.55	0.43	-0.12	0.43	0.06	0.50	0.06	0.44	0.40	-0.04
T_8	0.54	1.24	1.78	0.07	1.71	1.18	-0.53	1.18	1.23	2.41	0.07	2.34	1.72	-0.62
T_9	0.54	0.07	0.61	0.06	0.55	0.41	-0.14	0.41	0.06	0.47	0.06	0.41	0.38	-0.03
T_{10}	0.54	1.24	1.78	0.08	1.70	1.25	-0.45	1.25	1.23	2.48	0.09	2.39	1.80	-0.59

T_1: Control (NPK+FYM),T_2: NPK + FYM+ $ZnSO_4$ @ 12.50 kg/ha,T_3: NPK + FYM+ Borax @ 10.00 kg/ha,T_4: NPK + FYM+ *Azospirillum* , T_5 : NPK + FYM+ VAM , T_6 : NPK + FYM+ $ZnSO_4$ @ 12.50 kg/ha + *Azospirillum* ,T_7 : NPK + FYM+ Borax @ 10 kg/ha + *Azospirillum,* T_8 : NPK + FYM+ $ZnSO_4$ @ 12.50 kg/ha + VAM ,T_9:NPK+ FYM+ Borax @ 10 kg/ha + VAM,T_{10} : NPK + FYM+ $ZnSO_4$ @ 12.50 kg/ha + Borax @10 kg/ha + Azospirillum + VAM

Crop rotation: Finger millet (2005)- Soybean (2006), Soybean (2005)- Finger millet (2006), FYM @ 7.50 t/ha (22 ppm Zn)

Note: For Soybean crop seed treatment was carried out with *Bradyrhizobium* inoculant

For Finger millet – NPK @ 50:40:25 kg/ha and FYM @ 7.5 t/ha; Soybean – NPK @ 25:60:25 kg/ha and FYM @ 6.25 t/ha (22 ppm Zn)

application of NPK + FYM + $ZnSO_4$ + borax + *Bradyrhizobium japonicum* + VAM (T_{10} : 1.25 ppm) followed by NPK + FYM + $ZnSO_4$ + *Bradyrhizobium japonicum* (T_6 : 1.20 ppm). The addition of zinc was higher (1.23 ppm) with application of NPK + FYM + $ZnSO_4$ + borax + *Bradyrhizobium japonicum* + VAM (T_{10}), NPK + FYM + $ZnSO_4$ + VAM (T_8), NPK + FYM + $ZnSO_4$ + *Bradyrhizobium japonicum* (T_6) and NPK + FYM + $ZnSO_4$ (T_2). A net loss of zinc was observed in all the treatments. On the contrary, a higher loss of zinc was noticed in NPK + FYM + $ZnSO_4$ + VAM (T_8 :0.62 ppm), followed by NPK + FYM + $ZnSO_4$ + *Bradyrhizobium japonicum* (T_6 :0.61 ppm) (Table 4.11.7).

4.11.4.2 Soybean-finger millet based cropping system

The initial soil available zinc status of the experimental site was 0.54 ppm. The addition of zinc through organic manure and fertilizer was higher (1.23 ppm) in the treatments where $ZnSO_4$ was applied along with recommended NPK + FYM. The total zinc uptake by soybean crop was higher with application of NPK + FYM + $ZnSO_4$ + borax + *Bradyrhizobium japonicum* + VAM (T_{10} : 0.10 ppm) while lower zinc uptake was noticed in control (T_1 : 0.05 ppm). There was a negative balance of zinc noticed in all the treatments, while a higher negative zinc balance was recorded in NPK + FYM + $ZnSO_4$ (T_2 :0.43 ppm) treatment. It is noteworthy to state that lower and negative balance was observed in NPK + FYM + *Bradyrhizobium japonicum* (T_4 : 0.07 ppm).

The actual balance of zinc (during 2005) after harvest of soybean would be the initial soil available zinc during 2006 and it was higher in NPK + FYM + $ZnSO_4$ + borax + *A.brasilense* + VAM (T_{10} : 1.32 ppm). The addition of zinc through organic manure and fertilizer was higher (1.24 ppm) in the treatments where zinc sulphate was applied along with recommended NPK and FYM treatments. The higher zinc uptake by finger millet crop was noticed in NPK + FYM + $ZnSO_4$ + borax +

Table 4.11.8: Zinc balance in soil as influenced by zinc, boron and microbial inoculants application in soybean– finger millet based cropping system

Treatments	Soybean (2005)							Finger millet (2006)						
	Initial soil available Zn (ppm)	Addition of Zn through fertilizers and manures (ppm)	Total Zn (ppm)	Crop uptake of Zn (ppm)	Expected Zn balance (ppm)	Actual Zn balance (ppm)	Net gain (+) or Net loss (-) (ppm)	Initial soil available Zn (ppm)	Addition of Zn through fertilizers and manures (ppm)	Total Zn (ppm)	Crop uptake of Zn (ppm)	Expected Zn balance (ppm)	Actual Zn balance (ppm)	Net gain (+) or Net loss (-) (ppm)
	(1)	(2)	3=(1+2)	(4)	5=(3-4)	(6)	7=(6-5)	(1)	(2)	3=(1+2)	(4)	5=(3-4)	(6)	7=(6-5)
T_1	0.54	0.06	0.60	0.05	0.55	0.45	-0.10	0.45	0.07	0.52	0.04	0.48	0.46	-0.02
T_2	0.54	1.23	1.77	0.08	1.69	1.26	-0.43	1.26	1.24	2.50	0.06	2.44	1.72	-0.72
T_3	0.54	0.06	0.60	0.06	0.54	0.45	-0.09	0.45	0.07	0.52	0.05	0.47	0.45	-0.02
T_4	0.54	0.06	0.60	0.06	0.54	0.47	-0.07	0.47	0.07	0.54	0.05	0.49	0.46	-0.03
T_5	0.54	0.06	0.60	0.06	0.54	0.45	-0.09	0.45	0.07	0.52	0.05	0.47	0.44	-0.02
T_6	0.54	1.23	1.77	0.08	1.69	1.29	-0.40	1.29	1.24	2.53	0.07	2.46	1.77	-0.69
T_7	0.54	0.06	0.60	0.07	0.53	0.44	-0.09	0.44	0.07	0.51	0.05	0.46	0.43	-0.03
T_8	0.54	1.23	1.77	0.08	1.69	1.30	-0.39	1.30	1.24	2.54	0.06	2.48	1.74	-0.74
T_9	0.54	0.06	0.60	0.07	0.53	0.45	-0.08	0.45	0.07	0.52	0.05	0.47	0.41	-0.06
T_{10}	0.54	1.23	1.77	0.10	1.67	1.32	-0.35	1.32	1.24	2.56	0.07	2.49	1.82	-0.67

T_1: Control (NPK+FYM),T_2: NPK + FYM+ $ZnSO_4$ @ 12.50 kg/ha,T_3: NPK + FYM+ Borax @ 10.00 kg/ha,T_4: NPK + FYM+ *Azospirillum* , T_5 : NPK + FYM+ VAM , T_6 : NPK + FYM+ $ZnSO_4$ @ 12.50 kg/ha + *Azospirillum* ,T_7 : NPK + FYM+ Borax @ 10 kg/ha + *Azospirillum,* T_8 : NPK + FYM+ $ZnSO_4$ @ 12.50 kg/ha + VAM ,T_9:NPK+ FYM+ Borax @ 10 kg/ha + VAM,T_{10} : NPK + FYM+ $ZnSO_4$ @ 12.50 kg/ha + Borax @10 kg/ha + Azospirillum + VAM

Crop rotation: Finger millet (2005)- Soybean (2006), Soybean (2005)- Finger millet (2006)

Note: For Soybean crop seed treatment was carried out with *Bradyrhizobium* inoculant

For Finger millet – NPK @ 50:40:25 kg/ha and FYM @ 7.5 t/ha; Soybean – NPK @ 25:60:25 kg/ha and FYM @ 6.25 t/ha (22 ppm Zn)

A.brasilense + VAM (T_{10} : 0.07 ppm) and NPK + FYM + $ZnSO_4$ + *A.brasilense* (T_6 : 0.07 ppm). A net loss of zinc was noticed in all the treatments. Further, it was observed that a higher zinc loss of 0.74 ppm was noticed in the treatment which received NPK + FYM + $ZnSO_4$ + VAM (T_8) followed by NPK + FYM + $ZnSO_4$ (T_2 :0.72 ppm) (Table 4.11.8).

4.11.5 Boron balance studies in soil

4.11.5.1 Finger millet-soybean based cropping system

The initial soil available boron status of the experimental site was 0.43 ppm. The addition of boron through organic manure and fertilizer was higher (0.51 ppm) in the treatments where borax was applied along with recommended NPK and FYM. The uptake of boron by finger millet crop was almost same (0.03 ppm) in all the treatments. However, there was negative balance of boron noticed in all the treatments. The higher negative balance of 0.23 ppm was noticed in NPK + FYM + borax + VAM (T_9 :0.23 ppm) (Table 4.11.9).

The actual boron balance after the harvest of finger millet (2005) would be the initial soil available boron during 2006 and it was higher in NPK + FYM + $ZnSO_4$ + borax + *Bradyrhizobium japonicum* + VAM (T_{10} : 0.71 ppm) and NPK + FYM + borax (T_3 : 0.71 ppm) treatments. The addition of boron through organic manure and fertilizer was higher (0.50 ppm) where borax was applied along with recommended NPK and FYM. The uptake of boron by soybean crop was higher in NPK + FYM + $ZnSO_4$ + borax + *Bradyrhizobium japonicum* + VAM (T_{10} : 0.03 ppm). There was negative balance of boron was noticed in all the treatments. The higher negative balance of 0.21 ppm was noticed in NPK + FYM + borax (T_3) treatment (Table 4.11.19).

Table 4.11.9: Boron balance in soil as influenced by zinc, boron and microbial inoculants application in finger millet –soybean based cropping system

Treatments	Finger millet (2005)							Soybean (2006)						
	Initial soil available B (ppm)	Addition of B through fertilizers and manures (ppm)	Total B (ppm)	Crop uptake of B (ppm)	Expected B balance (ppm)	Actual B balance (ppm)	Net gain (+) or Net loss (-) (ppm)	Initial soil available B (ppm)	Addition of B through fertilizers and manures (ppm)	Total B (ppm)	Crop uptake of B (ppm)	Expected B balance (ppm)	Actual B balance (ppm)	Net gain (+) or Net loss (-) (ppm)
	(1)	(2)	3=(1+2)	(4)	5=(3-4)	(6)	7=(6-5)	(1)	(2)	3=(1+2)	(4)	5=(3-4)	(6)	7=(6-5)
T_1	0.43	0.02	0.45	0.03	0.42	0.37	-0.05	0.37	0.01	0.38	0.01	0.37	0.34	-0.03
T_2	0.43	0.02	0.45	0.03	0.42	0.38	-0.04	0.38	0.01	0.39	0.02	0.37	0.33	-0.04
T_3	0.43	0.51	0.94	0.03	0.91	0.71	-0.20	0.71	0.50	1.21	0.02	1.19	0.98	-0.21
T_4	0.43	0.02	0.45	0.03	0.42	0.37	-0.05	0.37	0.01	0.38	0.02	0.36	0.33	-0.03
T_5	0.43	0.02	0.45	0.03	0.42	0.36	-0.06	0.36	0.01	0.37	0.02	0.35	0.32	-0.03
T_6	0.43	0.02	0.45	0.03	0.42	0.37	-0.05	0.37	0.01	0.38	0.02	0.36	0.32	-0.04
T_7	0.43	0.51	0.94	0.03	0.91	0.70	-0.21	0.70	0.50	1.20	0.02	1.18	0.99	-0.19
T_8	0.43	0.02	0.45	0.03	0.42	0.37	-0.05	0.37	0.01	0.38	0.02	0.36	0.30	-0.06
T_9	0.43	0.51	0.94	0.03	0.91	0.68	-0.23	0.68	0.50	1.18	0.02	1.16	0.98	-0.18
T_{10}	0.43	0.51	0.94	0.03	0.91	0.71	-0.20	0.71	0.50	1.21	0.03	1.18	0.98	-0.20

T_1: Control (NPK+FYM),T_2: NPK + FYM+ $ZnSO_4$ @ 12.50 kg/ha,T_3: NPK + FYM+ Borax @ 10.00 kg/ha,T_4: NPK + FYM+ *Azospirillum* , T_5 : NPK + FYM+ VAM , T_6 : NPK + FYM+ $ZnSO_4$ @ 12.50 kg/ha + *Azospirillum* ,T_7 : NPK + FYM+ Borax @ 10 kg/ha + *Azospirillum,* T_8 : NPK + FYM+ $ZnSO_4$ @ 12.50 kg/ha + VAM ,T_9:NPK+ FYM+ Borax @ 10 kg/ha + VAM,T_{10} : NPK + FYM+ $ZnSO_4$ @ 12.50 kg/ha + Borax @10 kg/ha + Azospirillum + VAM

Crop rotation: Finger millet (2005)- Soybean (2006), Soybean (2005)- Finger millet (2006)

Note: For Soybean crop seed treatment was carried out with *Bradyrhizobium* inoculant

For Finger millet – NPK @ 50:40:25 kg/ha and FYM @ 7.5 t/ha; Soybean – NPK @ 25:60:25 kg/ha and FYM @ 6.25 t/ha (5 ppm B)

4.11.5.2 Soybean-finger millet based cropping system

The initial available boron status of the experimental site was 0.43 ppm (Table 4.11.10). The addition of boron through fertilizer and organic manure was higher (0.50 ppm) in the treatments where borax was applied along with recommended NPK and FYM. The total boron removed by soybean ranged from 0.02 to 0.03 ppm. However, a net loss of boron was noticed in all the treatments. On the contrary, a higher loss of boron was noticed in the treatment which received NPK + FYM + borax + VAM (T_9 : 0.20 ppm) and NPK + FYM + borax (T_3 : 0.20 ppm).

The actual boron balance after the harvest of soybean (2005) would be the initial soil available boron during 2006 and it was higher with application of NPK + FYM + $ZnSO_4$ + borax + *A.brasilense* + VAM (T_{10} : 0.72 ppm). The addition of boron through manure and fertilizer was (0.51 ppm) higher, where borax was applied along with recommended NPK and FYM. The uptake of boron was almost same (0.03 ppm) in all the treatments except in control (0.02 ppm). A net loss of boron was noticed in all the treatments. On the contrary, a higher loss of boron (0.21 ppm) was noticed in NPK + FYM + borax + VAM (T_9) treatment only.

In general, soybean-finger millet based cropping system registered higher available nitrogen, phosphorus, potassium, zinc and boron status in the soil as compared to finger millet-soybean cropping system.

4.12 ECONOMICS OF FINGER MILLET-SOYBEAN AND SOYBEAN-FINGER MILLET BASED CROPPING SYSTEMS AS INFLUENCED BY ZINC, BORON AND MICROBIAL INOCULANTS APPLICATION

4.12.1 Finger millet-soybean based cropping system

Among the different nutrient management practices, higher gross return was recorded with application of NPK + FYM + $ZnSO_4$ + borax + *A.brasilense / Bradyrhizobium japonicum* + VAM (T_{10} : Rs. 76,790/ha)

Table 4.11.10: Boron balance in soil as influenced by zinc, boron and microbial inoculants application in soybean– finger millet based cropping system

Treatments	Soybean (2005)							Finger millet (2006)						
	Initial soil available B (ppm)	Addition of B through fertilizers and manures (ppm)	Total B (ppm)	Crop uptake of B (ppm)	Expected B balance (ppm)	Actual B balance (ppm)	Net gain (+) or Net loss (-) (ppm)	Initial soil available B (ppm)	Addition of B through fertilizers and manures (ppm)	Total B (ppm)	Crop uptake of B (ppm)	Expected B balance (ppm)	Actual B balance (ppm)	Net gain (+) or Net loss (-) (ppm)
	(1)	(2)	3=(1+2)	(4)	5=(3-4)	(6)	7=(6-5)	(1)	(2)	3=(1+2)	(4)	5=(3-4)	(6)	7=(6-5)
T_1	0.43	0.01	0.44	0.02	0.42	0.38	-0.04	0.38	0.02	0.40	0.02	0.38	0.34	-0.04
T_2	0.43	0.01	0.44	0.02	0.42	0.37	-0.05	0.37	0.02	0.39	0.03	0.36	0.33	-0.03
T_3	0.43	0.50	0.93	0.02	0.91	0.71	-0.20	0.71	0.51	1.22	0.03	1.19	1.00	-0.19
T_4	0.43	0.01	0.44	0.02	0.42	0.37	-0.05	0.37	0.02	0.39	0.03	0.36	0.32	-0.04
T_5	0.43	0.01	0.44	0.02	0.42	0.38	-0.04	0.38	0.02	0.40	0.03	0.37	0.32	-0.05
T_6	0.43	0.01	0.44	0.03	0.41	0.37	-0.04	0.37	0.02	0.39	0.03	0.36	0.33	-0.03
T_7	0.43	0.50	0.93	0.03	0.90	0.71	-0.19	0.71	0.51	1.22	0.03	1.19	1.10	-0.09
T_8	0.43	0.01	0.44	0.03	0.41	0.36	-0.05	0.36	0.02	0.38	0.03	0.35	0.31	-0.04
T_9	0.43	0.50	0.93	0.02	0.91	0.71	-0.20	0.71	0.51	1.22	0.03	1.19	0.98	-0.21
T_{10}	0.43	0.50	0.93	0.03	0.90	0.72	-0.18	0.72	0.51	1.23	0.03	1.20	1.00	-0.20

T_1: Control (NPK+FYM),T_2: NPK + FYM+ $ZnSO_4$ @ 12.50 kg/ha,T_3: NPK + FYM+ Borax @ 10.00 kg/ha,T_4: NPK + FYM+ *Azospirillum* , T_5 : NPK + FYM+ VAM , T_6 : NPK + FYM+ $ZnSO_4$ @ 12.50 kg/ha + *Azospirillum* ,T_7 : NPK + FYM+ Borax @ 10 kg/ha + *Azospirillum,* T_8 : NPK + FYM+ $ZnSO_4$ @ 12.50 kg/ha + VAM ,T_9:NPK+ FYM+ Borax @ 10 kg/ha + VAM,T_{10} : NPK + FYM+ $ZnSO_4$ @ 12.50 kg/ha + Borax @10 kg/ha + Azospirillum + VAM

Crop rotation: Finger millet (2005)- Soybean (2006), Soybean (2005)- Finger millet (2006)

Note: For Soybean crop seed treatment was carried out with *Bradyrhizobium* inoculant

For Finger millet – NPK @ 50:40:25 kg/ha and FYM @ 7.5 t/ha; Soybean – NPK @ 25:60:25 kg/ha and FYM @ 6.25 t/ha (5 ppm B)

followed by NPK + FYM + $ZnSO_4$ + *A.brasilense / Bradyrhizobium japonicum* (T_6 : Rs. 74,606/ha). Lower gross returns of Rs. 50,769 per ha was recorded in control and rest of the treatments were found to be intermediate.

The maximum cost of cultivation was incurred due to application of NPK + FYM + $ZnSO_4$ + borax + *A.brasilense / Bradyrhizobium japonicum* + VAM (T_{10} :Rs.26,153/ha) followed by NPK + FYM + $ZnSO_4$ (T_8 :Rs.25,148/ha) and NPK + FYM + borax + VAM (T_9 : Rs.24,374/ha). Lower cost of cultivation was recorded in control (Rs.22,074/ha) (Table 4.12.1).

The maximum net returns was realized due to application of NPK + FYM + $ZnSO_4$ + *A.brasilense / Bradyrhizobium japonicum* (T_6 : Rs.50,753/ha) followed by application of NPK + FYM + $ZnSO_4$ + borax + *A.brasilense / Bradyrhizobium japonicum* + VAM (T_{10} : Rs.50,637/ha). Lower net returns was recorded in control (T_1 : Rs.28,695/ha) (Fig. 70).

The maximum profit per rupee spent on cultivation was obtained with application of NPK + FYM + $ZnSO_4$ + *A.brasilense / Bradyrhizobium japonicum* (T_6 : 2.13) followed by application of NPK + FYM + $ZnSO_4$ + VAM (T_8 : 1.95). The control treatment recorded lower profit per rupee spent on cultivation (1.30) and rest of the treatments were found to be intermediate (Table 4.12.1 and Fig. 70).

4.12.2 Soybean-finger millet based cropping system

Among the different nutrient management practices, relatively higher gross returns was recorded with application of NPK + FYM + $ZnSO_4$ + borax + *Bradyrhizobium japonicum / A. brasilense* + VAM (T_{10} : Rs.79,738/ha) followed by NPK + FYM + $ZnSO_4$ + *A.brasilense/ Bradyrhizobium japonicum* (T_6 : Rs.77,482/ha). Lower gross returns was recorded in control (T_1 : Rs.56.023/ha) (Table 4.10.2).

Table 4.12.1: Economics of finger millet -soybean based cropping system as influenced zinc, boron and microbial inoculants application

Treatment	Gross returns (Rs./ha)			Cost of cultivation (Rs./ha)			Net returns (Rs./ha)			B: C ratio		
	Finger millet	Soybean	Total	Finger millet	Soybean	Total	Finger millet	Soybean	Total	Finger millet	Soybean	Cropping system
	2005	2006		2005	2006		2005	2006		2005	2006	
T_1: Control (NPK + FYM)	24496	26273	50769	11299	10775	22074	13197	15498	28695	1.17	1.44	1.30
T_2 : NPK +FYM + $ZnSO_4$	31311	31668	62979	12136	11612	23748	19175	20056	39231	1.58	1.73	1.65
T_3 : NPK + FYM + Borax	30086	30584	60670	11749	11225	22974	18337	19359	37696	1.56	1.72	1.64
T_4: NPK + FYM + *A. brasilense*	29354	30376	59730	11374	10805	22179	17980	19571	37551	1.58	1.81	1.69
T_5 : NPK + FYM + VAM	28521	30174	58695	11999	11475	23474	16522	18699	35221	1.38	1.63	1.50
T_6 : NPK + FYM + $ZnSO_4$ + *A. brasilense*	35920	38686	74606	12211	11642	23853	23709	27044	50753	1.94	2.32	2.13
T_7 : NPK + FYM + Borax + *A brasilense*	31443	32274	63717	11824	11255	23079	19619	21019	40638	1.66	1.87	1.76
T_8: NPK + FYM + $ZnSO_4$+ VAM	35694	38442	74136	12836	12312	25148	22858	26130	48988	1.78	2.12	1.95
T_9: NPK + FYM + Borax + VAM	29994	30628	60622	12449	11925	24374	17545	18703	36248	1.41	1.57	1.49
T_{10}: NPK+ FYM +$ZnSO_4$+ Borax + *A. brasilense*+ VAM	37038	39752	76790	13361	12792	26153	23677	26960	50637	1.77	2.11	1.94

$ZnSO_4$ @ 12.50 kg/ha, Borax @ 10 kg/ha

Crop rotation: Finger millet (2005)- Soybean (2006), Soybean (2005)- Finger millet (2006)

Note: For Soybean crop seed treatment was carried out with *Bradyrhizobium* inoculant

For Finger millet – NPK @ 50:40:25 kg/ha and FYM @ 7.5 t/ha; Soybean – NPK @ 25:60:25 kg/ha and FYM @ 6.25 t/ha

Table 4.12.2: Economics of soybean- finger millet based cropping system as influenced by zinc, boron and microbial inoculants application

Treatment	Gross returns (Rs./ha)			Cost of cultivation (Rs./ha)			Net returns (Rs./ha)			B: C ratio		
	Soybean	Finger millet	Total	Soybean	Finger millet	Total	Soybean	Finger millet	Total	Soybean	Finger millet	Cropping system
	2005	2006		2005	2006		2005	2006		2005	2006	
T_1: Control (NPK + FYM)	31525	24498	56023	10775	11299	22074	20750	13199	33949	1.93	1.17	1.54
T_2 : NPK +FYM + $ZnSO_4$	36919	29155	66074	11612	12136	23748	25307	17019	42326	2.18	1.40	1.78
T_3 : NPK + FYM + Borax	35834	28053	63887	11225	11749	22974	24609	16304	40913	2.19	1.39	1.78
T_4: NPK + FYM + *A. brasilense*	35413	27706	63119	10805	11374	22179	24608	16332	40940	2.28	1.44	1.85
T_5 : NPK + FYM + VAM	35209	27429	62638	11475	11999	23474	23734	15430	39164	2.07	1.29	1.67
T_6 : NPK + FYM + $ZnSO_4$ + *A. brasilense*	43744	33738	77482	11642	12211	23853	32102	21527	53629	2.76	1.76	2.25
T_7 : NPK + FYM + Borax + *A brasilense*	37284	29329	66613	11255	11824	23079	26029	17505	43534	2.31	1.48	1.89
T_8: NPK + FYM + $ZnSO_4$+ VAM	43500	33501	77001	12312	12836	25148	31188	20665	51853	2.53	1.61	2.06
T_9: NPK + FYM + Borax + VAM	35693	28943	64636	11925	12449	24374	23768	16494	40262	1.99	1.32	1.65
T_{10}: NPK+ FYM +$ZnSO_4$+ Borax + *A. brasilense*+ VAM	44810	34928	79738	12792	13361	26153	32018	21567	53585	2.50	1.61	2.05

$ZnSO_4$ @ 12.50 kg/ha, Borax @ 10 kg/ha

Crop rotation: Finger millet (2005)- Soybean (2006), Soybean (2005)- Finger millet (2006)

Note: For Soybean crop seed treatment was carried out with *Bradyrhizobium* inoculant

For Finger millet – NPK @ 50:40:25 kg/ha and FYM @ 7.5 t/ha; Soybean – NPK @ 25:60:25 kg/ha and FYM @ 6.25 t/ha

The higher cost of cultivation due to application of NPK + FYM + $ZnSO_4$ + borax + *Bradyrhizobium japonicum / A.brasilense* + VAM (T_{10} : Rs.26,153/ha) followed by application of NPK + FYM + $ZnSO_4$ + VAM (T_8 : Rs.25,148/ha) and NPK + FYM + borax + VAM (T_9 : Rs.24,374/ha). Lower cost of cultivation was recorded in control (T_1 : Rs.22,074/ha).

A maximum net returns realized due to application of NPK + FYM + $ZnSO_4$ + *Bradyrhizobium japonicum / A.brasilense* (T_6 : Rs.53,629/ha) followed by NPK + FYM + $ZnSO_4$ + borax + *Bradyrhizobium japonicum / A.brasilense* + VAM (T_{10} : Rs.53,585/ha) (Fig. 71).

The data on B : C ratio indicated that, application of NPK + FYM + $ZnSO_4$ + *Bradyrhizobium japonicum / A. brasilense* (T_6 : 2.25) followed by NPK + FYM + $ZnSO_4$ + VAM (T_8 : 2.06). Lower B : C ratio (1.54) was recorded in control (T_1) and the rest of the treatments were found to be intermediate (Table 4.12.2 and Fig. 71).

DISCUSSION

V. DISCUSSION

Results of the field experiments conducted to study the "Relative response of finger millet-soybean rotation to application of zinc, boron and microbial inoculants" at AICRP for Dryland Agriculture Centre, U.A.S., GKVK, Bangalore, during *kharif* seasons of 2005 and 2006 are discussed in this chapter.

Finger millet (*Eleusine coracana* (L.) Gaertn.) a nutri-cereal (nutritious grain) ranks third in importance among millets in the country after sorghum and pearl millet. One of the striking features which made finger millet an important dryland crop is its resilence and ability to withstand weather aberrations when grown in soils having poor water holding capacity. Soybean [*Glycine max* (L.) Merrill.] a miracle low input cost legume is getting place of pride in agriculture across the edapho-environmental and socio-economic regimes due to its exemplary agronomic, industrial and nutritional characteristics.

With intensified crop production using high yielding crop varieties coupled with maximized use of high analysis chemical fertilizers have resulted in mining of soils leading to deficiencies of micronutrients especially Zn and B. The deficiency of these micronutrients is of major cause for poor yields or even crop failure. The improper and unjudicious use of nutrients is one of the major hurdles in increasing the production of finger millet and soybean.

Elimination of chemical fertilizers from a conventional farming system may cause a significant reduction in crop yield and results in loss of net farm income. In order to avoid such problem, it is necessary to adopt integrated soil building practices to improve and stabilize soil productivity, through a harmonious blend of organics, beneficial micro-organisms and inorganic fertilizers. In addition, the micronutrients,

biofertilizers are best suited under these circumstances as they are cheaper, pollution free, ecofriendly and renewable resources. Besides, increased production, the quality of produce is also important which is influenced primarily by crop variety, levels of fertilizers, soil type, growth promoting substances secreted by micro-organisms and climatic condition *etc.*

Rotation of the crops is one of the important components of sustainable farming systems as it provides efficient nutrient cycling. The continuous practice of cereal- cereal rotation might have an adverse effect on physico-chemical properties and fertility status of soil. Inclusion of legumes in the crop sequences improves the soil fertility and consequently the productivity of succeeding cereal crops better than cereal- cereal sequence (Ahlawat *et al.,* 1981).

The present study was modulated with a concept to fulfill the above sustainable and ecologically sound farming practices in finger millet-soybean based production system. It involves use of micronutrients, farm yard manure and microbial inoculants in an integrated nutrient supply system with chemical fertilizers.

5.1 WEATHER AND CROPS GROWTH

Environment is the foster parent of plants. The fluctuation in weather conditions is a true reflection on the expected yield. The total amount of rainfall received during 2005 was more (1374.40 mm) as compared to 2006 (708.80 mm), while the normal rainfall is in the range of 916 to 930 mm. The crop growth period was from August to November in both the years (Table 2). The amount of rainfall received during crop growth period during 2005 was 1023.4 mm as against the normal rainfall of 555.5 mm. This may be designated as higher rainfall having 50 per cent more and 23.8 per cent lower than the normal rainfall in

2005 and 2006, respectively. As a result of excess rainfall, adequate soil moisture in the root zone favoured the normal crop growth. In 2006, the actual rainfall received during crop growth period was 272 mm as against the normal rainfall of 569.2 mm. Hence, there was a shortage of rainfall during 2006. Rainfall distribution was generally more favourable for growth and grain formation during 2005 as compared to 2006. However, timely cultural operations (intercultivation) and better storage of moisture at field capacity level overcome the problem of low soil moisture. As a result the impact of low rainfall was not so much. A look at the mean maximum and minimum temperature and also at the relative humidity indicates that the experimental locality recorded maximum air temperature in the month of May (33.9°C) during 2005 and April (33.5°C) during 2006. The mean minimum temperature was more than normal for most of the months. The mean relative humidity fluctuated between 57 to 76 per cent.

The temperature regimes, relative humidity, pan evaporation, wind speed and mean sunshine hours that prevailed during period of experimentation were conducive to the growth and development of finger millet and soybean crops. Sowing/transplanting of the crops at right time helped in matching the crop growth to favourable climatic conditions (Table 2 and Fig. 1, 2 and 3). Establishment of finger millet and soybean crops was uniform and crop stand was good during both the years of experimentation. The crops were free from major pests and diseases as adequate plant protection measures were taken. The results of the two experiments conducted during 2005 and 2006 have been discussed in this chapter in the light of earlier findings conducted elsewhere.

5.2 EXPERIMENT-I(a) : RESPONSE OF FINGER MILLET-SOYBEAN ROTATION TO ZINC AND BORON NUTRITION

Crop: Finger millet

5.2.1 Effect of zinc and boron application on growth and growth parameters of finger millet

The grain yield depends on the synthesis and accumulation of photosynthates and their distribution among various plant parts. The synthesis, accumulation and translocation of photosynthates depends upon efficient photosynthetic structure as well as the extent of translocation into sink (grains) and also on plant growth and development during early stages of crop growth. The production and translocation of synthesized photosynthates depends upon mineral nutrition supplied either by soil or through foliar application. Most of the photosynthetic pathways are dependent on enzymes and coenzymes which are synthesized from mineral elements such as nitrogen, phosphorus, potassium and trace elements.

Nutrient supply is one of the most important factor that determines the growth of the crop. Inspite of liberal application of N, P and K fertilizer, normal growth of high yielding varieties of crops could not be obtained due to lower use of micronutrients. High fertilizer responsive varieties can express their full yield potential only when limiting trace elements are applied along with NPK fertilizers (Singh and Tripathi, 1975). The magnitude of response also increases with increasing soil fertility (Sakal *et al.*, 1988). Zinc is essential for several enzyme activities that regulate metabolic processes in plants. It is also involved in the auxin production, transformation of carbohydrates and regulation of sugar in plants.

Boron is an essential micronutrient, which is known to arrest the flower drop and increase the pod setting (Bose *et al.*, 1994). Besides it is also involved in cell division in the process of nodule formation. Boron also plays a significant role in carbohydrate and nitrogen metabolism, transport of substances, flower formation, pollen germination, pod setting and transport of phytohormones (Masood Ali and Mishra, 2001).

The pooled results revealed that, the plant height of finger millet increased significantly with the application of NPK + FYM + $ZnSO_4$ + borax (T_9 : 9.44, 41.76, 96.94 and 98.57 cm at 30, 60, 90 DAT and at harvest, respectively) as compared to control (Table 4.1.1 and Fig. 6). The improvement in plant height due to micronutrients application may be attributed to proper nourishment of crop and optimum growth. Addition of FYM might have helped in the release of micronutrients favourable for the crop growth. Also, increased activity of meristamatic cells and cell elongation with application of micronutrients (along with recommended dose of major nutrients) as they were known to have favourable effect on metabolic processes. Maliwal *et al.* (1985), Dadhich and Gupta (2005) and Jakhar *et al.* (2006) also observed higher plant height with Zn application. Pal *et al.* (1991) reported higher plant height with boron application.

The branches arised from basal nodes of the stem or crown in cereals are called as tillers. The rate of production and number of tillers in finger millet are dependent upon nutrient supply. Application of NPK + FYM + $ZnSO_4$ + borax (T_9) recorded significantly higher number of tillers per hill (1.58, 5.11, 6.63 and 6.80 tillers per hill at 30, 60, 90 DAT and at harvest, respectively) as compared to other treatments (Table 4.1.2 and Fig. 6). The increased number of tillers due to application of these micronutrients may be related to their physiological role in plants. The stimulatory effect of Zn on enzymes and on increased availability of

major nutrients might have caused for increased number of tillers in the present study. These results corroborate the findings of Aftab Hussain *et al.* (1988), Jat (1990), Mani (1991); Dadhich and Gupta (2005).

Further, it is well known fact that the persistence of the assimilatory surface area is a pre-requisite for prolonged photosynthate activity and ultimately crop productivity. Application of NPK + FYM + $ZnSO_4$ + borax (T_9) recorded significantly higher number of leaves, leaf area, LAI and LAD at different growth stages as compared to control. This improvement might be due to the additive effect of the zinc which is involved in different enzymatic activity of plant and beneficial role of farm yard manure in improving the physico-chemical and biological properties of soil. Besides higher accumulation of dry matter in leaves might have helped the photosynthetic area to remain active for longer period (Table 4.1.3 to 4.1.6 and Fig. 6) and was responsible for overall growth of plant in terms of dry matter production. These results are in agreement with the findings of Aftab Hussain *et al.* (1988), Keshwa and Jat (1991) and Dadhich and Gupta (2005).

The pre-requisite for getting higher yields in any crop is higher total dry matter production (TDM) and its partitioning into various plant parts. The total dry matter production of finger millet differed significantly due to micronutrients application. Significantly higher TDM production was recorded with application of NPK + FYM + $ZnSO_4$ + borax (T_9 : 2.55, 10.45, 31.33 and 32.73 g/plant at 30, 60, 90 DAS and at harvest, respectively) as compared to control (Table 4.1.7 to 4.1.10 and Fig. 7). This may be due to the favourable effect of higher dry matter distribution in leaf, stem, earhead and higher rate of dry matter production. These findings are in line with those of Aftab Hussain *et al.* (1988), Keshwa and Jat (1991) and Yadav *et al.* (1991b).

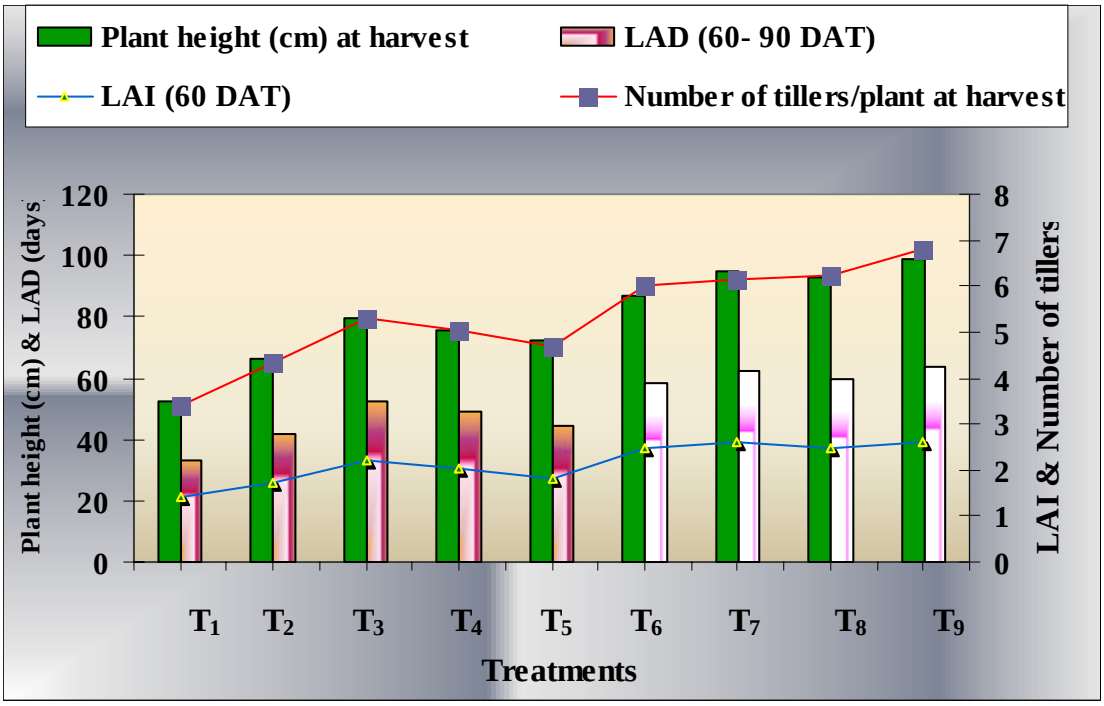


Fig.6 : Growth parameters of finger millet as influenced by zinc and boron nutrition

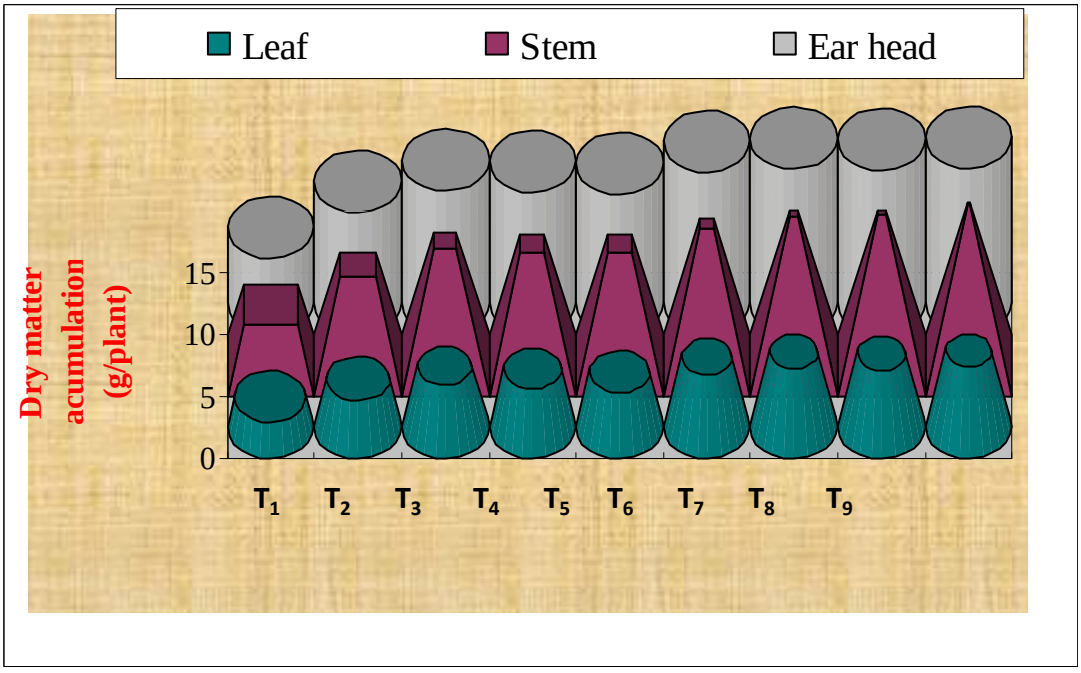


Fig 7 : Dry matter accumulation in leaf ,stem and ear head of finger millet at harvest as influenced by zinc and boron nutrition

5.2.2 Effect of zinc and boron application on yield and yield attributes of finger millet

Enhancement in yield of economic part is usually depended upon the total dry matter produced and its distribution among different parts of the plant. Application of NPK + FYM + $ZnSO_4$ + borax (T_9) recorded significantly higher grain yield (3613 kg/ha) over other treatments. However, it was found on par with application of NPK + FYM + $ZnSO_4$ (T_7 : 3564 kg/ha), NPK + FYM + borax (T_8 : 3506 kg/ha) and NPK + $ZnSO_4$ + borax (T_6 : 3424 kg/ha) (Table 4.1.13; Plate 2 and Fig. 10). In line with the results of present study Maliwal *et al*. (1985), Yadav *et al*. (1989), Patel and Karelia (1994), Purushotham *et al*. (1994), Dadhich and Gupta (2005) and Jakhar *et al*. (2006) have also observed similar results due to application of $ZnSO_4$. Pratima Sinha and Chatterjee (1994) have recorded higher grain yield due to borax application. Hence it is noteworthy to mention that the higher grain yield may be attributed to higher total dry matter accumulation which inturn was due to total nitrogen, phosphorus, potassium as well as zinc and boron uptake and their translocation to the reproductive parts and improvement in yield attributing characters like number of fingers per earhead, earhead length, finger length, grain yield per plant, 1000-grain weight, threshing per cent and number of productive tillers per plant (Table 4.1.11 and 4.1.12).

Data on straw yield revealed that higher straw yield was recorded with the application of NPK + FYM + $ZnSO_4$ + borax (T_9: 5566 kg/ha) (Table 4.1.13 and Fig. 10). This might be

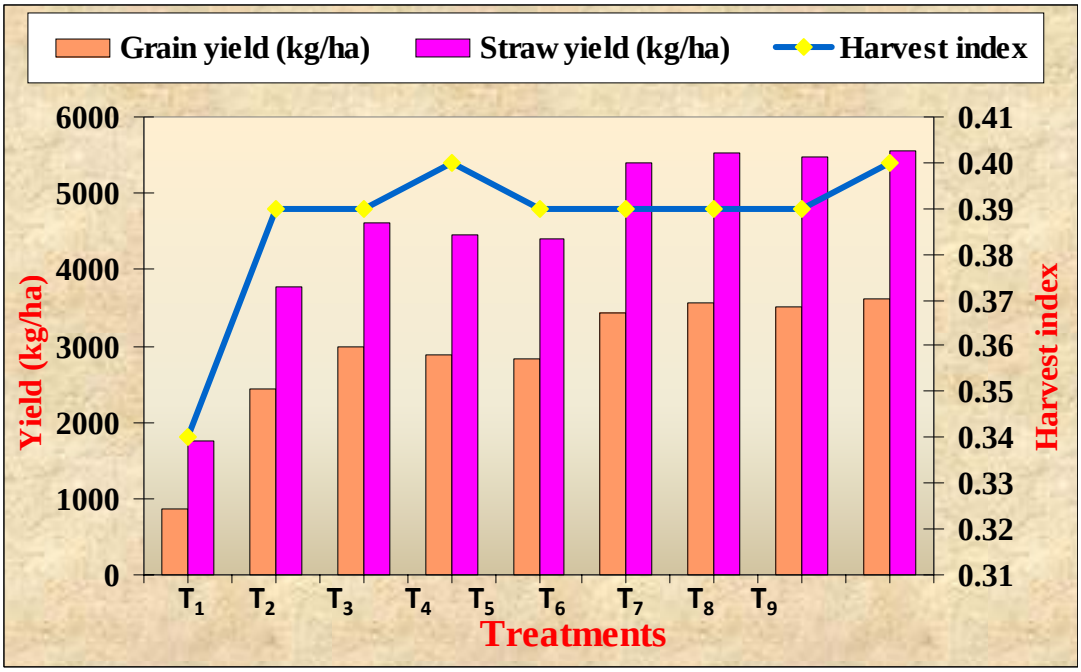


Fig.10: Grain yield, straw yield and harvest index of finger millet as influenced by zinc and boron nutrition

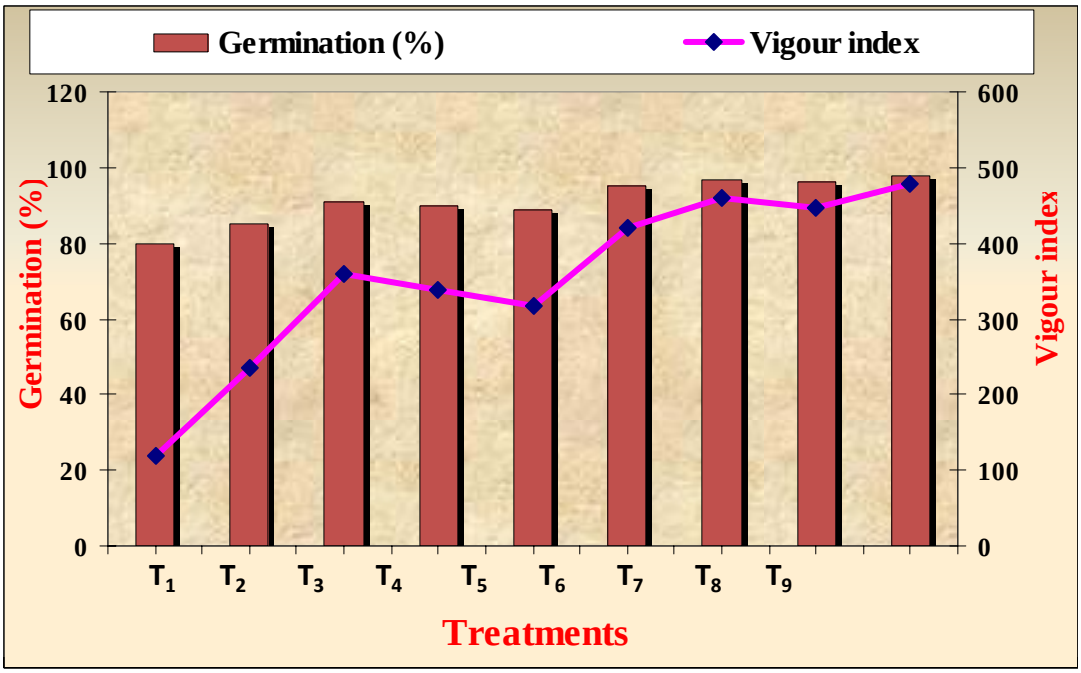
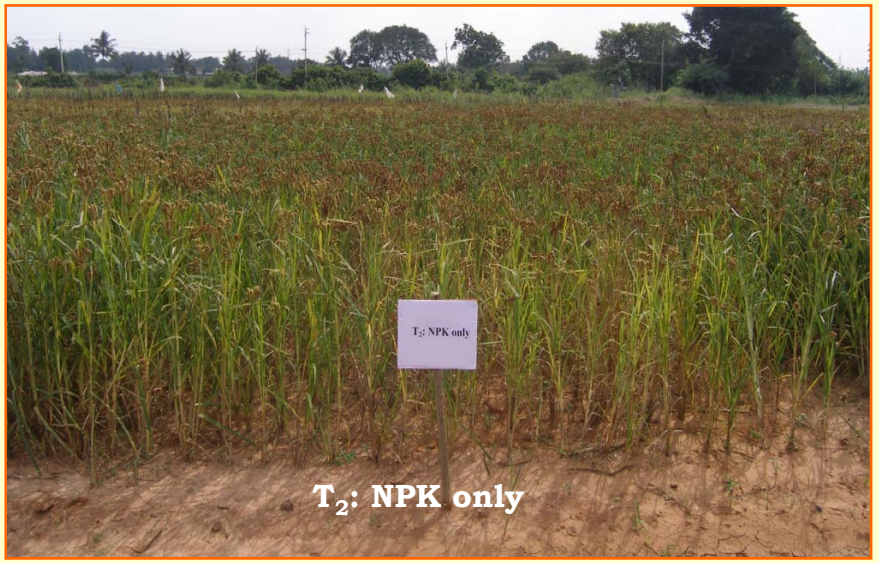


Fig.11: Germination and vigour index of finger millet as influenced by zinc and boron nutrition

T_1: Control (No NPK + No FYM)



T_2: NPK only

T_6:NPK+ $ZnSO_4$+ Borax

T_9:NPK+ FYM+ $ZnSO_4$+ Borax

Plate 2: Response of finger millet to zinc and boron nutrition (Expt. Ia)

due to improved vegetative growth and growth parameters, such as total dry matter production and its accumulation in different plant parts like leaves, stem and increased number of tillers (Table 4.1.1 to 4.1.10). Similar results have been reported by Devarajan *et al.* (1980), Yadav *et al.* (1989), Kavalappa (1989) Mani (1991) and Jakhar *et al.* (2006). The harvest index did not differ significantly due to zinc and boron application (Table 4.1.13 and Fig. 10). It may be due to proportionate production of grain and straw in finger millet by different nutrient treatments which kept harvest index almost static. Similar result was also obtained by Ananda (2004) in wheat due to application of NPK + FYM + $ZnSO_4$.

Economic yield is expressed as a function of factors that contribute to yield, which are known as yield attributes. The variations in yield due to treatments could be attributed to the variations in the yield attributing parameters. The main yield attributes in finger millet are number of productive tillers per plant, number of fingers per earhead, earhead length, finger length, grain yield per plant, 1000-grain weight and threshing percentage. Combined application of NPK + FYM + $ZnSO_4$ + borax (T_9) recorded significantly higher yield components *viz.,* number of productive tillers per plant, number of fingers per earhead, earhead length, finger length, grain yield per plant and 1000-grain weight which was 170, 59.4 44.8 89.5, 301.48 and 53.08 per cent, respectively higher as compared to control (Table 4.1.11 to 4.1.12). The difference in the performance of yield attributes in various treatments could be due to variations in translocation of photosynthates from vegetative to reproductive parts.

Further the improvement in soil fertility and productivity due to application of inorganic fertilizers, organic manures and micronutrients might have supported more number of productive tillers per plant and

number of fingers per earhead. Indeed, spectacular increase in grain yields due to FYM, zinc and borax application have also been earlier reported in cereals by several workers (Maliwal *et al.*, 1985; Aftab Hussain *et al.*, 1988; Mani, 1991; Pratima Sinha and Chatterjee, 1994 and Jakhar *et al.*, 2006.

The ability of a variety to bear a higher number of grain bearing tillers till maturity contributes to yield. Number of productive tillers per hill at harvest were higher with the application of NPK + FYM + $ZnSO_4$ + borax (T_9 : 5.13) as compared to control (Table 4.1.11 and Fig. 8). This might be due to increased soil nitrogen phosphorus, potassium and micronutrient status which resulted in profused tillering and development of strong and healthier tillers. These results are in accordance with the findings of Maliwal *et al.* (1985), Mani (1991) and Yadav *et al.* (1991b).

The above findings have been further supported by significant and positive correlation between grain yield of finger millet and yield parameters like number of productive tillers at harvest (r = 0.901), number of fingers per earhead (r = 0.789), earhead length (r = 0.820), finger length (r = 0.845), grain yield per plant (r = 0.925), test weight (r = 0.870) and threshing per cent (r = 0.668) (Table 4.1.20).

Similarly, regression analysis indicated that 93 per cent of finger millet grain yield was influenced by growth and yield parameters, as shown by the inter-relationship of source and sink in the plant with better uptake of nutrients by the conjunctive use of organics along with NPK and micronutrients. These results are similar to the earlier reports by Haider *et al.* (1993) in finger millet.

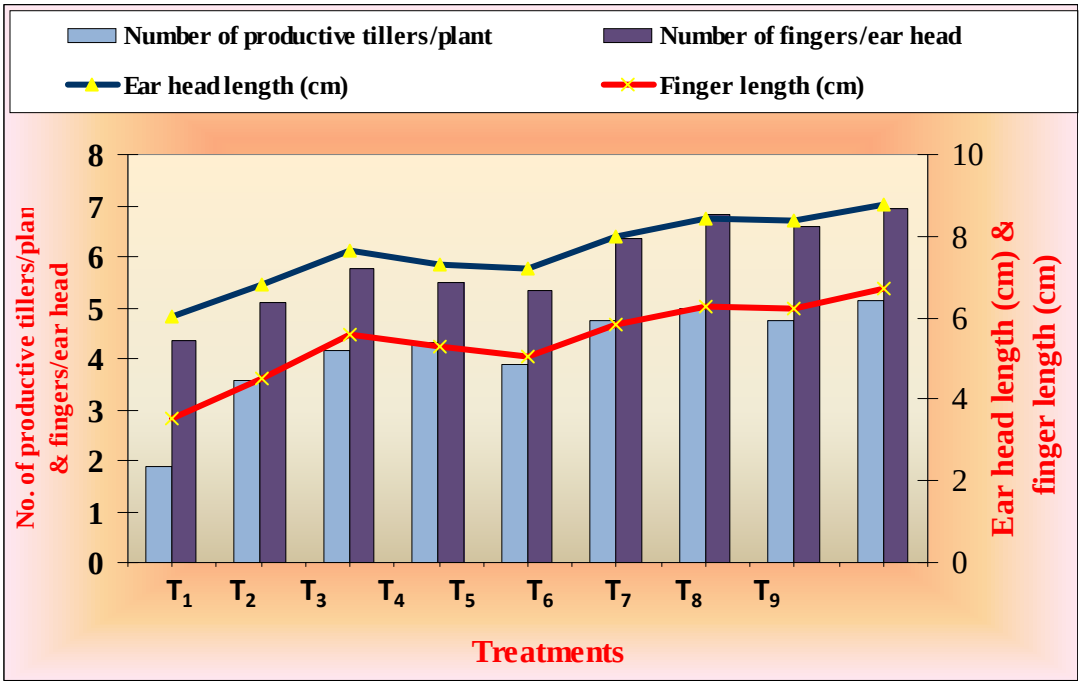


Fig. 8 : Number of productive tillers per plant, number of fingers per plant, ear head length and finger length of finger millet as influenced by zinc and boron nutrition

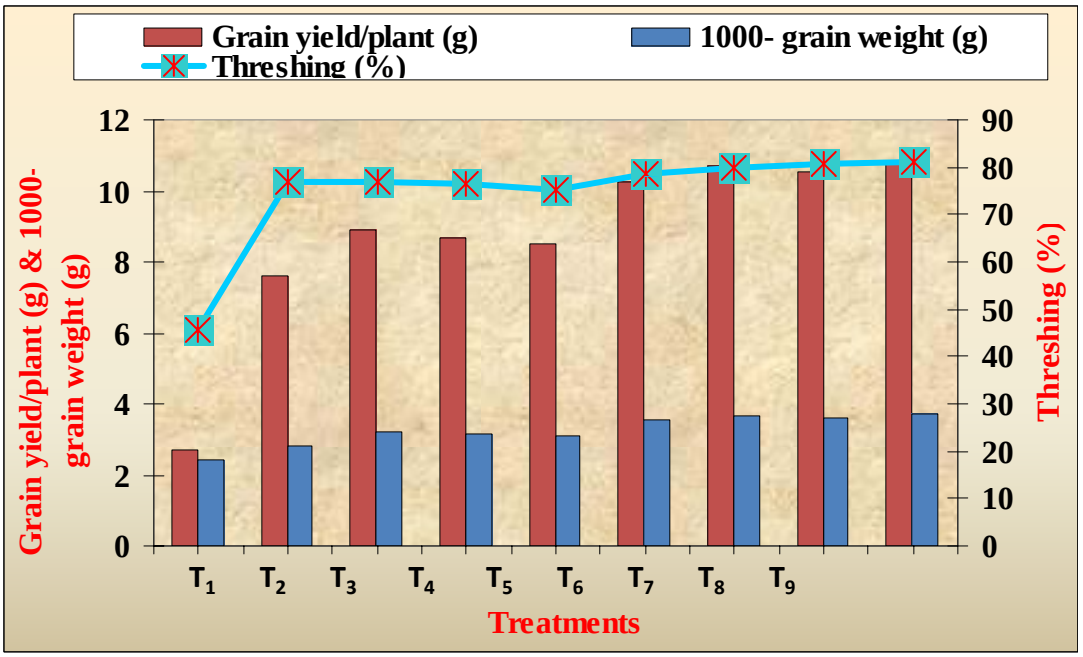


Fig. 9: Grain yield per plant,1000-grain weight and threshing per cent of finger millet as influenced by zinc and boron nutrition

5.2.3 Seed quality parameters of finger millet as influenced by zinc and boron application

Quality of the grain is as important as the grain yield itself in assessing the performance in relation to its functional usage. The quality of the produce depends on inherent genetic makeup and environmental factors. Among the environmental factors, balanced crop nutrition approach which envisages judicious balance of organic and inorganic fertilizers along with microbial inoculants at appropriate physiological growth stages play a vital role in determining the yield as well as the quality of the produce. Application of micronutrients play an important role in grain filling (Rajput *et al.*, 1995). Zinc application appears to have a remarkable effect on 1000-grain weight and other yield attributes. Further, zinc also helped in activation of dehydrogenase enzymes (like pyridine nucleotide, glucose-6-phsophate and trios phosphate *etc.*) and auxin metabolism (like tryptophan, synthetase, tryptamine metabolism). Boron plays a vital role in the physiological processes of plants such as cell maturation, tissue hydration (water economy of plants), sterility and formation of reproductive organs, pollen germination *etc.* (Agarwal and Sharma, 1978). Application of NPK + FYM + $ZnSO_4$ + borax (T_9) recorded significantly higher germination per cent (98%), dry weight of root and shoot (4.9 mg) and seed vigour index (478) as compared to control (Table 4.1.14 and Fig. 11). This might be due to optimum levels of micronutrients in seed stock which could improve seed quality, germination, vigour, viability and can result in better crop establishment. Present results are in confirmation with the findings of Atwal *et al.* (1998) and Shankar *et al.* (2005).

5.2.4 Effect of zinc and boron application on nutrients uptake by finger millet

5.2.4.1 Effect of zinc and boron application on nitrogen uptake

Uptake of nutrients is associated with the metabolic activities of plants and with the concentration and distribution of ions in the external medium. It has been proved that application of micronutrients along with recommended dose of NPK and FYM affects the absorption and utilization of major nutrients. Application of NPK + FYM + $ZnSO_4$ + borax (T_9) recorded significantly higher uptake of nitrogen by finger millet in grain (48.34 kg/ha), straw (41.19 kg/ha) and total nitrogen (90.70 kg/ha) and was found on par with the application of NPK + FYM + $ZnSO_4$ (T_7 : 47.96, 38.62 and 86.57 kg/ha, respectively) (Table 4.1.15 and Fig. 12). Availability of sufficient quantity of nutrients coupled with improvement in soil properties during entire crop growth period might have supported the higher uptake of nutrients. Similar results have been reported by Rahman (1986), Thimma Reddy (1987), Kavalappa (1989), Gulshan *et al.* (1999) and Shivakumar (1999). Synergistic effects among micronutrients (Zn and B), farm yard manure with nitrogen might have resulted in increased uptake of nitrogen. The increased uptake of nitrogen may be due to favourable effects of Zn on metabolic process of plant as an activator of several enzymes and inturn may directly or indirectly affect the synthesis of carbohydrates and protein (Soundara Rajan and Yassen, 1981; Indulkar and Malewar, 1994). Further, a higher uptake of nitrogen under micronutrients (Zn + B) might be due to better growth and total biomass production of the crop and its partitioning. The results corroborate the findings of Venkateswaralu and Misra (1987). The value of total uptake of N was significant and positively correlated with the grain yield (r = 0.930) (Table 4.1.20).

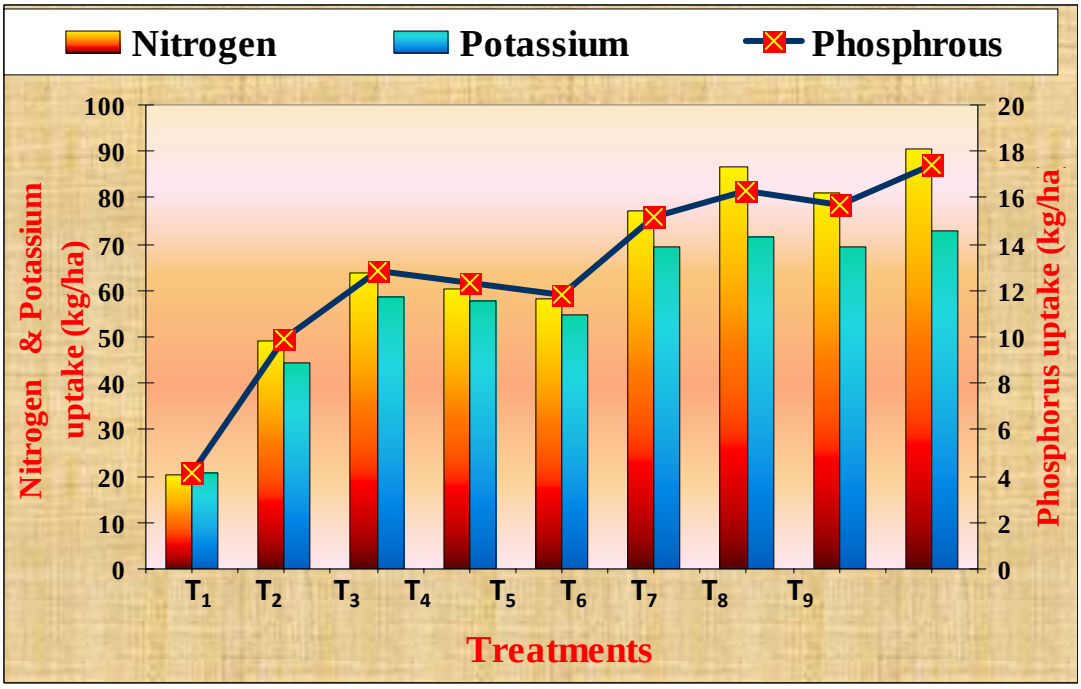


Fig.12 : Total uptake of nitrogen, phosphorus and potassium by finger millet as influenced by zinc and boron nutrition

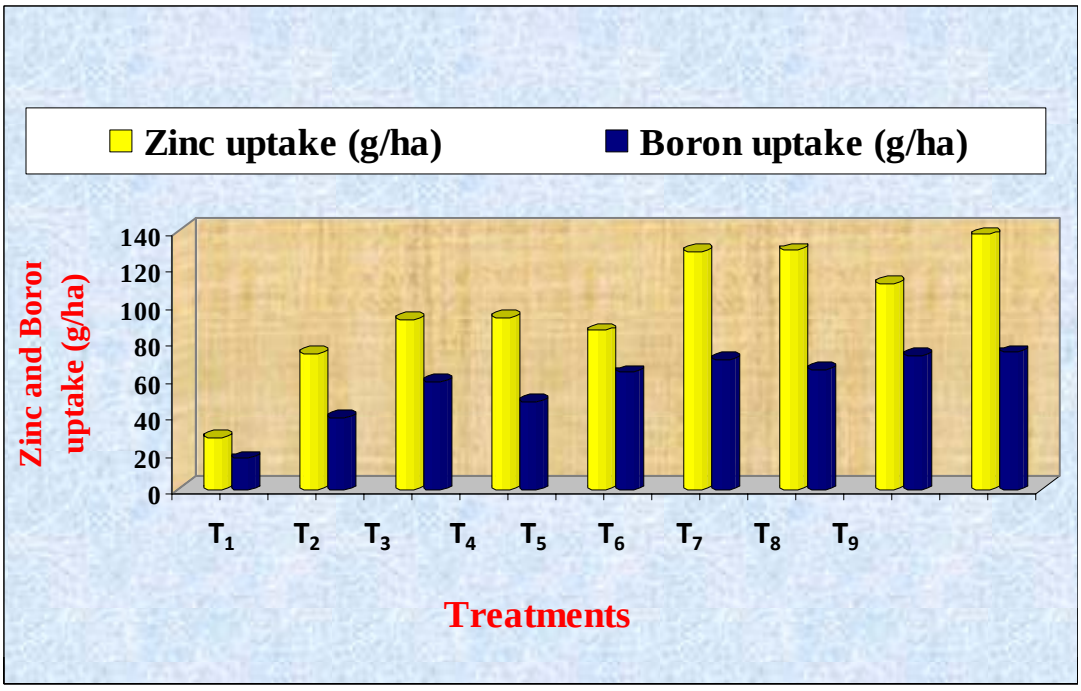


Fig.13 : Total uptake of Zinc and boron by Finger millet as influenced by zinc and boron nutrition

5.2.4.2 Effect of zinc and boron application on phosphorus uptake

The data on total uptake of phosphorus differed significantly due to micronutrients application. Application of NPK + FYM + $ZnSO_4$ + borax (T_9) recorded significantly higher phosphorus uptake by finger millet grain (9.36 kg/ha), straw (8.04 kg/ha) with total uptake (17.40 kg/ha) as compared to control(Table 4.1.16 and Fig. 12). Application of zinc favoured the root growth with mobilization of plant nutrients at optimum level resulting in higher absorption of nutrients. There was least uptake of phosphorus under no zinc and higher uptake under zinc applied plots. These results are in agreement with the findings of Soundara Rajan and Yassen (1981).The enhanced uptake of phosphorus by different crops with the application of borate has been documented by Wang *et al.* (1992). Further, application of FYM had increased the P uptake which might be ascribed to more availability of these nutrients from added fertilizers and to the solubility action of organic acids produced during the degradation of organic materials thus resulting in more release of the native and applied phosphorus. Similar results were also reported by Rahman (1986), Thimma Reddy (1987), Kavalappa (1989), Gulshan *et al.* (1999) and Shivakumar (1999). The value of total uptake of phosphorus was significant and positively correlated with grain yield (r = 0.919) (Table 4.1.20).

5.2.4.3 Effect of zinc and boron application on potassium uptake

The data on total potassium uptake, potassium uptake by finger millet grain and straw differed significantly due to micronutrients application. Application of micronutrients (Zn and B) along with recommended dose of NPK and FYM (T_9) recorded significantly higher potassium uptake by finger millet grain (16.55 kg/ha), straw (56.08 kg/ha) and total potassium uptake (72.63 kg/ha) as compared to control (Table 4.1.17 and Fig. 12). This could be due to the beneficial effect of

combined application of micronutrients, FYM and inorganic fertilizers in increasing the absorption of potassium. The higher potassium uptake through addition of zinc was primarily due to its increased concentration coupled with higher grain and straw yield. In line with the present findings Venkateswarlu and Misra, 1987; Cisse *et al.*, 1986 have also reported that manure addition increased nitrogen and phosphorus mobilization and root adsorption activity four fold when compared to fertilized plots, while potassium was increased two fold. These results are in agreement with the earlier findings of Rahman (1986), Thimma Reddy (1987), Kavalappa (1989), Gulshan *et al.* (1999) and Shivakumar (1999) who reported higher K_2O uptake due to addition of recommended NPK and FYM in finger millet and wheat. A significant and positive correlation between total potassium uptake and seed yield (r=0.933) has further substantiated the results (Table 4.1.20).

5.2.4.4 Effect of zinc and boron application on zinc uptake

The data on total Zn uptake differed significantly due to zinc and boron application. Application of NPK + FYM + $ZnSO_4$ + borax (T_9) recorded significantly higher total Zn uptake by finger millet grain (88.54 g/ha) and total uptake (137.38 g/ha), whereas, application of NPK + $ZnSO_4$ + borax (T_6) recorded higher uptake of zinc in the straw of finger millet (52.53 g/ha) as compared to control(Table 4.1.18 and Fig. 13) but it was found on par with the former treatment (T_9 : 48.84 g/ha). The increase in zinc uptake by application of farm yard manure may be attributed to production of complexing agents, which form stable organometallic complexes with zinc that facilitates its efficient utilization by plants resulting in increased yield, its concentration and uptake (Patel and Patel, 1992). Further, the increased zinc nutrition seemed to improve the metabolic activities of plant resulting in a significant increase in the zinc uptake. The results are in line with the findings of Yadav *et al.* (1989) and Indulkar and Malewar (1994) Further, the total

Zn uptake was significant and positively correlated with the grain yield (r=0.913)(Table 4.1.20).

5.2.4.5 Effect of zinc and boron application on boron uptake

Pooled data on boron uptake by finger millet grain, straw and total boron uptake differed significantly due to zinc and boron application. Application of NPK + FYM + $ZnSO_4$ + borax (T_9) recorded significantly higher boron uptake by finger millet grain (19.49 g/ha), straw (54.41 g/ha) and total uptake (73.89 g/ha) as compared to control(Table 4.1.19 and Fig. 13). This might be due to higher biomass production coupled with higher boron concentration. The increased boron uptake due to application of boron has been documented by Sinha *et al*. (1991) in different *kharif* and *rabi* crops. The value of total uptake of boron was significant and positively correlated with grain yield (r = 0.893) (Table 4.1.20).

5.3 Experiment-I (b): RESPONSE OF FINGER MILLET-SOYBEAN ROTATION TO ZINC AND BORON NUTRITION

Crop: Soybean

5.3.1 Effect of zinc and boron application on growth and growth parameters of soybean

Growth in plants has various phases which starts with activation of embryo and ends with maturation of seed (yield). The processes involved in plant growth and development are more often limited by deficiency of trace elements inspite of liberal application of major nutrients. In the pursuit of yield maximization, trials conducted in recent past has revealed that the use of imbalanced nutrients is the main constraint for the currently observed lower yield levels which could be increased by adopting integrated plant nutrient supply system involving

conjunctive use of zinc and boron along with recommended dose of fertilizers and FYM (Shankar *et al.*,2005).

The results of the present investigation revealed that application of NPK + FYM + $ZnSO_4$ + borax (T_9) has significantly increased the plant height (16.90, 31.85 and 36.75 cm at 30, 60 DAS and at harvest, respectively) as compared to control (Table 4.2.1 and Fig. 14).

This increase in plant height may be due to greater availability of macro and micronutrients from organic and inorganic sources which helped in acceleration of various metabolic processes. It is a well known fact that, zinc takes part in the metabolism of plant as an activator of several enzymes which in turn can directly or indirectly affect the synthesis of carbohydrate and proteins (Puste and Jana, 1995). Boron plays a vital role in transport of carbohydrates in plant system as well as in cell wall metabolism (Dugger, 1983). These nutrients were supplied adequately and timely to plants, which might have resulted in cell elongation and growth resulting in increased plant height at all the stages of plant growth. Further, application of farm yard manure along with NPK might have helped in better absorption of nutrients coupled with proper distribution of assimilates in the plant system. These results corroborate the findings of Rose *et al.* (1981), Reddy *et al.* (1991), Jain *et al.* (1995), Wang *et al.* (1995), Masood Ali and Mishra (2001) and Paradhakar and Deshmukh (2004) who have been reported higher plant height of various crops due to zinc application.

There was a marked increase in the number of green leaves per plant, leaf area, leaf area index (LAI) and leaf area duration of soybean due to application of NPK + FYM + $ZnSO_4$ + borax (T_9) as compared to control at different growth stages (Table 4.2.2 to 4.2.5). The LAI registered a curvilinear trend of increase upto 60 DAS and declined marginally later because of senescence and leaf fall. Application of NPK

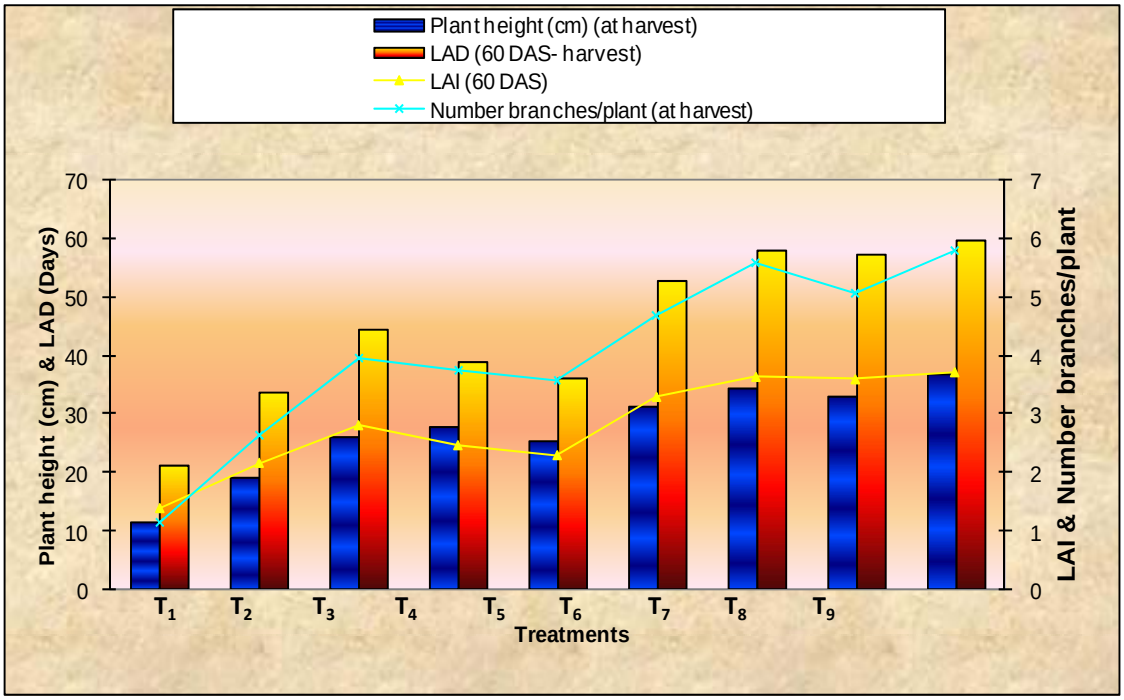


Fig.14 : Plant height, leaf area index, leaf area duration and number of branches per plant of soybean as influenced by zinc and boron nutrition

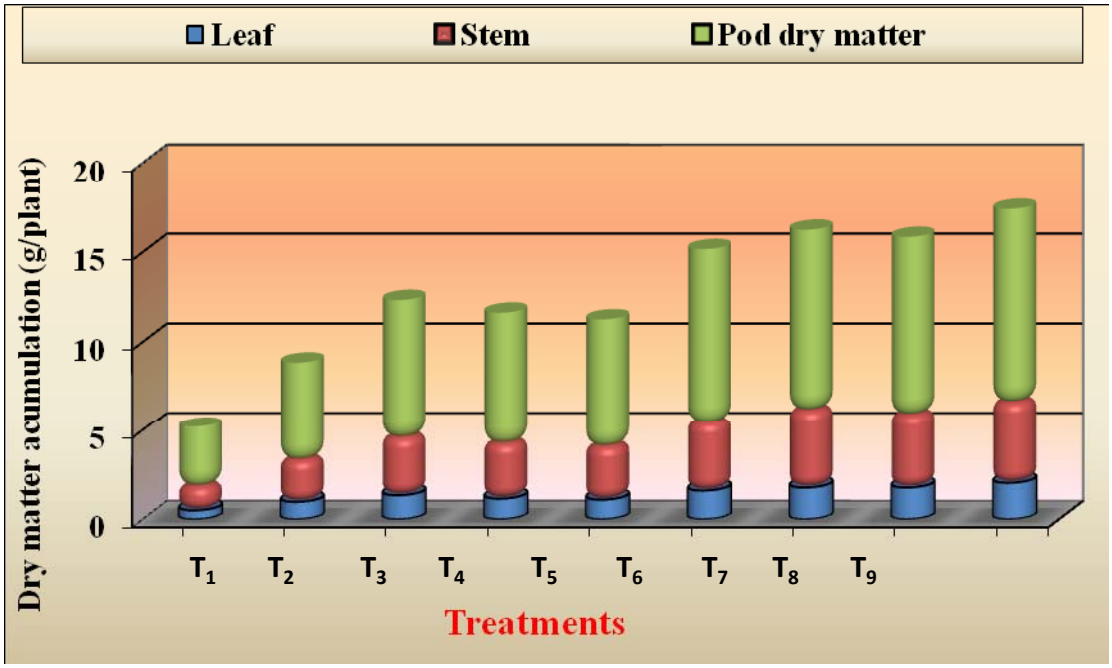


Fig.15 : Dry matter accumulation of soybean at harvest as influenced by zinc and boron nutrition

+ FYM + $ZnSO_4$ + borax (T_9) recorded significantly higher LAI (1.53, 3.68 and 0.29 at 30, 60 DAS and at harvest, respectively) throughout the growth period as compared to control (Table 4.2.4 and Fig. 14). Conjunctive use of micronutrients (Zn and B) along with recommended dose of NPK and FYM might have played their potent roles on enhanced cell division and elongation of leaves resulting in higher biomass. Further, this has been resulted in increased LAI which is indicative of high mobilizable protein pools available at the beginning of the reproductive phase and later on greater plant bearing capacity (Boote *et al.*, 1986). The higher leaf area and LAI with application of micronutrients along with recommended dose of fertilizer and manure was a consequence of higher number of leaves at 30 (5.42) and 60 DAS (19.26) (Table 4.2.2). Higher leaf area duration indicates a longer period of greenness of the leaves which might have resulted in more photosynthetic area activity for the growth and development of crop. These findings are in line with those of Puste and Jana (1988), Sarkar and Aery (1990), Bisht and Chandel (1991), Reddy *et al.* (1991), Jain *et al.* (1995), Navale and Gaikwad (1998), Aruna and Narasa Reddy (1999) and Liu Peng and Yang Yuai (2003).

Application of NPK + FYM + $ZnSO_4$ + borax (T_9) recorded significantly higher number of branches per plant at 60 DAS (4.77) and at harvest (5.77) as compared to control (Table 4.2.5 and Fig. 14). However, it was found on par with the application of NPK + FYM + $ZnSO_4$ (T_7) and NPK + FYM + borax (T_8). This increase in number of branches per plant may be due to higher physiological efficiency and photosynthetic rates (Bisht and Chandel, 1991). The findings are in line with those of Reddy *et al.* (1991), Wang *et al.* (1995), Navale and Gaikwad (1998), Masood Ali and Mishra (2001) and Paradhkar and Deshmukh (2004) who have been observed such significant improvement in number of branches due to zinc and boron application in different legumes.

The higher total dry matter (TDM) production coupled with maximum translocation of dry matter (DM) into sink decides the yield of crops (Krishnamurthy *et al.*, 1973). The results on dry matter production differed significantly due to zinc and boron application. It is evident from the pooled data that, application of NPK + FYM + $ZnSO_4$ + borax (T_9), NPK + FYM + $ZnSO_4$ (T_7) and NPK + FYM + borax (T_8) recorded significantly higher total dry matter accumulation (TDMA) at all the growth stages of crop as compared to control (Table 4.2.6 to 4.2.8 and Fig. 15). This may be due to the favourable effect of optimum nutrition on higher dry matter distribution in leaf, stem and pods. This improvement in dry matter production with application of zinc might be ascribed to the active participation of zinc in chlorophyll biosynthesis, in prosthetic group and metallic constituent of enzyme systems. Net result was increase in photosynthetic efficiency of soybean which led to the higher dry matter production. These results are in conformity with those of Puste and Jana (1988), Sarkar and Aery (1990), Tomar *et al.* (1990), Saxena and Chandel (1997), Barman *et al.* (1998), Vasavi Rani *et al.* (2000) and Kuldeep Singh and Hans Raj (2001). Evidences suggests that boron deficiency in plants decreases the biomass and disturbs the carbonhydrate and phenol metabolism (Dugger, 1983). These results are in accordance with the findings of Pabitra Kumar Mani and Haldar (1996), Rahman *et al.* (1999) and Pratima Sinha and Chatterjee (2003). This increase could also be attributed to the positive effect of farm yard manure in increasing the nutrients uptake leading to higher dry matter production (Reddy *et al.*, 1992).

The cumulative effect of all these sources of nutrients might have resulted in higher dry matter accumulation and its distribution in different plant parts. Further, the increase in TDMA with ageing was mainly due to the improvement in growth parameters like plant height, number of branches and leaf area (Table 4.2.1 to 4.2.3).

Soybean, being a leguminous crop, is capable of fixing atmospheric nitrogen through symbiosis by root nodules which act as factories of nitrogen fixation (Balasubramanian, 1996). In all the treatments, number and weight of nodules increased significantly over control (Table 4.2.9 and 4.2.10). Application of NPK + FYM + $ZnSO_4$ + borax (T_9) recorded significantly higher number of nodules per plant and nodule dry weight which was 338, 180and 330; 875, 413 and 533 per cent higher at 45, 60 and 75 DAS, respectively as compared to control. The significant increase in nodulation could be attributed to the synthesis of plant growth promoting substances like auxin due to zinc application. This inturn enhanced root initiation and shoot elongation of plant causing stimulatory effect on production and development of nodules. The results are in agreement with the findings of Shankar and Andanigowda (1981), Kulkarni *et al.* (1989) and Sarkar and Aery (1990). Golakiya and Patel (1986) and Rahman *et al.*(1999) who observed favourable effects on nodule count due to boron application. Beneficial effect of FYM in increasing the nodule number and weight might be attributed to the release of organic acids during the decomposition which helps in dissolving the native bound phosphorus which play vital function such as cell division, photosynthesis, root growth and inturn increase the nitrogenase activity.

5.3.2 Effect of zinc and boron application on yield and yield attributes of soybean

Application of micronutrients (Zn and B) caused significant variations in yield. Application of NPK + FYM + $ZnSO_4$ + borax (T_9) recorded significantly higher seed yield (1936 kg/ha) as compared to control. However, it was found on par with the application of NPK + FYM + $ZnSO_4$ (T_7 : 1908 kg/ha) and NPK + FYM + borax (T_8 : 1875 kg/ha) (Table 4.2.13; Plate 3 and Fig. 18). The increase in yield might be attributed basically to the reason that zinc shows beneficial effects on

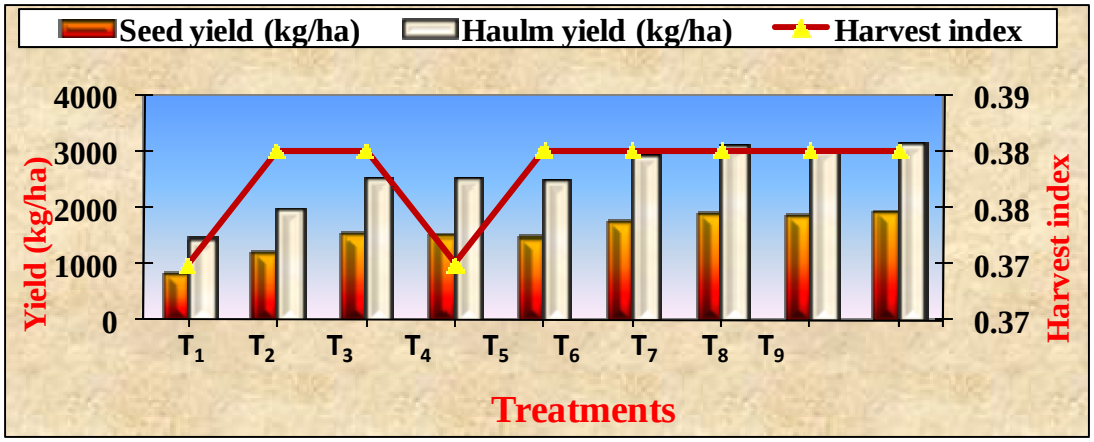


Fig.18 : Seed yield, haulm yield and harvest index of soybean as influenced by zinc and boron nutrition

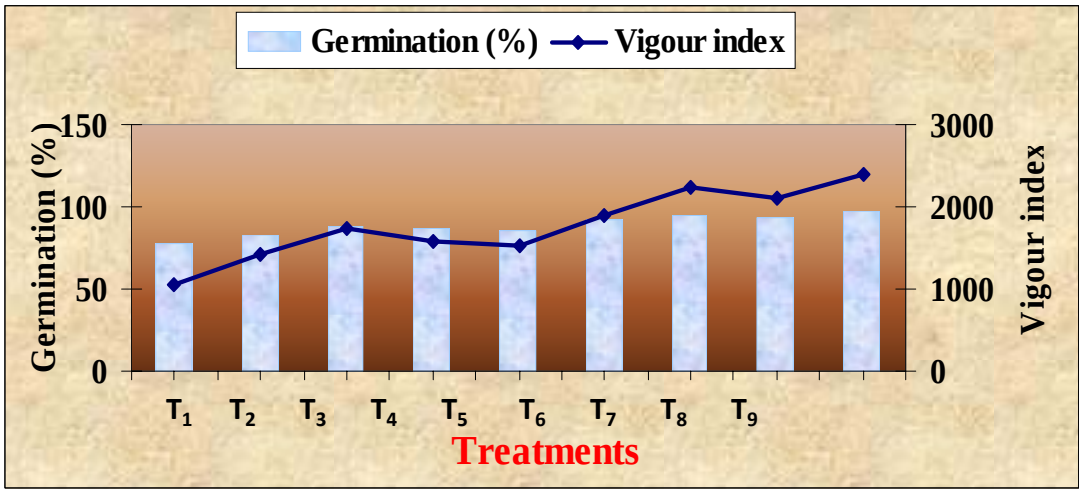


Fig.19 : Germination and vigour index of soybean as influenced by zinc and boron nutrition

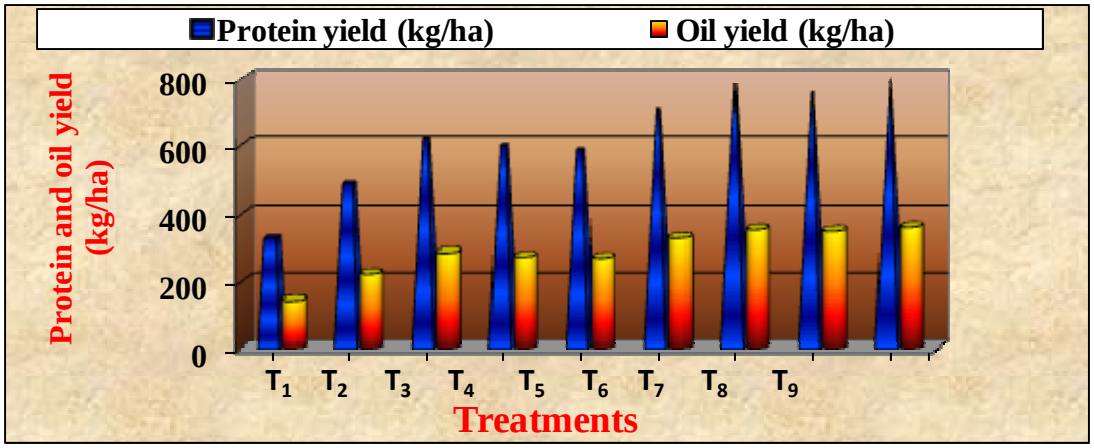


Fig. 20 : Protein and oil yield of soybean as influenced by zinc and boron nutrition

T_1: Control (No NPK + No FYM)

T_2: NPK only

T_6:NPK+ $ZnSO_4$+ Borax

T_9:NPK+ FYM+ $ZnSO_4$+ Borax

Plate 3: Response of soybean to zinc and boron nutrition (Expt. Ib)

chlorophyll content and so it indirectly influences the photosynthesis and reproduction. The channelization of photosynthates during reproductive stage might have been influenced by zinc, by way of its involvement in electron transfer (Baker *et al.*, 1982) and activation of various enzymes (Okhi, 1978), which inturn can directly or indirectly affect the synthesis of carbohydrates and proteins. This might have contributed to the increase in the yield attributes. Favourable influences on the yield attributes due to zinc application contributed to significant increase in seed yield. Similar favourable effect of zinc was reported by Shivashankar *et al.* (1974), Kalia and Sharma (1988), Gupta and Vyas (1994), Nagaraju and Yadahalli (1996), Raghuwanshi *et al.* (1997), Saxena and Chandel (1997), Vasvi Rani *et al.* (2000), Gurkirpal Singh *et al.* (2001) and Thakur *et al.* (2001) in different legumes. In addition to zinc, application of boron favoured better root growth and nitrogen assimilation with higher nodulation which in turn resulted in better growth and development of sink size (number of pods/plant, number of seeds/plant, pod length, pod yield and higher seed yield). Present results are in confirmation with those of Kalia and Sharma (1988), Chandel *et al.* (1989), Pratima Sinha and Chatterjee (2003) and Singh *et al.* (2006).

Application of farm yard manure with recommended levels of NPK resulted in maximum yield which can be attributed to sustained release of available nutrients during the crop growth period (Rani Perumal *et al.*, 1991). The differential growth response due to application of micronutrients (Zn and B) alone or in combination with farm yard manure may be ascribed to sorption of inorganic and organic colloids (Deka and Poonia, 1996). The spectacular increase in yields due to application of NPK and FYM have also been reported in soybean by several workers (Sharma and Dixit, 1987; Singh, 1991; Bobde *et al.*, 1998; Babhulkar *et al.*, 2000; Alok Tiwari *et al.*, 2002; Deshmukh *et al.*, 2005). The results are further supported by significant and positive

correlation between seed yield and growth parameters like TDM at harvest (r = 0.782), leaf area at harvest (r = 0.805), nodule number (r = 0.820) and nodule dry weight at 60 DAS (r = 0.770), number of branches at harvest (r = 0.753). In addition the yield is positively correlated with yield parameters like number of pods per plant (r = 0.770), number of seeds per plant (r = 0.746), pod length (r = 0.831), pod yield per plant (r = 0.779), seed yield per plant (r = 0.785) and test weight (r = 0.634) (Table 4.2.21). Amarnath *et al.* (1990) has also reported a positive correlation of seed yield with seeds per pod, branches per plant and 100- seed weight in soybean.

The regression analysis showed a positive partial regression for growth and yield parameters. The regression equation based on all the character showed that they contributed to seed yield by 94 per cent.

The data on haulm yield of soybean differed significantly due to micronutrients application. Application of NPK + FYM + $ZnSO_4$ + borax (T_9), NPK + FYM + $ZnSO_4$ (T_7), NPK + FYM + borax (T_8) and NPK + $ZnSO_4$ + borax (T_6) recorded significantly higher haulm yield (3152, 3107, 3056 and 2956 kg/ha, respectively). However, all these treatments were found statistically on par with each other (Table 4.2.13 and Fig. 18). The higher haulm yield in these treatments may be accounted for the balanced application of nutrients which was conducive to better growth, development and nutrient uptake. Application of NPK + FYM + $ZnSO_4$ + borax (T_9) resulted in higher haulm yield which could be ascribed to its profound influence on vegetative growth (leaf area, plant height, total dry matter and its distribution in different plant parts of the crop (Table 4.2.1 to 4.2.8). indeed, the balanced fertilization seems to help restoration of better nutritional environment, facilitating fuller expression of crop potential for its growth, yield components and ultimately yield. Similar results have also been reported by Ahmed *et al.* (1986), Sakal *et*

al. (1998), Navale and Gaikwad (1998), Thakur *et al.* (2001) and Singh *et al.* (2006).

The harvest index (HI) did not differ significantly due to micronutrients application. It may be due to proportionate production of seed and haulm yields in soybean by different nutrient treatments which kept HI values almost constant (Table 4.2.13 and Fig. 18).

Yield contributing characters of soybean were influenced significantly by the application of organics in combination with recommended fertilizers and micronutrients. Application of NPK + FYM + $ZnSO_4$ + borax (T_9) resulted in significantly higher number of pods (23.65), number of seeds per plant (2.85), pod length (4.75 cm), pod yield (10.83 g/plant), seed yield (5.22 g/plant), test weight (14.35 g) as compared to control (Table 4.2.11 to 4.2.12; Fig. 16 and 17). However, it was found on par with application of NPK + FYM + $ZnSO_4$ (T_7) and NPK + FYM + borax (T_8). The improvement in yield attributes and consequent to higher yield by zinc might be possible due to the enhanced synthesis of carbohydrates and proteins and their transport to the sink through effective physiological activities in plants, as evident from improved physiological parameters like dry matter production and LAI. The results corroborate the findings of Kalia and Sharma (1988), Channabasavanna and Setty (1993), Kushwaha (1993), Puste and Jana (1995) and Gurkirpal Singh *et al.* (2001) who have observed the improvement in yield parameters of soybean due to application of zinc sulphate over control.

It is well known fact that boron application influences seed setting, mobilization of sugars from source to sink, growth of pollen tube and fertilization. Further, the beneficial effect of FYM applied in conjunction with boron in the present experiment may be due to formation of boron – diol complexes with the break down products of FYM. On a weight basis,

organic matter retains more boron than mineral soil constituents (Sakal *et al.*, 1999). In line with present study, the findings of Kalia and Sharma (1988), Deosarkar *et al.* (2002) and Sumit Chaturvedi and Chandel (2005) who were also of the same opinion.

5.3.3 Seed quality parameters of soybean as influenced by zinc and boron application

Grain protein is important in human and animal nutrition. In the present study, application of NPK + FYM + $ZnSO_4$ + borax (T_9) recorded higher protein (41.19%) followed by NPK + FYM + $ZnSO_4$ (T_8 : 40.16%). Similarly, significant differences in protein yield were observed due to combined application of NPK + FYM + $ZnSO_4$ + borax (T_9 :792.95 kg/ha) as compared to control (T_1 :326.54 kg/ha). However, it was found on par with the application of NPK + FYM + $ZnSO_4$ (T_7 :777.75 kg/ha) and NPK + FYM + borax (T_8 :753.14 kg/ha) (Table 4.2.14 and Fig. 20). The increased protein yield may be due to higher seed yield, besides the vital role played by zinc in the synthesis of plant hormones, chlorophyll formation and carbohydrate and in auxin metabolism. Boron plays an important role in the synthesis of amino acid which is a component of protein (Mengel and Kirkby, 1984). The results are in conformity with those earlier reported by Kapur *et al.* (1977), Ahmed *et al.* (1986), Jha and Chandel (1987), Krishnappa *et al.* (1992), Ibrahim (1992) and Tomar *et al.* (1995). Further, the accomplished studies indicate that the accumulation of phenols in acutely boron deficient soybean seeds is due to the regulation of pentose phosphate cycle via the formation of acid borate complexes. This might indirectly affected the formation and development of seeds. The accumulation of phenols in edible parts causes poor digestibility of proteins, thus ultimately affecting the quality of soybean (Sikka *et al.*, 1989). The concentration of protein decreased considerably in boron deficient seeds which might be attributed to impaired synthesis of amino acids which are the essential building

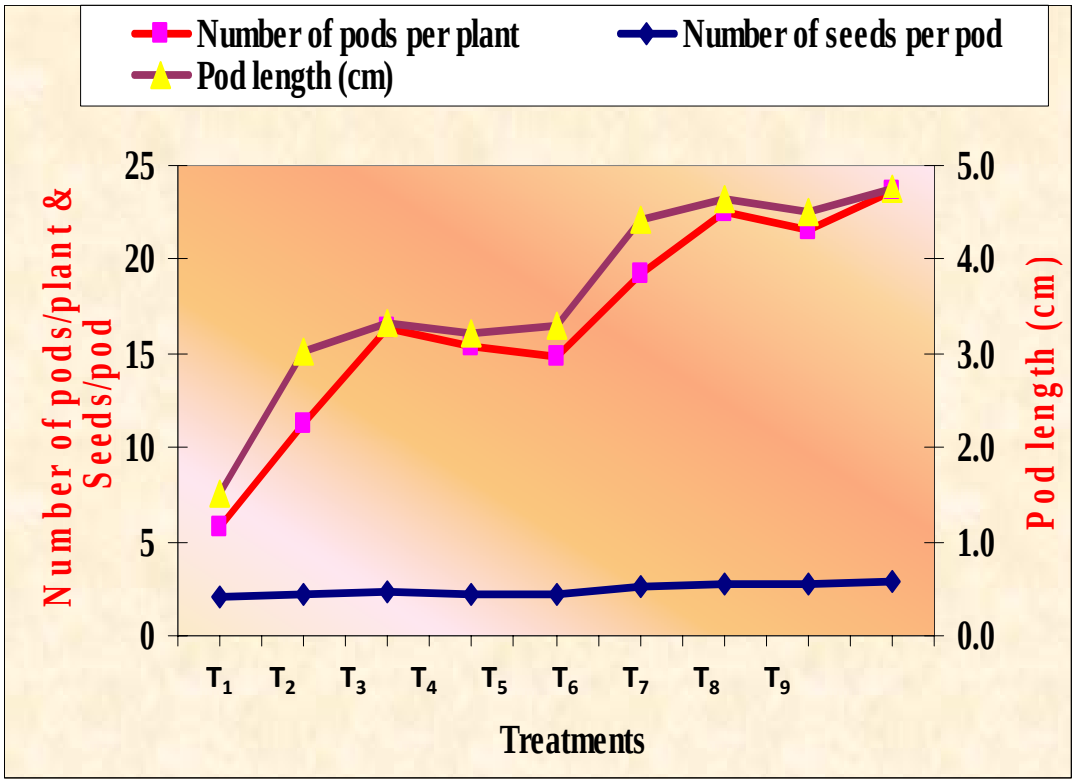


Fig.16 : Number of pods per plant ,number of seeds per pod and pod length of soybean as influenced by zinc and boron nutrition

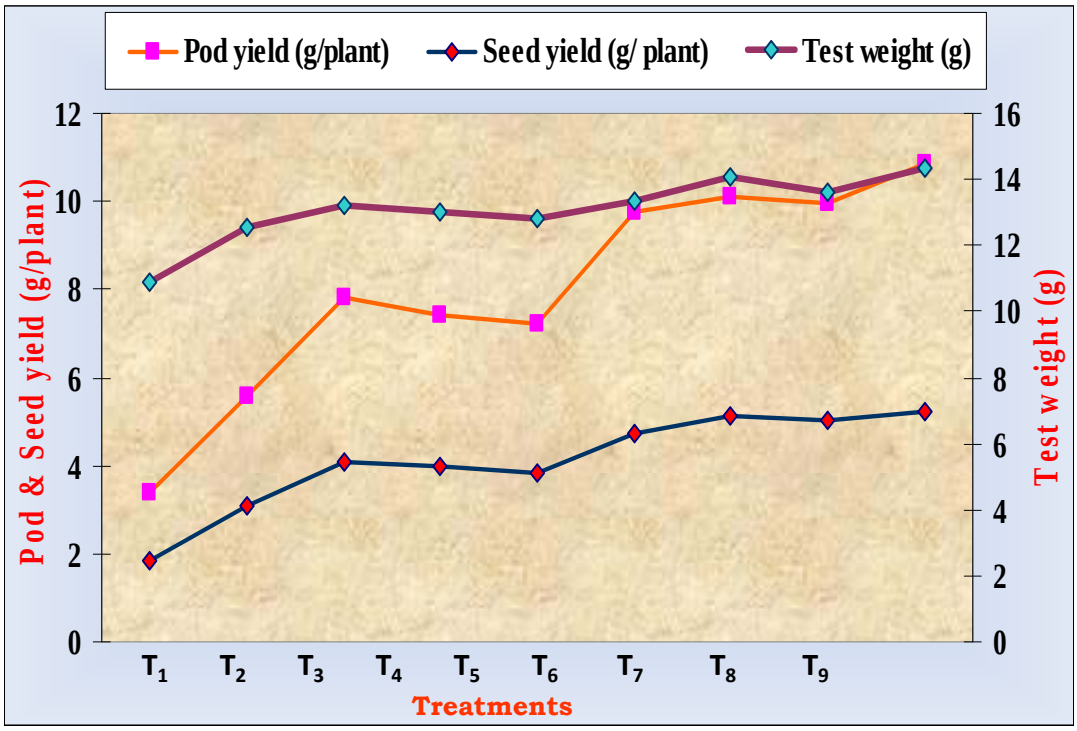


Fig.17 : Pod yield, seed yield and test weight of soybean as influenced by zinc and boron nutrition

blocks of proteins (Mahajan *et al.*, 1994). The results are in line with the findings of those of Dongale and Zinde (1978), Shukla *et al.* (1983), Pratima Sinha and Chatterjee (2003) and Singh *et al.* (2006).

The beneficial effect exhibited by FYM when it was applied in conjunction with chemical fertilizers could possibly be due to synergistic role of FYM in increasing the nutrient availability, physical structure of soils, microbial enviornment and sustaining it over a period of time as compared to chemical fertilizer alone. These results are in concordance with the findings of Sharma and Mishra (1997), Singh *et al.* (2003) and Paradhakar and Deshmukh (2004).

Application of NPK + FYM + $ZnSO_4$ + borax (T_9) recorded higher oil content (18.75%) and significantly higher oil yield (362.04 kg/ha) as compared to control (Table 4.2.14 and Fig. 20). However, it was found on par with the application of NPK + FYM + $ZnSO_4$ (T_7 : 354.83 kg/ha) and NPK + FYM + borax (T_8 : 350.06 kg/ha) with respect to oil yield. This increase in oil content of soybean with the application of zinc may be on account of the role played by zinc in activating the enzymes responsible for synthesis of oil (Tisdale *et al.*, 1985). The results are in conformity with the findings of Gupta and Vyas (1994) and Tomar *et al.* (1995). Further, application of FYM along with NPK favoured the higher availability of phosphorus in soil which resulted in higher synthesis of oil as phosphorus is directly involved in oil synthesis particularly in formation of phospholipid and esterification of fatty acids which increased the oil yield. In line with the present study, similar findings were also reported by Ramamurthy and Shivashankar (1996), Dikshit and Khatik (2002) and Singh *et al.* (2003). The increase in oil content and yield due to boron application have also been earlier reported by Singh and Singh (1976), Sankaran *et al.* (1977), Dongale and Zinde (1978), Shukla *et al.* (1983) and Mahajan *et al.* (1994) in groundnut and

Pratima Sinha and Chatterjee (2003) and Singh *et al.* (2006) in soybean. Further, the values of protein and oil yield were significantly and positively correlated with seed yield (r = 0.914 and 0.899, respectively) (Table 4.2.21).

Application of NPK + FYM + $ZnSO_4$ + borax (T_9) recorded significantly higher germination (97.00%), shoot and root dry weight (24.85 mg) and seed vigour index (2397) as compared to control (T_1). (Table 4.2.15 and Fig. 19). It is well known fact that boron and zinc might helps in the biosynthesis of carbohydrates and protein in plants. The presence of higher amounts of carbohydrate, protein and total soluble salt in seeds are beneficial in improving the germination and vigour index of seed (Werner Bergmann, 1992). Hence, high germination and vigour index was noticed in the above treatment too. Further, these results corroborate the findings of Shankar *et al.* (2005).

5.3.4 EFFECT OF ZINC AND BORON APPLICATION ON NUTRIENTS UPTAKE BY SOYBEAN

5.3.4.1 Nitrogen uptake by soybean seed, haulm and total plant uptake

Combined application of zinc sulphate and borax along with recommended dose of NPK and FYM (T_9) recorded significantly higher nitrogen uptake by soybean seed (127.57 kg/ha), haulm (39.13 kg/ha) and total nitrogen uptake (166.70 kg/ha) as compared to rest of the treatments (Table 4.2.16 and Fig. 21). The increase in nitrogen uptake by soybean seed and haulm due to application of micronutrients might be due to the enzymatic effect in the metabolic process (Mahatim Singh *et al.*, 1978). The increase in nitrogen uptake due to increase in dry matter production and nutrient concentration was reported earlier by Zhang and Zhang (1986) and Anil *et al.* (1990).

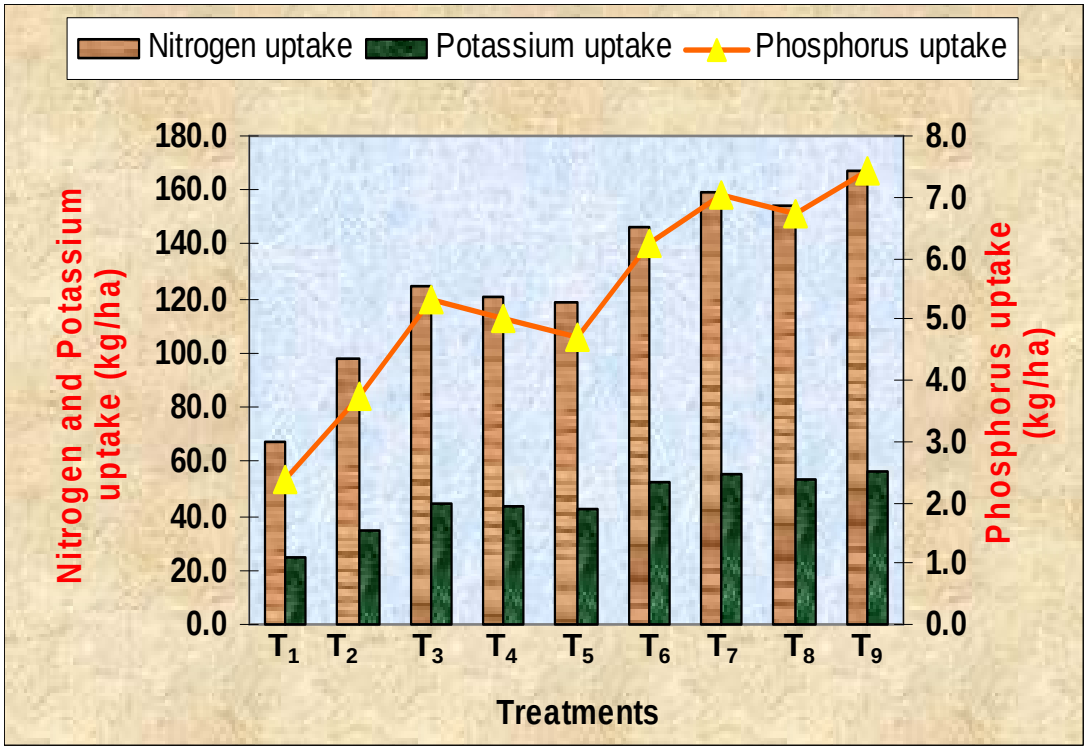


Fig.21: Total nitrogen, phosphorus and potassium uptake of soybean as influenced by zinc and boron nutrition

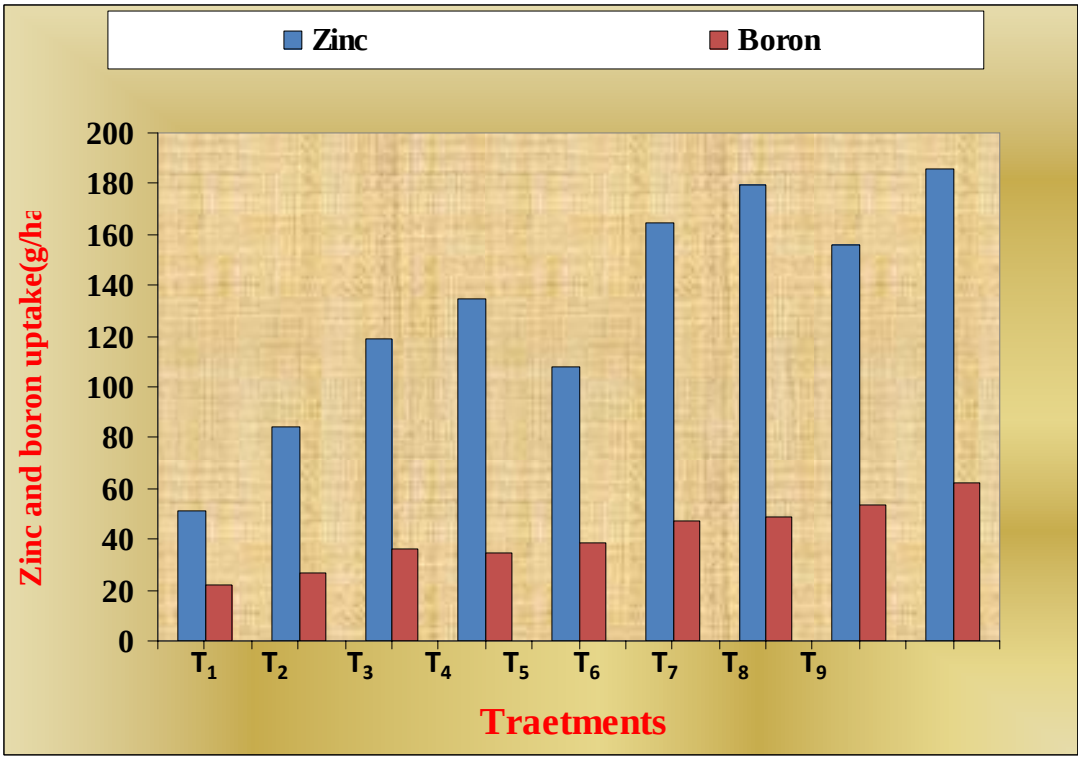


Fig.22 : Zinc and boron uptake of soybean as influenced by zinc and boron nutrition

5.3.4.2 Effect of zinc and boron application on phosphorus uptake

Significantly higher removal of phosphorus by soybean seed (3.38 kg/ha), haulm (4.04 kg/ha) and total phosphorus uptake (7.41 kg/ha) was noticed with the application of NPK + FYM + $ZnSO_4$ + borax (T_9) as compared to control (Table 4.2.17 and Fig. 21). Application of phosphorus along with FYM increased its concentration in soil solution and ultimately helped in the formation of more nodules, vigorous root development, better N_2 fixation and overall development of plants. The significant increase in nodulation due to phosphorus application could be the reason for significant increase in phosphorus uptake by soybean crop. Ahmed *et al.* (1986) also observed higher phosphorus uptake due to combined application of phosphorus and zinc in mungbean.

5.3.4.3 Effect of zinc and boron application on potassium uptake

Potassium uptake by soybean crop showed significant response to Zn and B application. Significantly higher potassium uptake in seed (9.49 kg/ha), haulm (47.16 kg/ha) and total potassium uptake (56.65 kg/ha) was recorded with the application of NPK + FYM + $ZnSO_4$ + borax (T_9) over rest of the treatments (Table 4.2.18 and Fig. 21). Moreover, FYM treatments were found superior to other treatments. This might be owing to increased supply of potassium nutrient sources to the crop, as well as due to the indirect effect resulting from reduced loss of organically supplied nutrient. These results are in agreement with the findings of Nimje and Seth (1988), Reddy *et al.* (1992), Singh and Singh (1994), Sharma and Mishra (1997) and Sumit Chaturvedi and Chandel (2005).

5.3.4.4 Effect of zinc and boron application on zinc uptake

Zinc and boron application is one of the factor to augment the yield and productivity of crops. Zinc application appears to be a limiting factor

in increasing the yield of soybean crop. The deficiency of zinc is predominantly appearing in soybean growing tracts due to intensive agriculture involving high analysis chemical fertilizers. Evidences suggested that the uptake of micronutrients (Mn, Zn, Fe, Cu, Mo and B) was higher at harvest stage indicating the direct relationship of uptake of nutrients with dry matter production (Thiyageshwari and Ramanathan, 2001). The increase in Zn uptake was due the better and greater availability of zinc at the root zone (Kumar and Singh, 1979; Jha and Chandel, 1987; Devarajan and Palaniappan, 1995). In the present investigation, the pooled data indicates that the Zn uptake by seed, haulm and total Zn uptake by soybean plant was significantly higher with the application of NPK + FYM + $ZnSO_4$ + borax (T_9 : 119.80, 65.85 and 185.65 g/ha, respectively) as compared to control (Table 4.2.19 and Fig. 22).

5.3.4.5 Effect of zinc and boron application on boron uptake

Application of NPK + FYM + $ZnSO_4$ + borax (T_9) recorded significantly higher boron uptake by soybean seed (25.30 g/ha), haulm (36.79 g/ha) and total boron uptake (62.09 g/ha) as compared to rest of the treatments (Table 4.2.20 and Fig. 22). This might be due to the fact that application of boron in deficient soils, increases its concentration in soil solution. Hence, their availability increased in soil and consequently greater boron uptake by soybean crop. The results corroborate the findings of Tripathi and Singh (1984), Shinde and Kale (1985), Pratima Sinha and Chatterjee (2003) and Singh *et al.* (2006). Moreover, application of boron along with FYM increased the boron uptake in seed and haulm. This reflected the beneficial effect of FYM to enhance boron availability to crops. Further, the values of total uptake of N, P_2O_5, K_2O, Zn and B were significant and positively correlated with the seed yield (r = 0.836, 0.844, 0.839, 0.819 and 0.823, respectively) (Table 4.2.21).

Vedram *et al.* (2002b) also reported a positive correlation between total uptake of NPKS and Zn with grain yield in mungbean.

5.4 Effect of zinc and boron application on population of soil micro-organisms and soil enzymes activity in finger millet-soybean and soybean-finger millet based cropping system

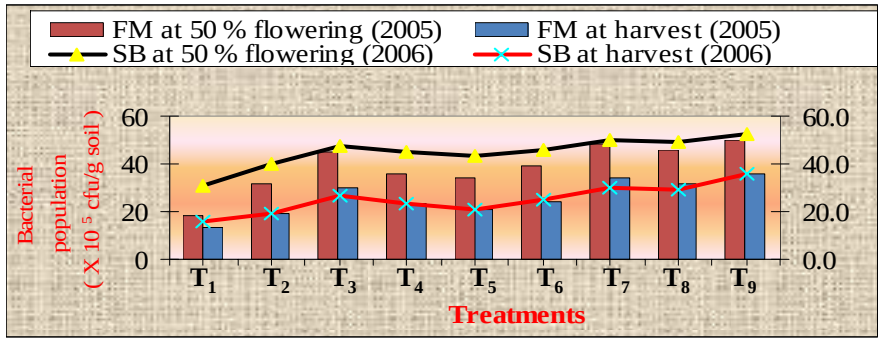
Soil and crop management practices in general and those that influence the fertility in particular have an immediate impact on microbial population which inturn influenced the activity of soil enzymes.

5.4.1 Effect of zinc and boron application on soil microorganisms

Population of diversified microbes (Table 4.3.1 and 4.3.2) was greatly influenced at 50 per cent flowering stage in comparison to harvest due to zinc and boron application. In the present investigation, irrespective of cropping systems, application of micronutrients (Zn and B) along with recommended dose of major nutrients and FYM significantly influenced the population of microbes.

5.4.1.1 Bacterial population

The bacterial population differed significantly due to zinc and boron application with an increasing trend at 50 per cent flowering followed by a decline at harvest (Table 4.3.1 and 4.3.2; Fig. 23). Application of farm yard manure along with recommended dose of fertilizers and micronutrients resulted in enhanced bacterial population as compared to control. Indeed, at 50 per cent flowering and at harvest of crops significantly maximum population of bacteria was observed with application of NPK + FYM + $ZnSO_4$ + borax (T_9) which was followed by NPK + FYM + $ZnSO_4$ (T_7), NPK + FYM + borax (T_8) and NPK + FYM (T_3) in both finger millet-soybean and soybean-finger millet cropping system. The possible reason for relatively higher rate of multiplication of bacteria in FYM treated plot is that as FYM acted as organic substrate for



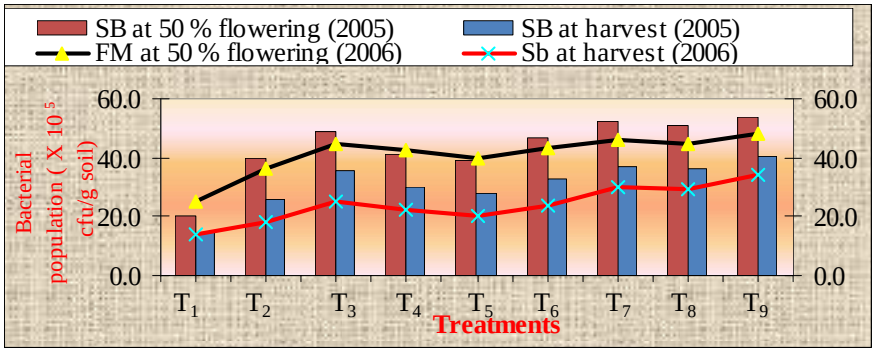
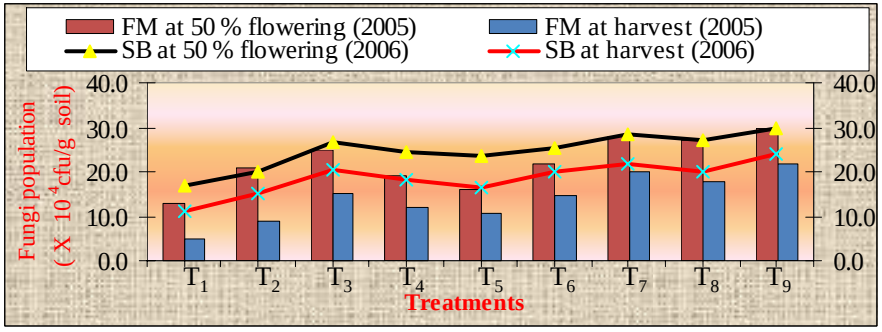


Fig. 23 : Population of bacteria at 50 per cent flowering and at harvest of finger millet and soybean as influenced by zinc and boron application in finger millet –soybean and soybean-finger millet based cropping system



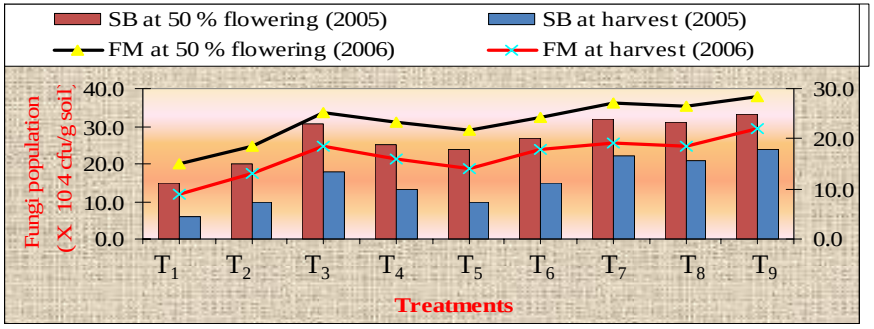
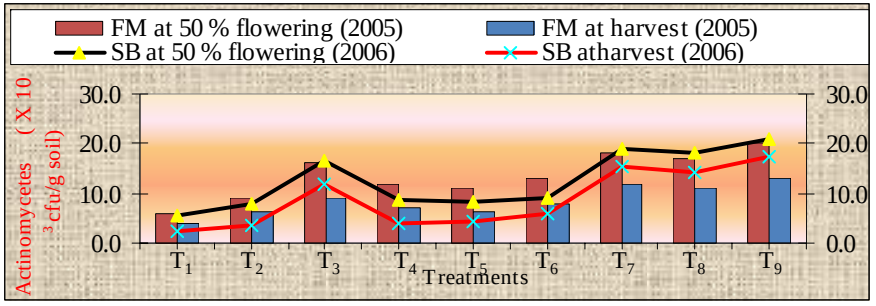


Fig. 24 : Population of fungi at 50 per cent flowering and at harvest of finger millet and soybean as influenced by zinc and boron application in finger millet –soybean and soybean-finger millet based cropping system



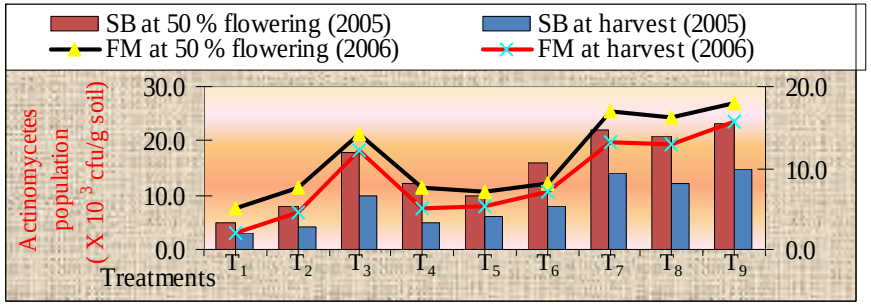


Fig. 25 : Population of actinomycetes at 50 per cent flowering and at harvest of finger millet and soybean as influenced by zinc and boron application in finger millet –soybean and soybean-finger millet based cropping system

stimulation of bacterial growth. Similar findings have been reported by Sharma *et al.* (1986) and Chouksey *et al.*, 1995).

5.4.1.2 Fungal population

There was significant increase in fungal population at 50 per cent flowering and at harvest of crops due to zinc and boron application over control (Table 4.3.1 and 4.3.2; Fig. 24).

In the present investigation, significantly maximum population of fungi was observed with the application of NPK + FYM + $ZnSO_4$ + borax (T_9) as compared to control at 50 per cent flowering and at harvest in both cropping systems. The higher fungal population might have been possible owing to enhanced supply of available food and energy to these organisms. Similar results were also reported by Chouksey *et al.* (1995) and Anon. (2007). Ramaswami (1966) observed more count of fungi in laterite soil rich in organic matter.

5.4.1.3 Actinomycetes population

The data on actinomycetes population also significantly increased due to application of micronutrients along with organics. In the present investigation at 50 per cent flowering and at harvest of finger millet and soybean crops, significantly maximum population of actinomycetes was observed due to application of NPK + FYM + $ZnSO_4$ + borax (T_9) as compared to control (Table 4.3.1 and 4.3.2; Fig. 25). Sharma *et al.* (1986) also established a positive relationship between organic material and actinomycetes in soil. The results of the present investigation are in agreement with the findings of Chouksey *et al.* (1995), Rajender Reddy *et al.* (1999) and Anon. (2007).

Moreover, in the present investigation, the population of bacteria, fungi and actinomycetes were higher under soybean than under finger

millet crop. This might be due to the fact that as soybean is a legume component which is known to release a part of unused NO_3 fixed through symbiotic nitrogen fixation into the soil. Also a lot of low molecular weight organic compounds are released to the soil as exudates. These serve as a substrate to soil microbes and their population builds-up in the soil (Masood Ali *et al.*, 2002). The findings are in line with those of Manna *et al.* (1996). Further, the addition of micronutrients along with FYM enriched the soil with optimum level of nutrients which favoured the crop growth which inturn resulted in release of more root exudates which acts as a source of carbon and energy for microorganisms in both crops.

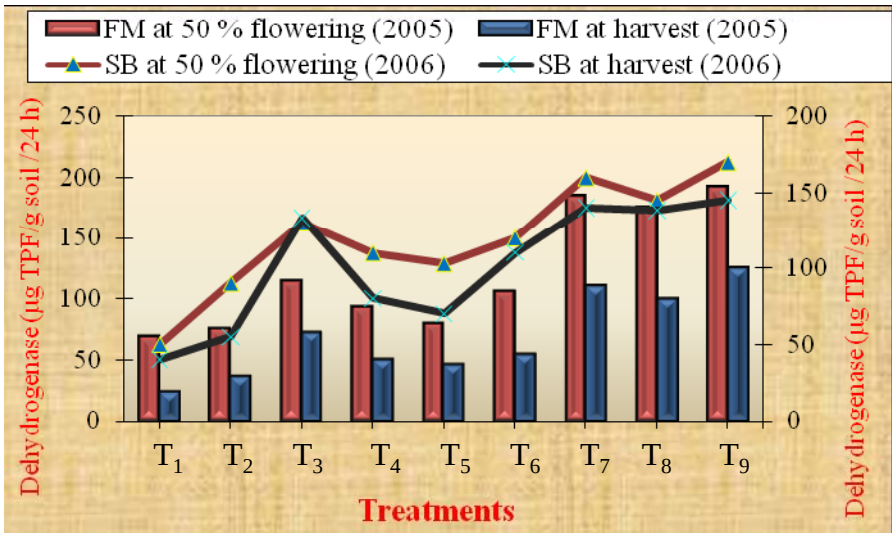
5.4.2 Effect of zinc and boron application on soil enzymes activity at 50 per cent flowering and at harvest of the crops

5.4.2.1 Dehydrogenase activity in soil

Dehydrogenases are enzymes, which acts as an index to soil microbial activity. The dehydrogenase activity in the present study was significantly higher due to application of NPK + FYM + $ZnSO_4$ + borax (T_9) as compared to control (Table 4.3.3 and 4.3.4; Fig. 26). Moreover, the FYM treated plots were found to be extremely superior in the removal of hydrogen. It might be probably due to the increased population of soil microbes by the addition of FYM which inturn released this enzyme. These results are in conformity with those of Manna *et al.* (1996), Singaram and Kamalakumari (1995), Anon. (1997a), Anon. (2000b) and Anon. (2007).

5.4.2.2 Urease activity in soil

The urease activity as observed in this study indicates that significant difference was observed due to application of micronutrients along with recommended NPK and FYM in both the cropping systems



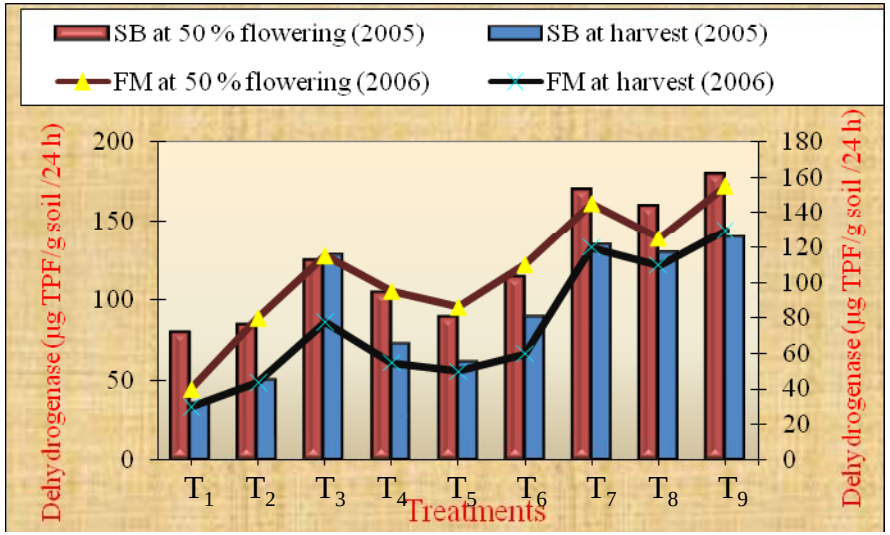
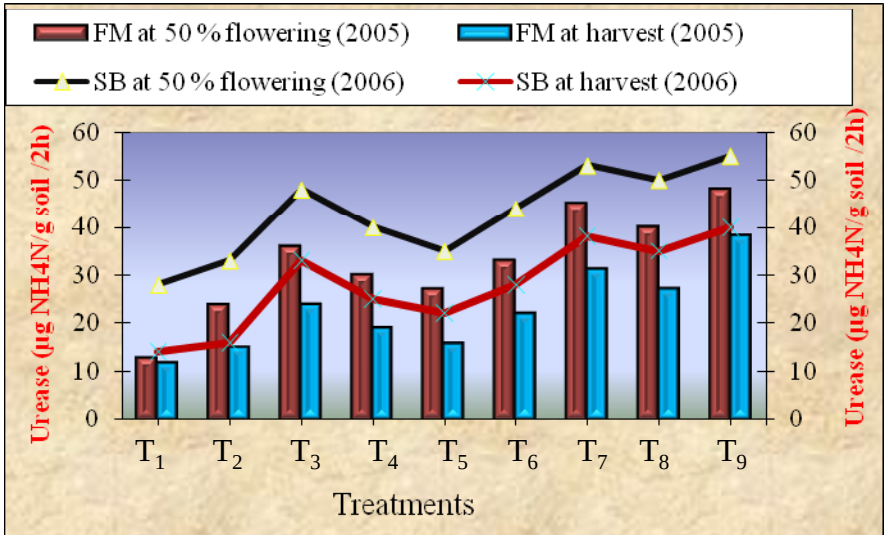


Fig. 26 : Dehydrogenase activity in soil at 50 per cent flowering and at harvest of finger millet and soybean as influenced by zinc and boron application in finger millet –soybean and soybean –finger millet based cropping system



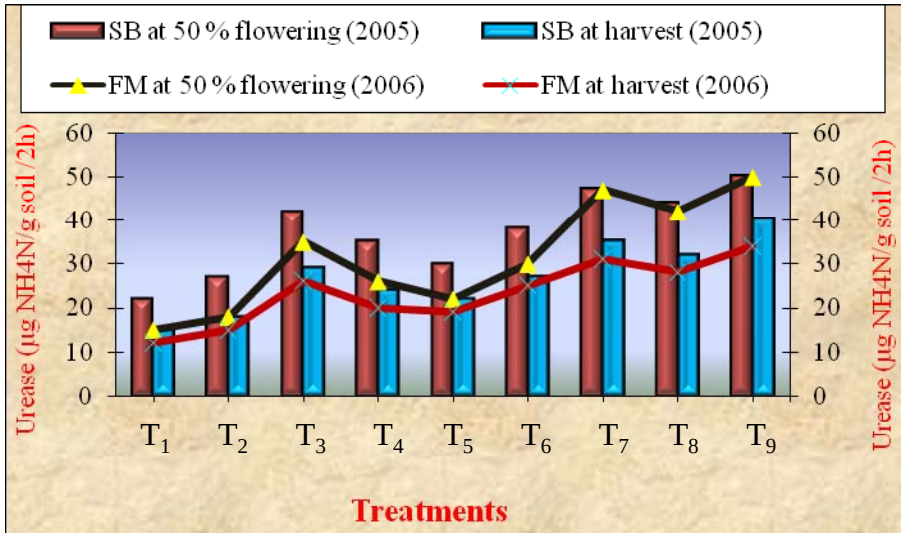


Fig. 27 : Urease activity in soil at 50 per cent flowering and at harvest of finger millet and soybean as influenced by zinc and boron application in finger millet –soybean and soybean –finger millet based cropping system

(Table 4.3.3 and 4.3.4; Fig. 27). Combined application of FYM with NPK and micronutrients (T_9) produced significantly higher activity of urease as in the case of other enzymes. The role of farm yard manure is multidimensional ranging from building up of organic matter, maintaining favourable soil physical properties and balanced supply of nutrients which promoted the activity of soil microbes which helped in recording higher activity of urease. Indeed, the present results are in confirmation with those of Manna *et al*. (1996) and Anon. (2007). Khan (1970) also observed increase in urease activity in manured treatments due to higher microbial activity as compared to control treatments.

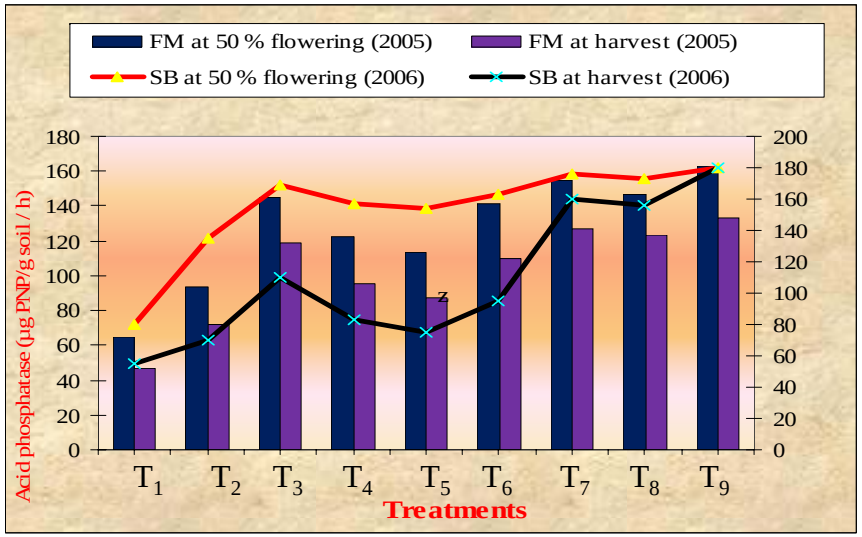
5.4.2.3 Acid phosphatase activity in soil

The conversion of organic P into inorganic P is mainly brought about and governed by phosphatase activity. It is dependent on pH, organic matter and available P status of the soil.

In the present study acid phosphatase activity in the soil was found to be maximum with the application of NPK + FYM + $ZnSO_4$ + borax (T_9) at 50 per cent flowering and at harvest in both cropping systems. Application of NPK + FYM + $ZnSO_4$ (T_7), NPK + FYM + borax (T_8) and NPK + FYM (T_3) are the next best treatments with regard to activity of acid phosphatase in soil (Table 4.3.3 and 4.3.4; Fig. 28). This could be due to the higher population of microorganisms with the addition of organics. The acid phosphatase activity increased initially and then declined with the age of crop as in case of other enzymes. Similar results have also been reported by several workers (Speir and Ross, 1978; Singaram and Kamalakumari, 1995; Anon., 2007).

5.4.2.4 Alkaline phosphatase activity in soil

In the present investigation, application of NPK + FYM + $ZnSO_4$ + borax (T_9), NPK + FYM + $ZnSO_4$ (T_7), NPK + FYM + borax (T_8) and NPK +



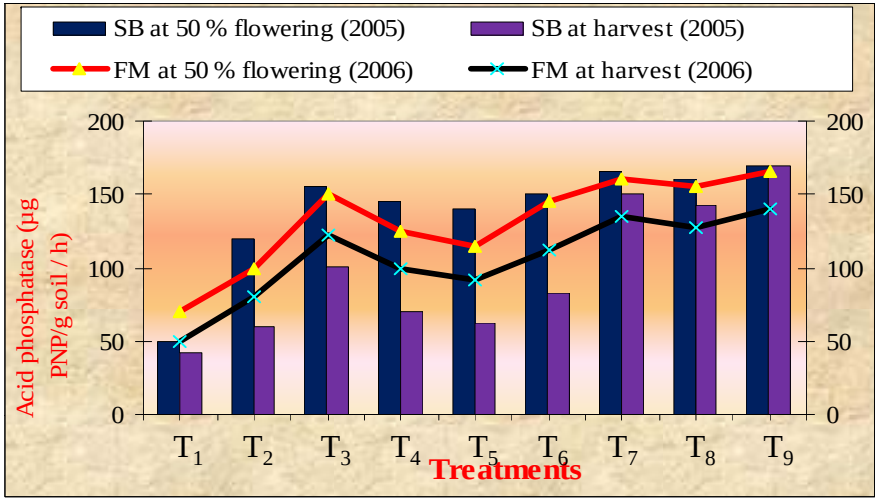
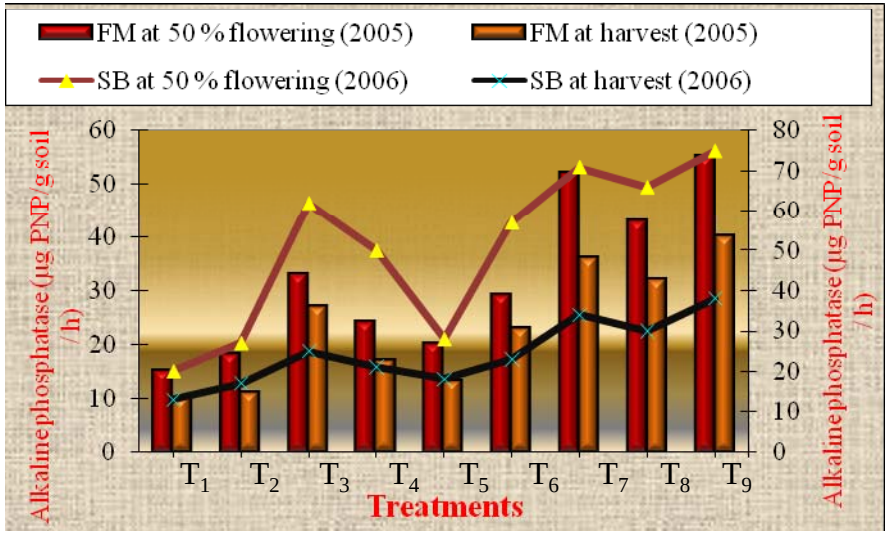


Fig. 28: Acid phosphatase activity in soil at 50 per cent flowering and at harvest of finger millet and soybean as influenced by zinc and boron application in finger millet –soybean and soybean –finger millet based cropping system



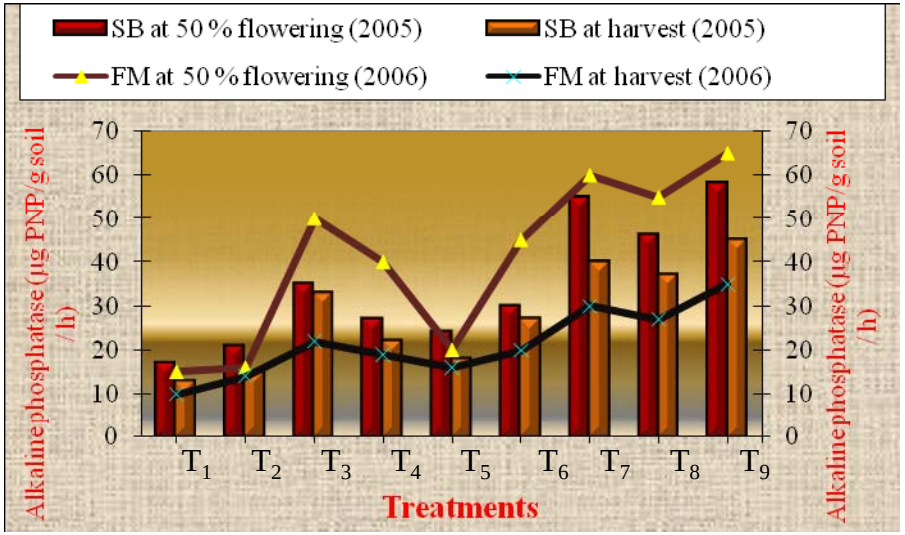


Fig. 29: Alkaline phosphatase activity in soil at 50 per cent flowering and at harvest of finger millet and soybean as influenced by zinc and boron application in finger millet –soybean and soybean –finger millet based cropping system

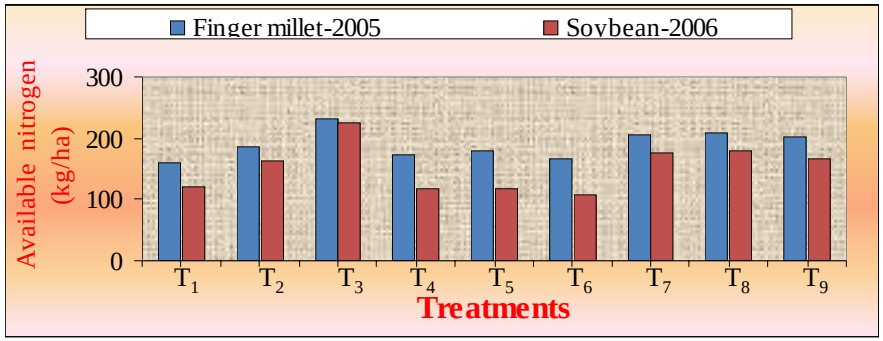
FYM (T_3) resulted in significantly higher alkaline phosphatase activity at 50 per cent flowering and at harvest in both the cropping systems (Table 4.3.3 and 4.3.4; Fig. 29). The enhanced activity of alkaline phosphatase enzyme upon addition of micronutrients and farm yard manure might be due to higher activity of heterotrophic microorganisms. Similar are the findings of Chhonkar and Tarafdar (1984) and Singaram and Kamalakumari (1995).

The increase in the enzyme activity with application of organics and micronutrients may be ascribed to the increased microbial activity as a result of increased availability of substrate (organic carbon) through FYM which inturn might have released these enzymes of extracellular origin. The lower activity of different enzymes in soil at harvest might be due to the reduced microbial population in soil because of the exhaustion of substrate. Furthermore, the activity of soil enzymes were higher under soybean than in finger millet due to higher microbial population which prevailed in the rhizosphere. The enhanced activity of soil enzymes due to addition of FYM and micronutrients promoted the recycling of nutrients in the soil eco-system. The findings are unique in nature and perhaps first of its kind and needs further studies in this direction.

5.5 EFFECT OF ZINC AND BORON APPLICATION ON AVAILABILITY OF NUTRIENTS IN SOIL AND MICRO NUTRIENT USE EFFICIENCEY IN FINGER MILLET-SOYBEAN AND SOYBEAN-FINGER MILLET BASED CROPPING SYSTEM

5.5.1 Available nitrogen in the soil

The data on the available nitrogen content after harvest of crops differed significantly due to micronutrients application (Table 4.4.1 and Fig. 30). Significantly higher available nitrogen in soil was recorded with application of NPK + FYM (T_3) after harvest of finger millet (231.04 kg/ha)



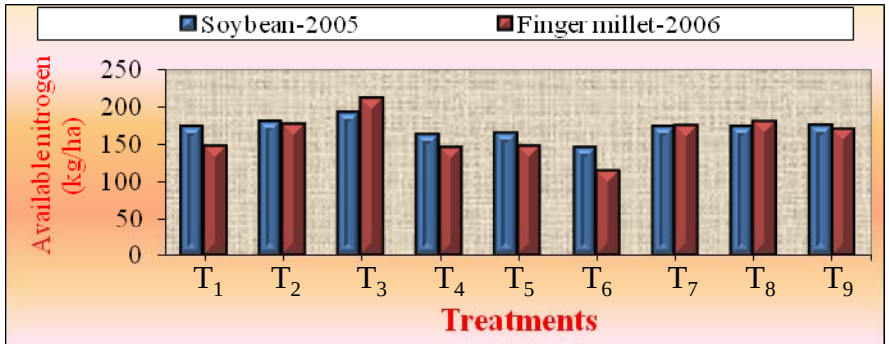
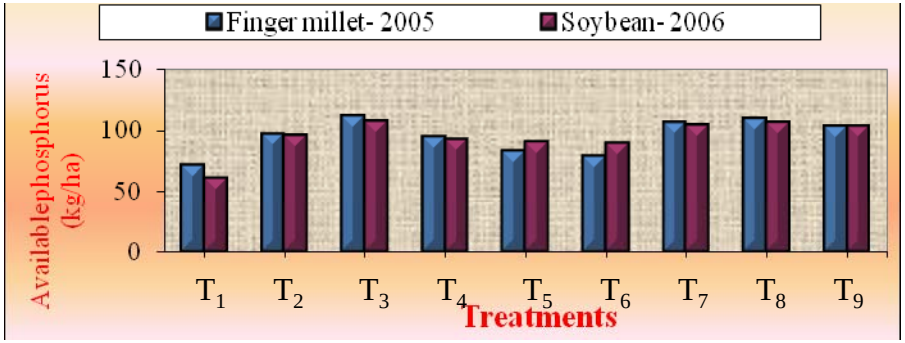


Fig. 30 : Available nitrogen status in soil after harvest of finger millet and soybean as influenced by zinc and boron application in finger millet –soybean and soybean –finger millet based cropping system



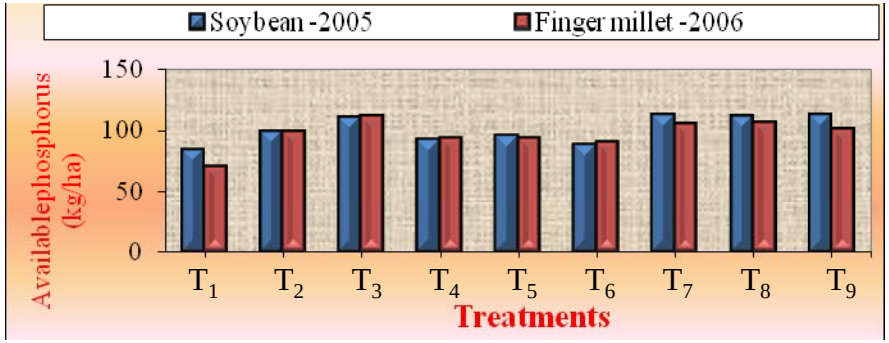
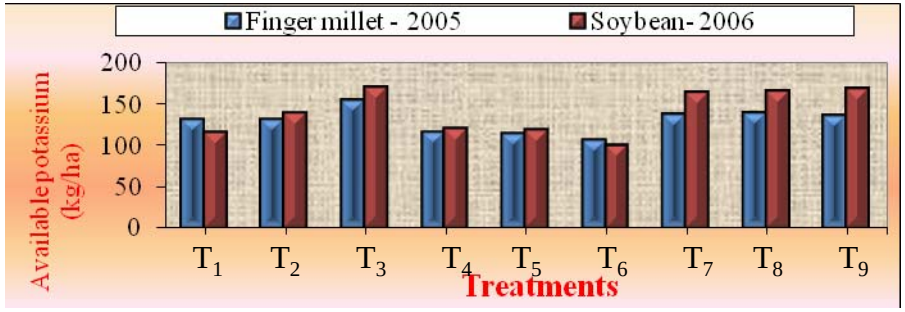


Fig. 31 : Available phosphorus status in soil after harvest of finger millet and soybean as influenced by zinc and boron application in finger millet –soybean and soybean –finger millet based cropping system



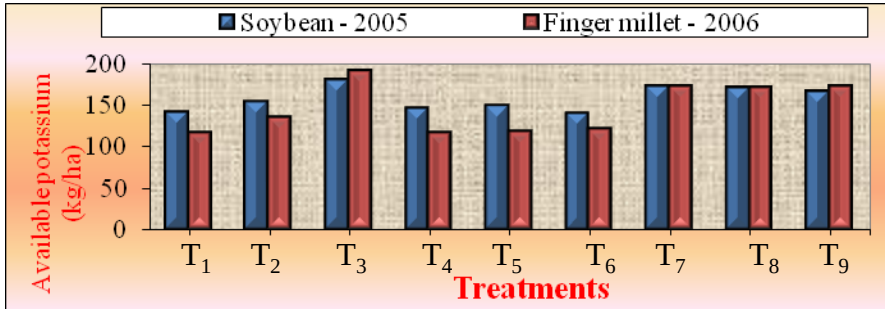


Fig. 32: Available potassium status in soil after harvest of finger millet and soybean as influenced by zinc and boron application in finger millet –soybean and soybean –finger millet based cropping system

and soybean (226.32 kg/ha) in finger millet-soybean rotation. Lower available nitrogen content in soil was recorded in control. Similar trend was noticed in soybean-finger millet rotation. The increase in available nitrogen content of soil in case of use of NPK along with FYM could be ascribed to the increased organic matter and total nitrogen content of soil. The increase in available nitrogen due to combined application of NPK and FYM might also be attributed to greater multiplication of soil microbes caused by the addition of organic materials for the conversion of organically bound nitrogen to inorganic form. Nitrogen in organic form is less prone to leaching and volatalization losses. The lower available nitrogen in NPK + FYM + $ZnSO_4$ + borax (T_9) treatment might be due to higher uptake of nitrogen as influenced by interactive behaviour of zinc and boron with organics which was ultimately reflected in the grain and straw yields. Similar results were also reported by Kavalappa (1989), Singh (1991), Gopalakrishnan and Palaniappan (1992), Gajanana *et al.* (2000) and Rajshree *et al.* (2005).

5.5.2 Available phosphorus in the soil

Application of NPK + FYM (T_3), NPK + FYM + $ZnSO_4$ + borax (T_9), NPK + FYM + $ZnSO_4$ (T_7) and NPK + FYM + borax (T_8) recorded significantly higher available phosphorus content as compared to control in soil in both the cropping systems (Table 4.4.1 and Fig. 31). Lower available phosphorus was recorded in control in both the cropping systems. The possible reason for this could be attributed to the dissolution of native phosphorus compounds by decomposition products of FYM. Besides FYM itself could contribute considerably to this available pool upon mineralization as it containing 0.23 per cent P_2O_5. These results are in conformity with the findings of Singh (1991), Gopalakrishnan and Palaniappan (1992) and Gajanana *et al.* (2000).

5.5.3 Available potassium in the soil

Significantly higher potassium content in soil was recorded with application of NPK + FYM (T_3) in both the cropping systems. However, it was found on par with the application of NPK + FYM + $ZnSO_4$ (T_7), NPK + FYM + borax (T_8) and NPK + FYM + $ZnSO_4$ + borax (T_9) in both the cropping systems (Table 4.4.1 and Fig. 32). This was obviously due to the direct effect of potassium fertilizers and the contribution for the available potassium pool from the FYM. FYM has been reported to be a direct and ready source of potassium and also helps in minimizing the leaching loss of potassium by retaining potassium ions on exchange sites of the decomposition products. Similar results were also reported by Kavalappa (1989), Singh (1991) and Dikshit and Khatik (2002).

5.5.4 Available zinc in soil

Available zinc content in soil after harvest of the crops differed significantly due to micronutrients application (Table 4.4.2 and Fig. 33). Application of NPK + FYM + $ZnSO_4$ + borax (T_9), NPK + FYM + $ZnSO_4$ (T_7), NPK + FYM + borax (T_8) and NPK + $ZnSO_4$ + borax (T_6) recorded significantly higher available zinc as compared to rest of the treatments in both cropping systems. This might be due to the role of FYM in balancing the crop use related zinc exhaustion. Evidences suggests that organic matter is the key factor in preserving zinc availability in soils. Its availability contributes zinc directly to meet crop needs and organic matter decomposition products interact with soil – zinc to augment its plant available forms (Katyal *et al.*, 1992). Nevertheless external application of $ZnSO_4$ also contributed to the available zinc pool. The present finding of considerable build up of zinc status following zinc application was also reported by Jha and Chandel (1987), Indulkar and Malewar (1994) and Barman *et al.* (1998).

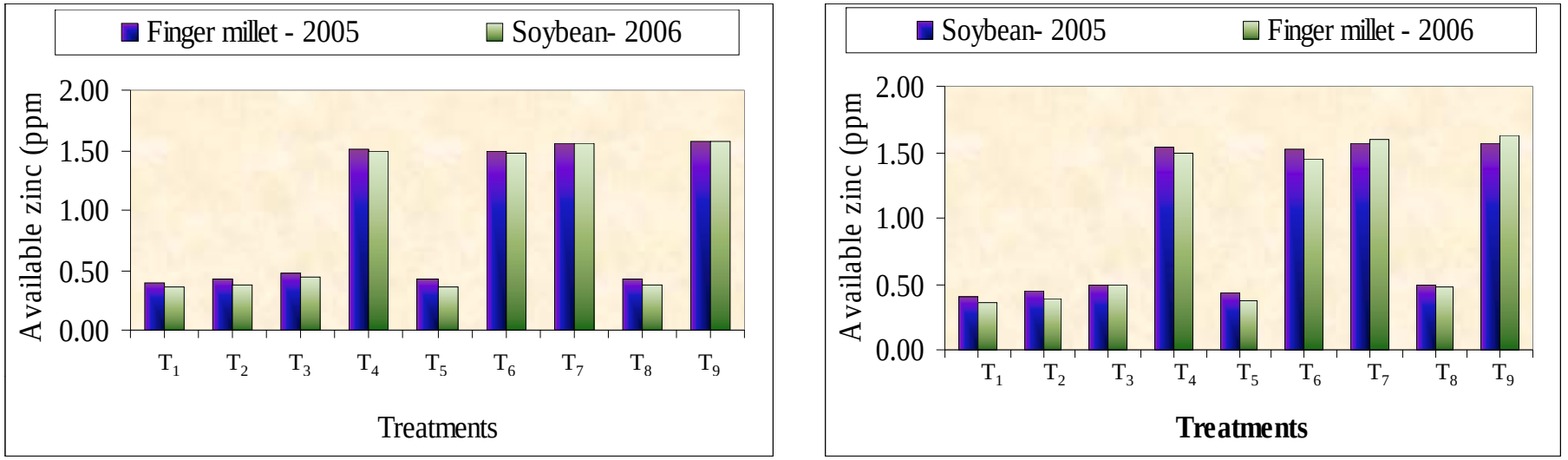


Fig. 33: Available zinc status in soil after harvest of finger millet and soybean as influenced by zinc and boron application in finger millet –soybean and soybean -finger millet based cropping system

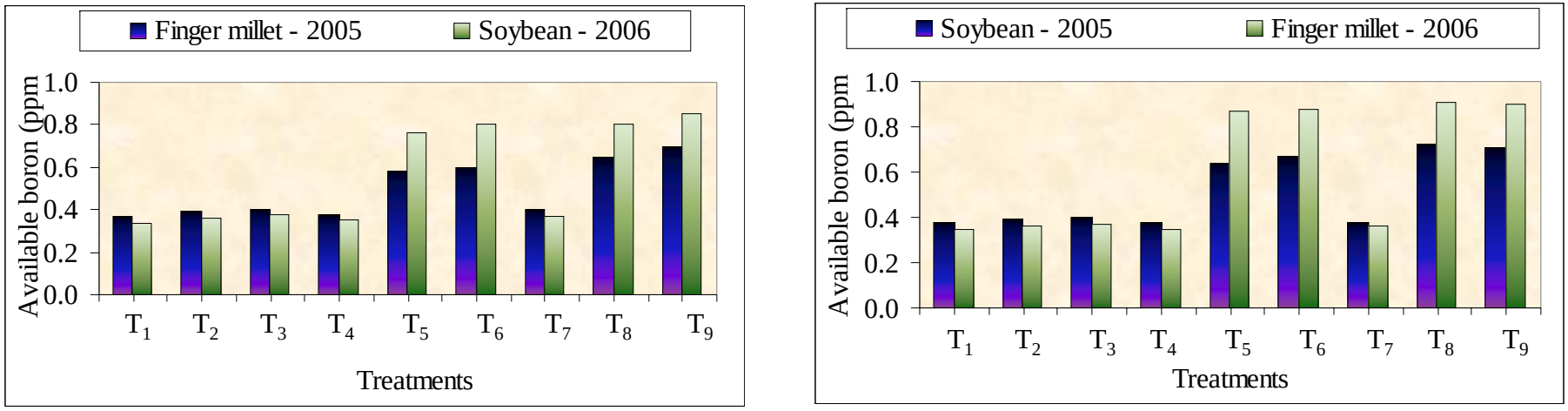


Fig.34: Available boron status in soil after harvest of finger millet and soybean as influenced by zinc and boron application in finger millet –soybean and soybean -finger millet based cropping system

5.5.5 Available boron in soil

Significant increase in available boron content in soil was observed due to application of borax along with zinc sulphate, recommended dose of NPK and FYM in both the cropping systems (Table 4.4.2 and Fig. 34). Build up of boron in soil might be due to direct effect of borax application and the contribution to the available boron pool from the FYM. Shinde and Kale (1985) also observed higher available boron content in plots where borax was applied to groundnut.

5.5.6 Micronutrient use efficiency (MUE)

Efficient nutrient management has emerged as one of the most important factors in sustaining the high production levels of intensive cropping system. In the present investigation, application of NPK + FYM + borax (T_8) recorded higher MUE in both the cropping systems. Application of NPK + FYM + $ZnSO_4$ (T_7) was next best treatment with regard to micronutrient use efficiency (Table 4.4.2). The MUE (Zn and B use efficiency) was superior in combined application of FYM and micronutrients as compared to inorganics alone. This might be due to the fact that organically complexed zinc and boron constituted the major fraction contributing to total zinc and boron uptake which inturn resulted in higher yield. The findings are pioneering in nature and as such not much of information is available in this direction. In order to corroborate in this direction and needs in depth studies in different agro eco systems to draw valid reasons.

5.6 NUTRIENT BALANCE IN FINGER MILLET-SOYBEAN AND SOYBEAN-FINGER MILLET BASED CROPPING SYSTEMS AS INFLUENCED BY ZINC AND BORON APPLICATION

5.6.1 Nitrogen balance

The nutrient balance is an important parameter in deciding the sustainability in soil fertility management. The data on nitrogen balance

in finger millet-soybean and soybean-finger millet based cropping systems are presented in Table 4.5.1 and 4.5.2. On perusal of data on nitrogen balance in finger millet-soybean based cropping system revealed that, there was a negative balance of nitrogen after harvest of finger millet while a positive balance observed after the harvest of soybean. The range of nitrogen loss was from 30.95 to 59.39 kg N per ha after harvest of finger millet whereas a net gain of nitrogen after harvest of soybean from 22.84 to 65.17 kg N per ha. This is because, the preceding crop before sowing of finger millet was finger millet. Evidences suggested that continuous practice of monoculture or cereal-cereal cropping might have created adverse effect on the productivity and soil health (Masood Ali *et al.*, 2002). The positive balance of nitrogen after soybean harvest might be due to legume effect as legumes are known to add significant amount of organic matter to soil through leaf drop and root biomass besides, symbiotically fixed nitrogen.

Further, a net gain (after harvest of soybean) and net loss (after harvest of finger millet) of nitrogen was observed in soybean-finger millet cropping system. But the net loss of nitrogen was less after the harvest of finger millet in soybean-finger millet cropping system. Since legumes are known to benefit the succeeding crops in the rotation (Masood Ali *et al.*, 2002). The results are in accordance with the studies of Ramesh and Sammi Reddy (2004) who have reported a positive balance of nitrogen in soil in soybean based cropping system especially with the application of recommended dose of nitrogen.

5.6.2 Phosphorus balance in soil

In general, there was a net negative balance observed in both the cropping systems (Table 4.5.3 to 4.5.4). which might be attributed to addition of more phosphorus into the soil as compared to crop uptake and all the added P_2O_5 might not been mineralized during the crop

growth period and some might have got fixed in the soil. The results of present study are in line with the findings of Thimma Reddy (1987) and Desiti Duryodhana (2002) in finger millet.

5.6.3 Potassium balance in soil

On perusal of the data it indicates that there was net loss of potassium observed after harvest of finger millet in finger millet-soybean cropping system (Table 4.5.5 to 4.5.6), since the preceding crop was finger millet. Exhaustion of potassium by these crops was more which resulted in a net negative balance of K_2O in the soil. There was a net gain of potassium observed after harvest of soybean in both the cropping systems. Contrary to earlier net loss of K_2O after harvest of finger millet, there was a positive balance of K_2O observed in soybean-finger millet cropping system. The difference in actual and expected balance varied from treatment to treatment due to differences in yield levels and K_2O uptake by the respective crops. The positive balance after harvest of soybean crop might be due to addition of K_2O in excess of uptake of crops. The positive balance of K_2O after harvest of finger millet in soybean-finger millet cropping system might be ascribed as fixed potassium might have been made available by soybean in the sequence and enriched the soil. Similar improvement in K status was observed under groundnut-sorghum sequence (Pawar and Jadhav, 1995).

5.6.4 Zinc balance in soil

There was a negative balance in zinc was noticed in finger millet-soybean (0.02 to 0.30 ppm) and soybean-finger millet (0.02 to 1.18 ppm) cropping systems (Table 4.5.7 to 4.5.8). The negative zinc balance was obviously due to the fact that crops in the system exercise differentiality in terms of exhaustion and utilization of soil and fertilizer zinc. The loss of zinc was more, when it was applied through $ZnSO_4$, otherwise loss was less since utilization of fertilizer zinc by the crops seldom exceeds 2 per

cent (Deb *et al.*, 1986), most of the added zinc remains unutilized in the soil and thus has potential of meeting external zinc requirements of the crops grown in succession (Rajkumar Rattan *et al.*, 1997).

5.6.5 Boron balance in soil

There was net loss of boron noticed in both the cropping systems (Table 4.5.9 and 4.5.10). Nevertheless, the net loss was more in the treatments when boron was added externally through borax. This might be due to less utilization of boron by the crops. As such not much information is available to confirm the present findings, hence, it needs further research.

5.7 ECONOMICS OF FINGER MILLET-SOYBEAN AND SOYBEAN-FINGER MILLET BASED CROPPING SYSTEM AS INFLUENCED BY ZINC AND BORON APPLICATION

The economic returns determine the profitability of a system. The farmers adopt only such practices that are more profitable. The price of inputs and farm produce change from time to time and place to place. Thus profitable nutrient management in crop production also varies accordingly.

Assessment of treatments in terms of economic traits in finger millet-soybean based cropping system revealed that maximum net returns was noticed due to application of NPK + FYM + $ZnSO_4$ (T_7 : Rs. 44,138/ha) followed by NPK + FYM + $ZnSO_4$ + borax (T_9 : Rs. 44,122/ha) owing to higher economic yields obtained in these treatments, whereas, lower net returns was recorded in control (T_1 : Rs. 8299/ha) due to lower yields (Table 4.6.1 and Fig. 35). The B: C ratio was found to be higher with application of NPK + $ZnSO_4$ + borax (Rs. 2.14) followed by NPK + FYM + borax (1.90), but application of FYM decreased the B : C ratio

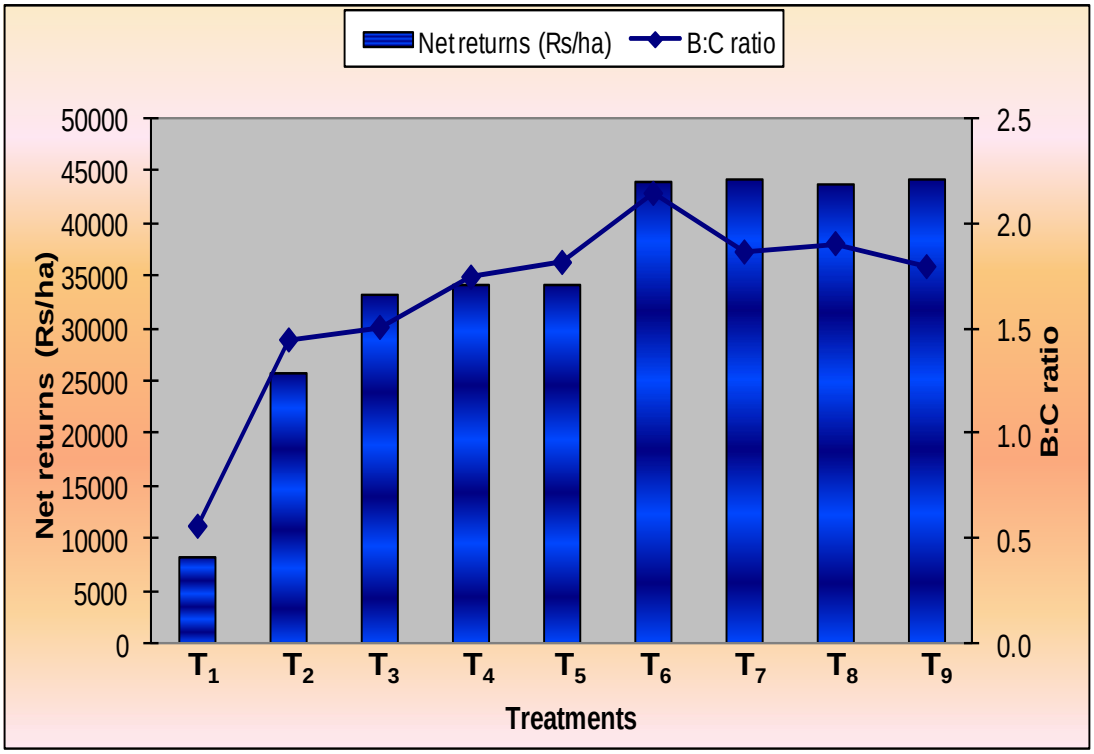


Fig.35 :Net returns and B:C ratio of finger millet –soybean based cropping system as influenced by zinc and boron nutrition

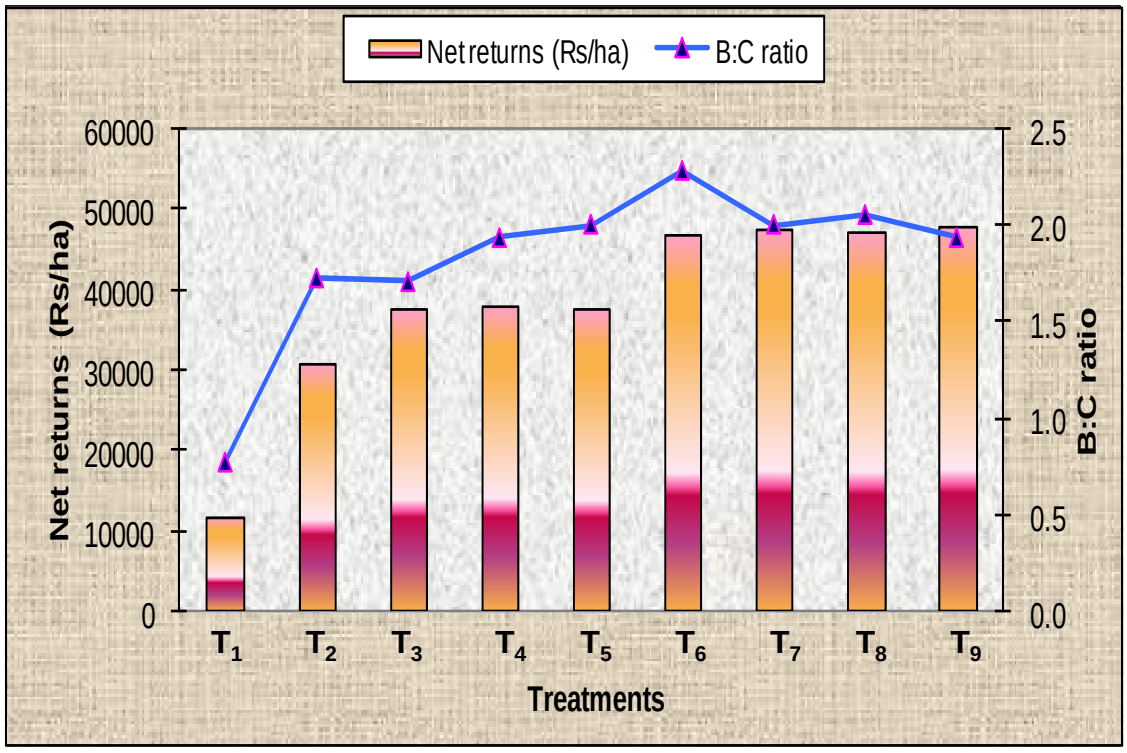


Fig.36: Net returns and B:C ratio of soybean – finger millet based cropping system as influenced by zinc and boron nutrition

mainly due to higher cost of FYM used in this experiment. The control treatment recorded lower B : C ratio (Rs. 0.55).

In soybean-finger millet cropping system, application of NPK + FYM + $ZnSO_4$ + borax (T_9) recorded higher net returns (Rs.47,825/ha) followed by NPK + FYM + $ZnSO_4$ (Rs.47,705/ha)(Table 4.6.2 and Fig. 36). This may be attributed to higher yields of the crops. The benefit : cost ratio was found to be higher with the application of NPK + $ZnSO_4$ + borax (T_6 :Rs. 2.29) followed by NPK + FYM + borax (T_8 : Rs. 2.06). Owing to higher cost of FYM, B: C ratio was intermediate in NPK + FYM + $ZnSO_4$ + borax (T_9) treatment. The results are in line with the findings of Keshwa and Jat (1991), Rajput *et al.* (1995) and Anon. (2007).

5.8 Experiment-II (a): RESPONSE OF FINGER MILLET-SOYBEAN ROTATION TO CONJUNCTIVE USE OF ZINC, BORON AND MICROBIAL INOCULANTS

Crop: Finger millet

5.8.1 Effect of zinc, boron and microbial inoculants application on growth and growth parameters of finger millet

Crop growth is manifested through certain parameters such as plant height, number of tillers per hill, leaf area and dry matter accumulation which have a direct influence on crop yield. Among several factors responsible for increase in finger millet production, plant nutrition is one of the major factors besides, micronutrients application and microbial inoculation.

The results of the present investigation revealed that application of NPK + FYM + $ZnSO_4$ + borax + *A.brasilense* + VAM (T_{10}) recorded higher plant height (10.01, 42.57, 95.59 and 97.08 cm at 30, 60, 90 DAT and at harvest, respectively) as compared to control (Table 4.7.1 and Fig.37). This might be due to the fact that *Azospirillum* is known to produce plant

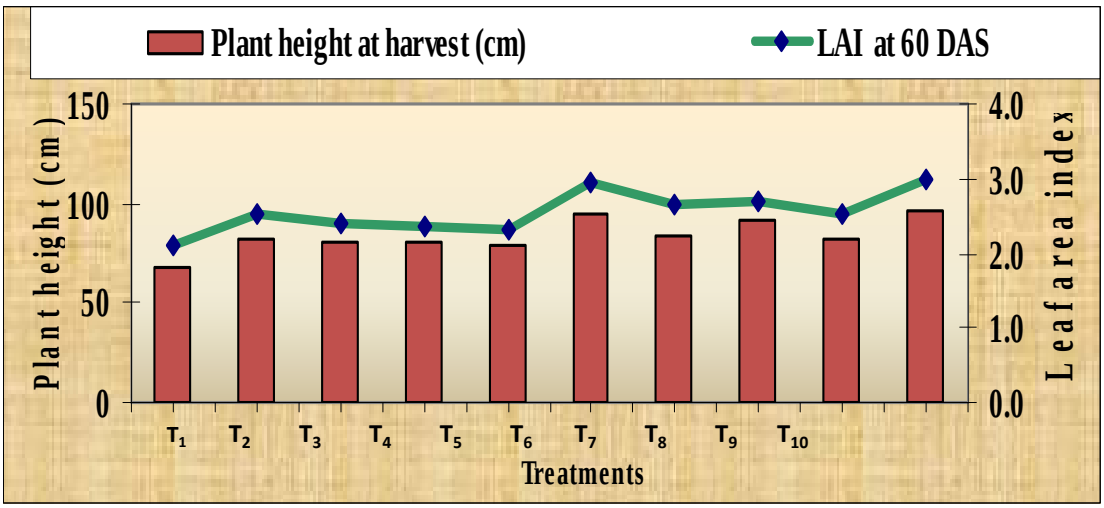


Fig.37: Plant height and leaf area index of finger millet as influenced by application of zinc, boron and microbial inoculants

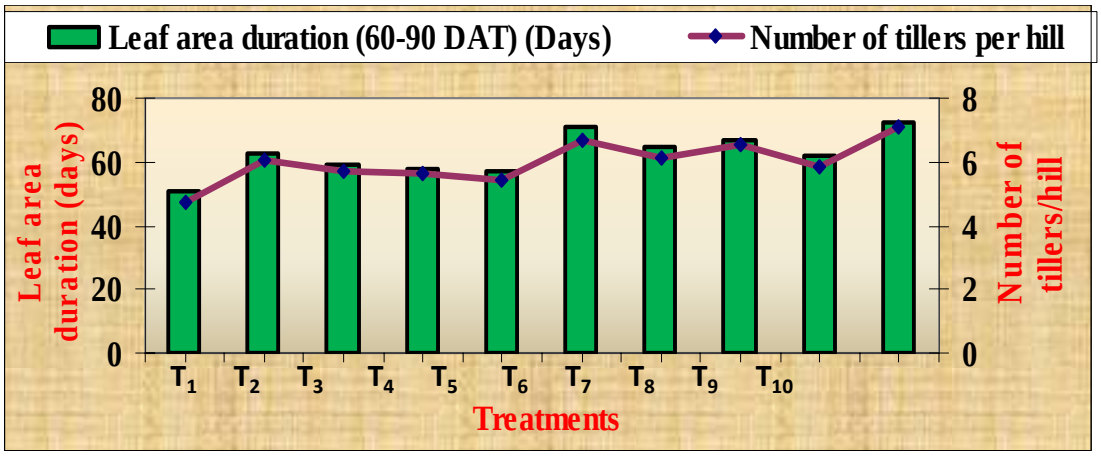


Fig.38 : Leaf area duration and number of tillers per plant of finger millet as influenced by application of zinc, boron and microbial inoculants

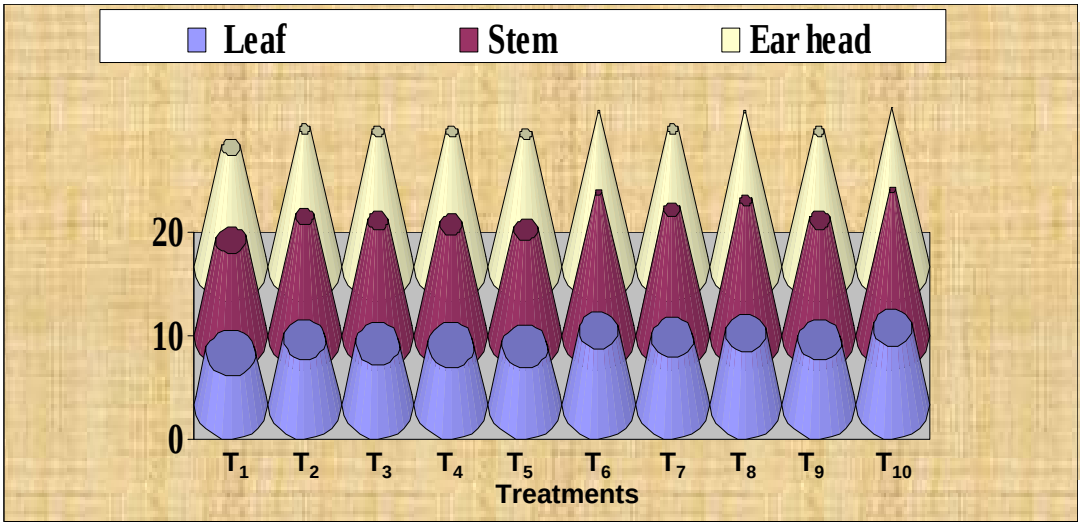


Fig.39 : Dry matter accumulation among plant parts of finger millet at harvest as influenced by application of zinc, boron and microbial inoculants

growth promoting substances such as auxins, gibberellins and cytokinins besides N_2 fixation. These plant growth promoting substances viz., IAA and GA play an important role in root elongation and shoot growth (Tien *et al.*, 1979). Similarly, zinc plays an important role in IAA production which inturn enabled the plants to grow better (Pathak *et al.*, 1975; Wang *et al.*, 1995). The increased plant height owing to the reason that zinc takes part in the metabolism of plant in activating several enzymes which inturn directly or indirectly affect the synthesis of carbohydrates and protein (Narwal *et al.*, 1993). Black (1968) reported that due to enhanced nutrient uptake there will be increased cell elongation and multiplication. The results of present investigation are in agreement with the findings of Sahab Singh *et al.* (1980), Gautam *et al.* (1985), Alwar Arunachalam *et al.* (1995) and Mishra and Patjoshi (1996) who have also reported significantly higher plant height due to inoculation of *A.brasilense* in sorghum, pearlmillet, finger millet and maize respectively.

The rate of production and number of tillers in crops like finger millet are dependent upon nutrient supply. Application of NPK + FYM + $ZnSO_4$ + borax + *A.brasilense* + VAM (T_{10}) recorded significantly higher number of tillers per hill at 30 (1.78), 60 (5.21), 90 DAT (6.93) and at harvest (7.09) which was found to be at par with application of NPK + FYM + *A.brasilense* (T_6), NPK + FYM + $ZnSO_4$ + VAM (T_8) at all the growth stages (Table 4.7.2 and Fig.38). This might be due to the fact the application of zinc to soil increased its availability to crop which inturn resulted in increased number of tillers. Further, dual inoculations of A.brasilense and VAM have cumulative effect on N_2 fixation and mobilization of micronutrients like Zn, Mn, Fe and Cu from the soil. The stimulating effect of these nutrients on various physiological process of plant resulted in increased number of tillers per hill. The results of the present investigation are in agreement with the findings of Gautam *et al.*

(1985) and Joshi and Rao (1989) who have also reported higher number of tillers per plant due to inoculation of *A.brasilense* in pearlmillet while, Dadhich and Gupta (2005) reported increase in number of tillers due to Zn application in pearlmillet.From scanning of literature, it is evident that, there is no much information available in this direction and perhaps the present study is pioneering one and needs further research in this direction.

The synthesis and accumulation of photosynthates mainly depends on the number of leaves and their area, while prolonged photosynthetic activity depends on LAD. Aftab Hussain *et al.* (1988) reported that elongation and expansion of leaves require optimum zinc level. In the present investigation, significantly higher number of green leaves, leaf area, leaf area index and leaf area duration was recorded with the application of NPK + FYM + $ZnSO_4$ + borax + *A.brasilense* + VAM (T_{10}) followed by NPK + FYM + $ZnSO_4$ + *A.brasielsne* (T_6) and NPK + FYM + $ZnSO_4$ + VAM (T_8)(Table 4.7.3 to 4.7.6; Fig.37 and 38). This might be due to the involvement of zinc in biosynthesis of plant hormones by activating tryptophan, which is a precursor of IAA (auxin), which inturn promotes the vertical growth. The IAA is a component of various enzymes, such as carbonic anhydrase and alcoholic dehydrogenase, which have suggestive role in chlorophyll formation, photosynthesis and metabolic reactions in plants leading to higher number of leaves, LA, LAI and LAD. These results are in agreement with the findings of Keshwa and Jat (1991). Chakraborty *et al.* (2002) observed higher LAI and LAD of finger millet due to seed inoculation of *A.brasilense* which produce an additive effect on different growth characters better than sole application of nitrogen.

The seed yield is an end product, which obviously depends upon the dry matter production and its distribution into reproductive parts at

later stages of crop growth. In the present study, total dry matter accumulation and DMA in leaf, stem and earhead varied significantly due to micronutrients and microbial inoculants application. The data on pooled analysis over two years indicated that, application of NPK + FYM + $ZnSO_4$ + borax + *A.brasilense* + VAM (T_{10}) recorded significantly higher total dry matter per plant at 30, 60, 90 DAT and at harvest(2.98,12.27,36.10 and 37.29 g/plant, respectively) (Table 4.3.7 to 4.3.10; Fig.39). The increased total dry matter production per plant is reflected by increased stem and leaf dry weight per plant throughout the growing period. This might be due to the additive effect of the two micronutrients. Zinc is a metallic component of one or more enzymes which are involved in various physiological functions, growth, development and productivity of the plant. There was better uptake of nitrogen by finger millet due to *Azospirillum* inoculation. Inoculation in combination with micronutrients ultimately led to better growth and dry matter production. Similar increase in dry matter yield of cereal crops at different stages due to inoculation of *A.brasilense* have been reported by Yorum Kapulnik *et al.* (1981), Patil *et al.* (1992) and Chakraborty *et al.* (2002). The increase in dry weight are presumed to be hormone mediated.

Tarafdar (1995) noticed higher cytokinin activity in the shoot of VA mycorrhizal plants. As cytokinins promote leaf growth and cell expansion, it is possible that cytokinins may play a role in alterations of shoot morphology in mycorrhizal plants. Similar increase in dry matter production of shoot, root dry weight and total biomass due to inoculation of VAM have been reported by Bagyaraj and Manjunath (1980), Tewari *et al.* (1993), Rathore and Singh (1995) and Majjigudda and Sreenivasan (1997) in different cereal crops.

5.8.2 Effect of zinc, boron and microbial inoculants application on yield and yield attributes of finger millet

Grain yield being a complex character, is the sum of many morphological and biochemical events which occur during the crop growth and development. The yield per unit land area depends on the total bio-productivity and its partitioning into the economically important parts. In the present investigation, application of NPK + FYM + $ZnSO_4$ + borax + *A.brasilense* + VAM (T_{10}) recorded significantly higher grain yield (4143 kg/ha) over rest of the treatments (Table 4.7.13; Fig. 43 and Plate 4). However, it was found to be at par with the application of NPK + FYM + $ZnSO_4$ + *A.brasilense* (T_6: 4043 kg/ha) and NPK + FYM + $ZnSO_4$ + VAM (T_8: 4018 kg/ha). The increase in yield may be ascribed to increased growth attributes, leaf expansion and DMA besides, combined application of zinc and boron at optimum level. It is well known fact that, application of zinc helps in fixation of atmospheric nitrogen and increases the nitrogenase activity. In addition, the conjunctive use of boron along with zinc helps in retention of flower drop and improvement in grain settings (Dilipkumar Das, 2000). In general the higher economic yield under NPK + FYM + $ZnSO_4$ + borax + *A.brasilense* + VAM (T_{10}) was mainly as a result of higher nutrient supply, which helped the crop to receive optimum level of nutrients besides additional N_2 fixed by *Azosopirillum* and mobilization of P, Zn, Mn, Fe and Cu by VAM near the rhizosphere of inoculated plants. The increased availability of zinc to plants might have stimulated metabolic and enzymic activities which resulted in improved growth and more crop yield. The results corroborates the findings of Srinivasan (1992), Indulkar and Malewar (1994) due to Zn application. In addition boron helps in translocation of photosynthates to sink. The present findings are in line with the findings of Rajput (1999) who observed higher grain yield of pearlmillet due to

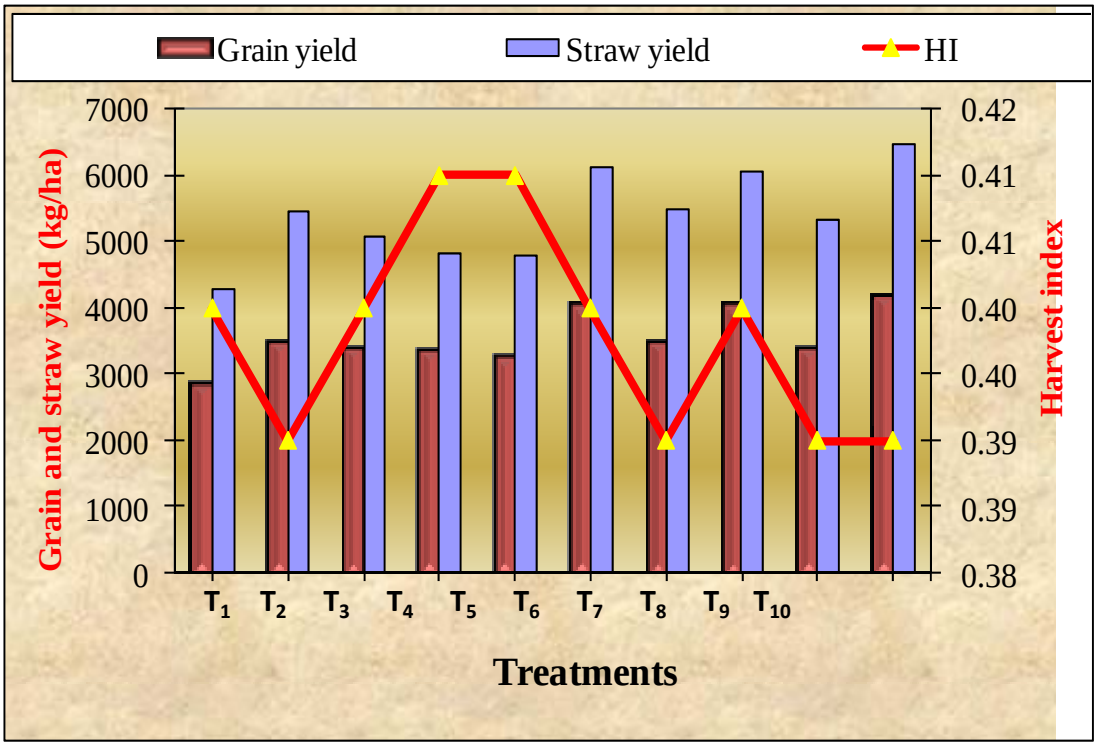


Fig.43 : Grain yield, straw yield and harvest index of finger millet as influenced by application of zinc, boron and microbial inoculants

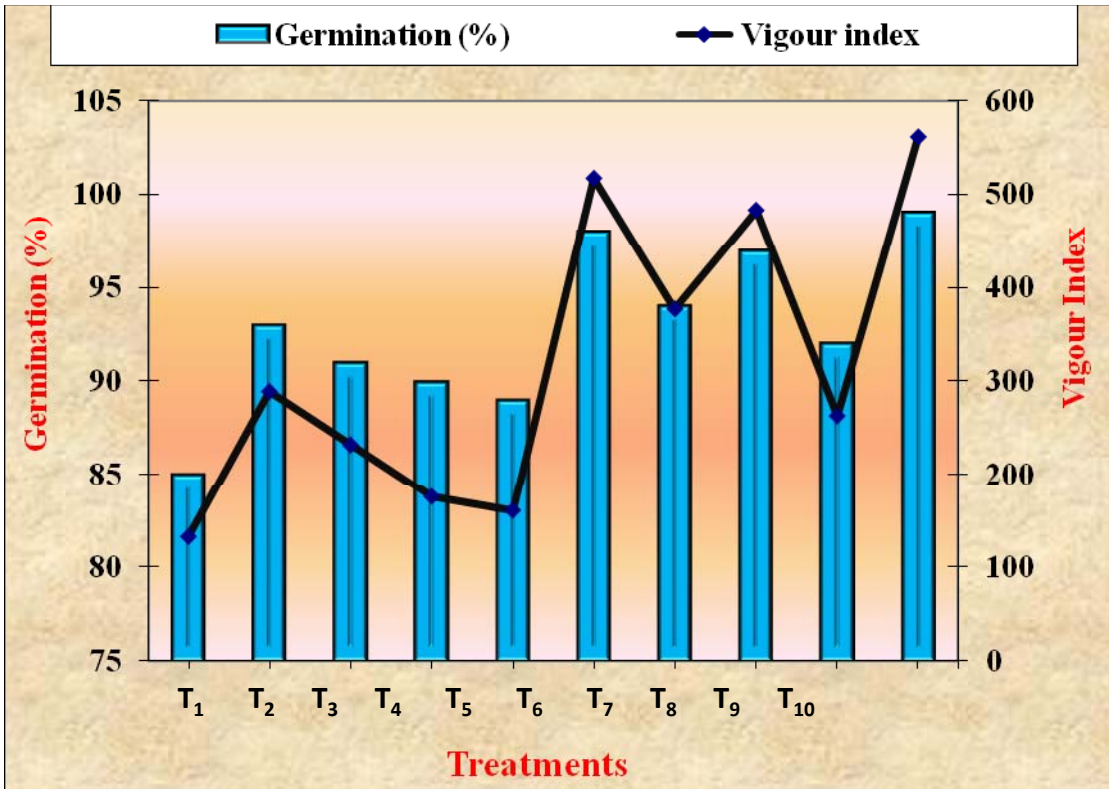
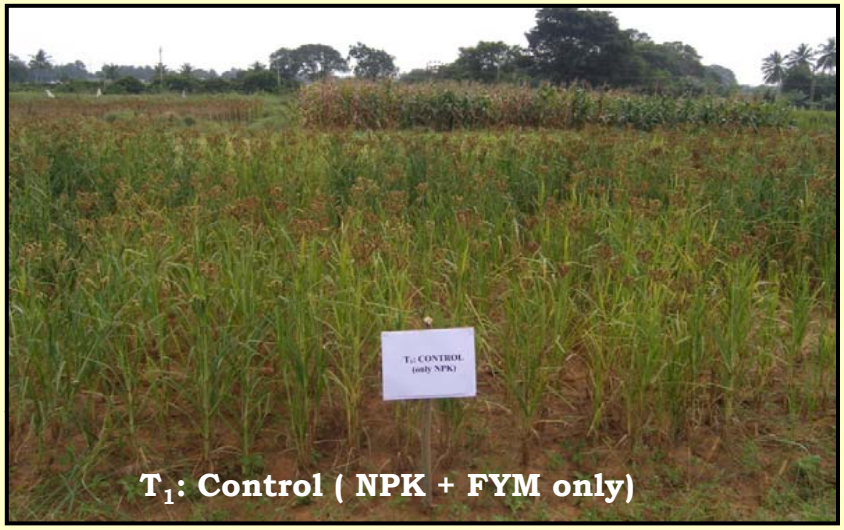
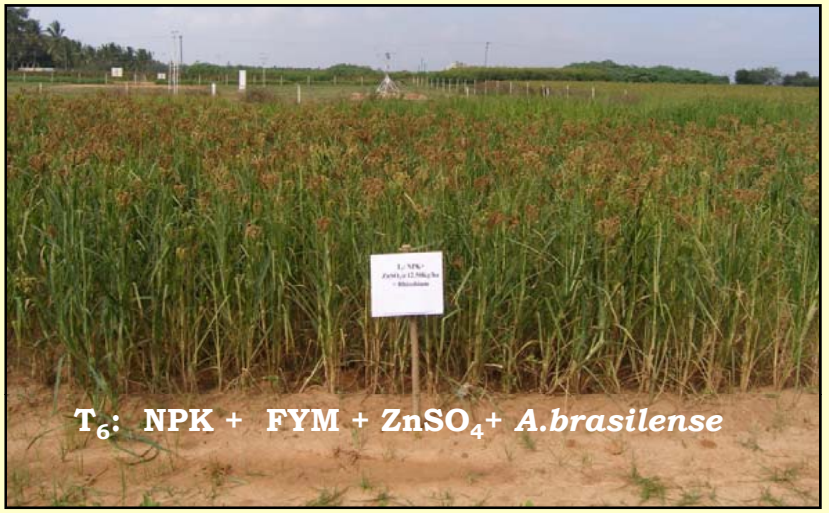


Fig. 44 : Germination per cent and vigour index of finger millet as influenced by application of zinc, boron and microbial inoculants nutrition





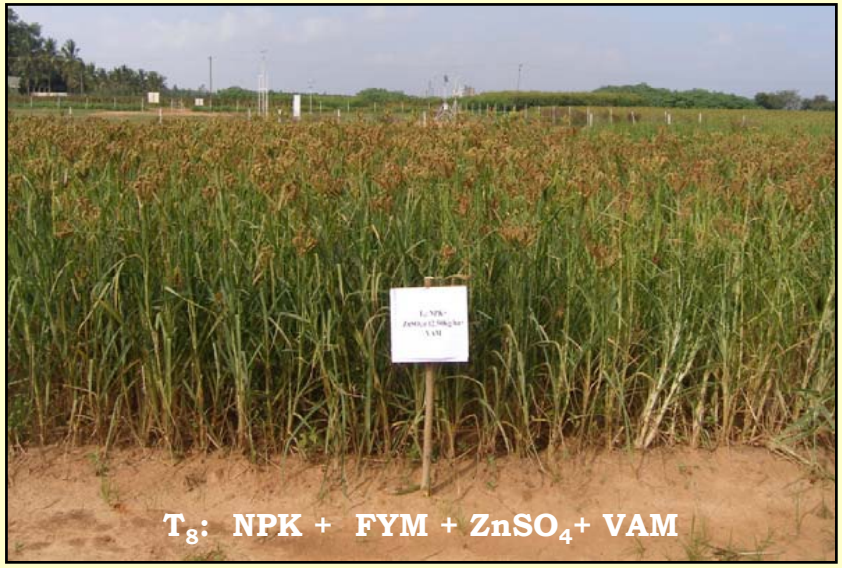


Plate 4: Response of finger millet to conjunctive use of zinc, boron and microbial inoculants (Expt. IIa)

dual inoculation of *A.brasilense* and VAM. The results are in conformity with those of Sakal *et al.* (1999) in maize due to boron application.

As reported by Assumus *et al.* (1995), the increase in yield due to inoculation of *A.brasilense* have been attributed to mechanisms such as nitrogen fixation, phytohormone production and nitrate reduction by *Azospirillum*. Indeed, plant growth promoting effects of *Azospirillum* are mainly derived from morphological and physiological changes of the inoculated plant roots and enhancement of water and mineral uptake. Purushothaman and Oblisami (1985), Gautam and Kaushik (1988), Anon. (1989b), Shankaralingappa (1993), Chakraborty *et al.* (2002) and Ramamoorthy and Christopher Lourduraj (2002) have also reported increase in grain yield due to inoculation of *Azospirillum brasilense*, while Majjigudda and Sreenivasan (1997) and Duraisamy and Mani (2000) have reported higher seed yield due to inoculation of VAM in wheat and finger millet crops, respectively.

The data on straw yield of finger millet also differed significantly due to micronutrients and microbial inoculants application. Significantly higher straw yield was registered with the application of NPK + FYM + $ZnSO_4$ + borax + *A.brasilense* + VAM (T_{10} : 6467 kg/ha) as compared to other treatments (Table 4.7.13 and Fig.43). The increase in straw yield may be due to increase in vegetative growth as evidenced from higher plant height, dry matter production and its accumulation in different plant parts like leaves, stem and increased number of tillers (Table 4.7.1 to 4.7.8). The higher straw yield under these treatments was mainly as a result of higher nutrient supply, which helped the crop to receive optimum level of nutrients besides fixation of nitrogen with application of *Azospirillum*. Similar increase in straw yield due to inoculation of *Azospirillum* was reported by Gautam *et al.* (1985), Venkateshwarlu (1985) and Sardar Singh and Brahm Singh (1987) in pearlmillet and

Purushothaman and Oblisami (1985), Anon. (1989b), Shankaralingappa (1993) and Chakraborty *et al.* (2002) in finger millet. Duraisamy and Mani (2000) reported increase in straw yield due to VAM inoculation and Devarajan *et al.* (1980) observed higher straw yield of finger millet due to zinc application. Harvest index did not differ significantly due to micronutrients and microbial inoculants application (Table 4.7.13 and Fig.43). It may be due to proportionate production of grain and straw in finger millet by different nutrient treatments, which kept harvest index almost static. Similar result was also observed by Ananda (2004) in wheat due to application of NPK + FYM + $ZnSO_4$.

The increase in yield with various treatments was closely associated with the difference in yield parameters. In the present investigation, application of NPK + FYM + $ZnSO_4$ + borax + *A.brasilense* + VAM (T_{10}) recorded significantly higher number of productive tillers per hill (5.84), number of fingers per earhead (7.76), earhead length (9.57 cm), finger length (7.45 cm), grain yield per plant (12.43 g/plant), 1000-grain weight (3.80 g) and threshing percentage (81.19 %) as compared to control (Table 4.7.11 to 4.7.12; Fig. 40,41 and 42). This might be due to the fact that the crop has not experienced nutrient stress at any growth stage. The superior performance of dual inoculation of *Azospirillum* and VAM might be due to better establishment of plant. Dual inoculation increased the nitrogen uptake and mobilization of native and applied zinc and phosphorus which resulted in higher growth parameters such as plant height, leaf area and DMA. Higher production of photosynthates due to sufficient assimilatory area of vigorous plants would have synthesized the carbohydrates and translocated to the reproductive parts such as developing ears which resulted in better filling and more grain weight leading to increased yield components. The results are in agreement with the earlier findings of Yorum Kapulnik *et al.* (1981) in foxtail millet, Gautam *et al.* (1985), Joshi and Rao (1989) in pearlmillet,

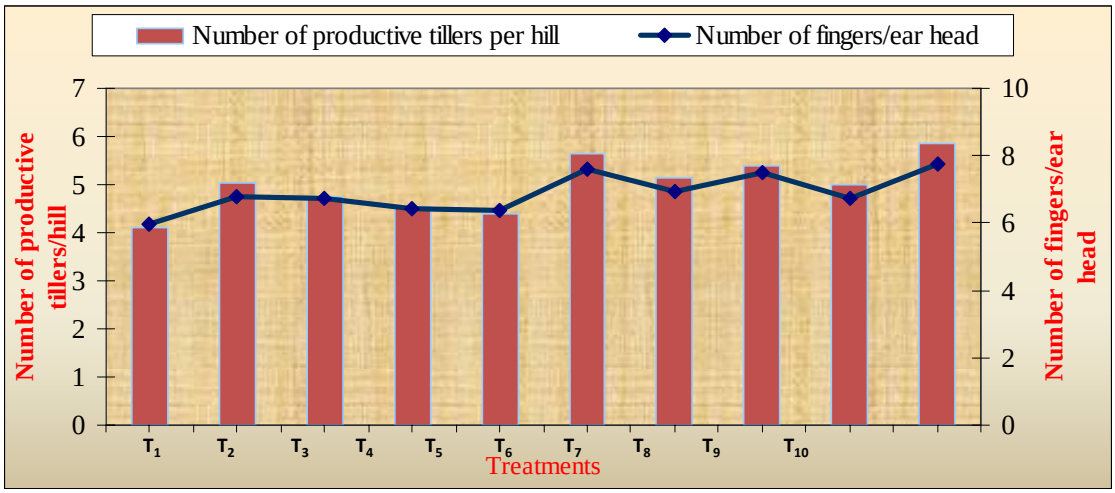


Fig. 40: Number of productive tillers per hill and number of fingers per ear head as influenced by application zinc, boron and microbial inoculants

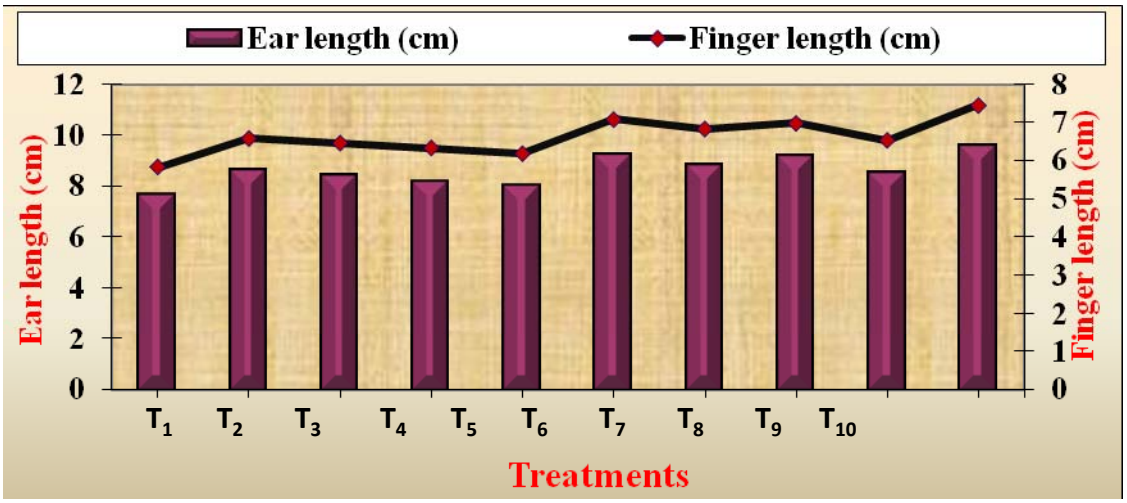


Fig. 41: Ear head length and finger length of finger millet as influenced by application of zinc, boron and microbial inoculants

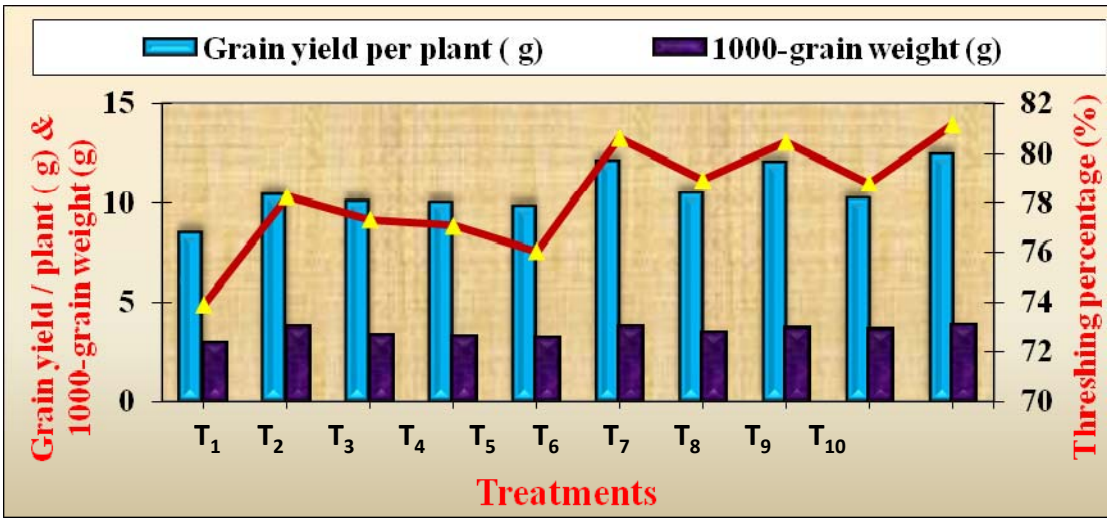


Fig.42: Grain yield,1000-grain weight and threshing per cent of finger millet as influenced by application of zinc, boron and microbial inoculants

Anon. (1989a), Shankaralingappa (1993), Alwar Arunachalam *et al.* (1995), Chakraborty *et al.* (2002) and Ramamoorthy and Christopher Lourduraj (2002) in finger millet.

Furthermore, the increased availability of zinc to plants might have, stimulated metabolic and enzymatic activities which resulted in higher yield parameters. The differences in grain yield per plant could be due to differences in number of fingers per ear and their length. The increased length of fingers due to micronutrients application might have acted as a higher sink for development of more grains leading to higher grain yield (Table 4.7.11 and Fig.41). The results of the present investigation are in agreement with the findings of Maliwal *et al.* (1985) and Reddi Ramu and Reddy (2007) in respect of higher grain yield and 1000-grain weight in pearl millet and maize, respectively due to zinc application. While, Pratima Sinha and Chatterjee (1994) in respect of 1000-grain weight due to boron application in pearlmillet. Mandal (1994) also reported increase in grains per spike due to boron application in wheat.

Number of productive tillers per hill at harvest were significantly higher with the application of NPK + FYM + $ZnSO_4$ + borax + *A.brasilense* + VAM (T_{10}) as compared to control (NPK + FYM)(Table 4.7.11 and Fig.40). This could be attributed to the adequate supply of nutrients by the conjunctive use of recommended dose of NPK, FYM, micronutrients (Zn and B) and dual inoculation with *Azospirillum* and VAM. High intake and recovery of nutrients from the applied nutrients, which resulted in higher tillering ability of the crop plants. Similar increase in productive tillers per plant was also reported by Anon. (1989b), Alwar Arunachalam *et al.* (1995) and Ramamoorthy and Christopher Lourduraj (2002) in finger millet due to inoculation of *Azospirillum* and Maliwal *et al.* (1985) due to Zn application in pearlmillet.

These results were further supported by significant and positive correlation between grain yield of finger millet with growth parameters like TDM at harvest (r=0.705),leaf area at harvest(r=0.707),number of tillers at harvest(r=0.674) and yield parameters like number of productive tillers at harvest (r = 0.749), number of fingers per ear head (r = 0.692), ear head length (r = 0.741), finger length (r = 0.697), grain yield per plant (r = 0.623) and 1000-grain weight (r = 0.581)(Table 4.7.20).These results are in agreement with the earlier findings of Ananda (2004) in wheat and Rangamannar and Rao (1982) in finger millet who have reported a positive correlation between grain yield with growth and yield parameters.

Similarly, regression analysis also indicated that 73 per cent of finger millet grain yield was influenced by growth and yield parameters, as shown by the inter-relationship of source and sink in the plant with better uptake of nutrients by the conjunctive use of organics along with NPK, Zn, B and microbial inoculants.Perhaps this the first report in this direction.

5.8.3 Seed quality parameters of finger millet as influenced by zinc, boron and microbial inoculants application

Role of seed as the top most input in improving the crop yields and it does not need any emphasis. The effect of soil health on the seed quality is camouflaged due to large gap in supply and demand. It is predictable that, the land degradation due to continued cropping without replenishing the resource base affects the yields with time. However, due recognition is not given on its effect on quality of the produce including seed. The vigour tests are commonly evaluated according to their ability to predict some aspects of potential seed performance particularly seedling growth rate, seedling emergence in field, plant uniformity, crop yield and storability. In this context, seed vigour tests have been

conducted to know the effect of zinc, boron and microbial inoculants nutrition. In the present investigation, application of NPK + FYM + $ZnSO_4$ + borax + *A.brasilense* + VAM (T_{10}) registered significantly higher germination per cent (99) (Table 4.7.4 and Fig. 44). The ability of *Azospirillum* to synthesize and secrete growth promoting substances and such as auxins, gibberllins and cytokinens (Chunchun kumar *et al.*, 1998) may be responsible for beneficial effect of this organism on the seed stocks which resulted in higher germination of seeds.

Further, significantly higher dry weight of root and shoot (5.70 mg) and seed vigour index (561)were recorded with the application of NPK + FYM + $ZnSO_4$ + borax + *A.brasilense* + VAM (T_{10}) as compared to control (Plate 5). The higher vigour index may be due to better source sink relation and the availability of balanced nutrients to crop (Table 4.7.15 to 4.7.19). The increase in seed quality traits may also be ascribed to better seed size besides, zinc might have helped in synthesis of carbohydrates and protein in plants, resulting in increased TSS and reducing sugars. Further, the increase in the formation of root hairs and lateral roots in the seedling due to inoculation of *Azospirillum* was reported by Venkateswarlu and Rao (1984) in pearlmillet while Champawat and Pathak (1993) have reported increase in shoot and root dry weight of pearlmillet due to VAM inoculation.

The role of boron in the fertilization and flowering processes is highly appreciable as it resulted finally in getting higher yield and/or quality of the seeds and fruits. Without sufficient boron in the environment of the pollen tube prior to flowering, the pollen will not extend and grow from the pollen grain down through the style to enable fertilization with the ovule to take place. This partial or complete failure of fertilization leads to the characteristic fruit/seed drop, deformed fruit and partially filled seed heads responsible for large scale losses

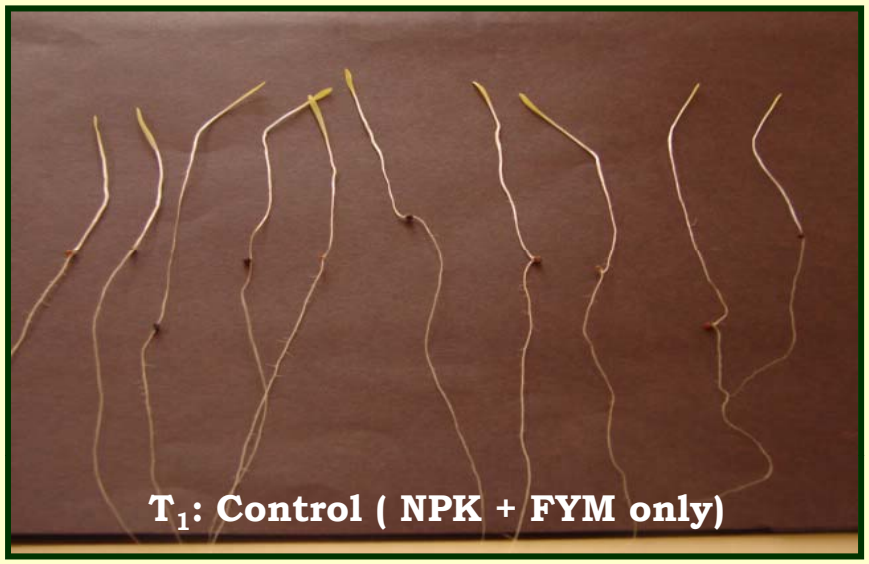


Plate 5: Seed vigour of finger millet as influenced by zinc, boron and microbial inoculants

(Shrotriya and Martin Phillips, 2002). The micronutrient enriched seed maintained better vigour even after one year of storage at room temperature (Atwal *et al.*, 1998). Similar increase in germination, dry weight of root and shoot and vigour index was also reported by Shankar *et al.* (2005) in finger millet due to zinc and boron application. In the present investigation also higher germination and vigour index of finger millet was observed due to boron application (Table 4.7.14). These findings are of pioneering in nature. There is a need for exploiting and exploring the potential of micronutrients in enhancing the productivity of food grains and a research step is right in this direction.

5.8.4 EFFECT OF ZINC, BORON AND MICROBIAL INOCULANTS APPLICATION ON NUTRIENTS UPTAKE BY FINGER MILLET

5.8.4.1 Effect of zinc, boron and microbial inoculants application on nitrogen uptake

The growth and yield of crop plants are determined by the presence of sufficient quantities of nutrients for plant uptake (Babannavar, 1990).

Nitrogen is known to increase the root growth and proliferation, thereby creating more absorptive area for uptake of other essential nutrients. In the present investigation, application of NPK + FYM + $ZnSO_4$ + borax + *A.brasilense* + VAM (T_{10}) recorded significantly higher nitrogen uptake by finger millet grain (60.11 kg/ha), straw (50.48 kg/ha) and total nitrogen uptake (110.59 kg/ha) as compared to control (Table 4.7.15 and Fig.45). This may be attributed to the additional N_2 fixed by *Azospirillum* near the rhizosphere of the inoculated plants. Plant growth promoting effects of *Azospirillum* are mainly derived from morphological and physiological changes of the inoculated plant roots which resulted in enhanced uptake of water and mineral uptake (Follik *et al.*, 1994). The present findings are in line with the results of Venkateswarlu and Rao (1984), Jha and Mathur (1993) in pearlmillet and Chakraborty *et al.*

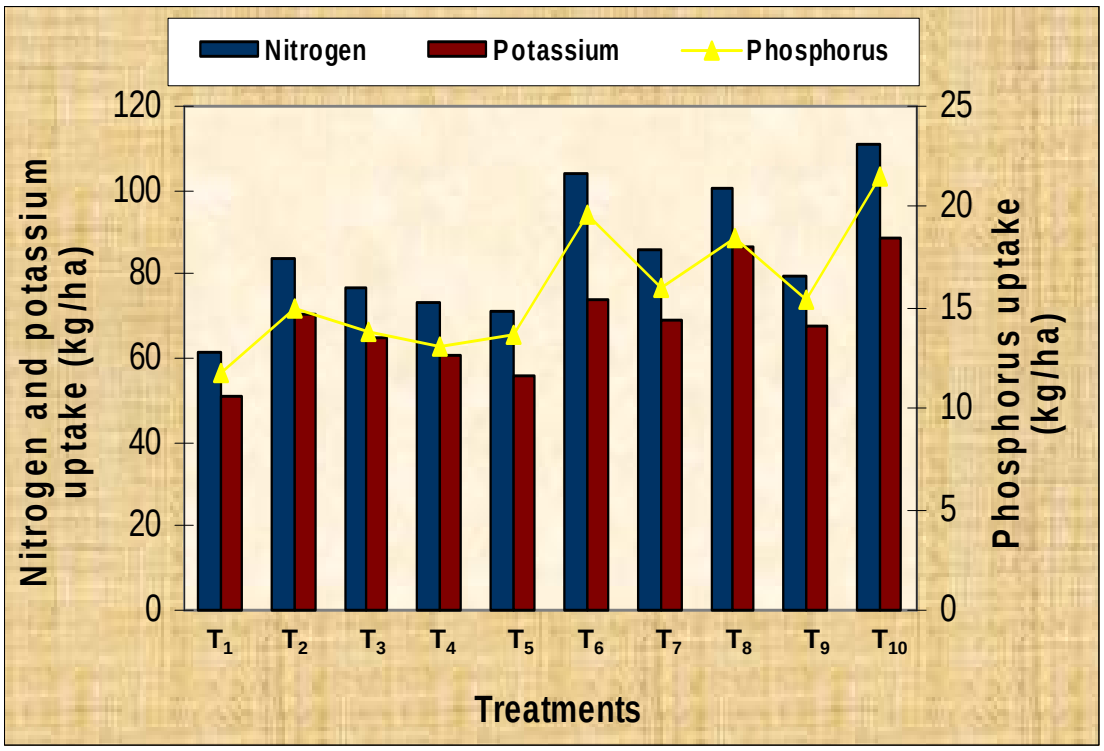


Fig. 45: Total nitrogen, phosphorus and potassium uptake of finger millet as influenced by application of zinc, boron and microbial inoculants

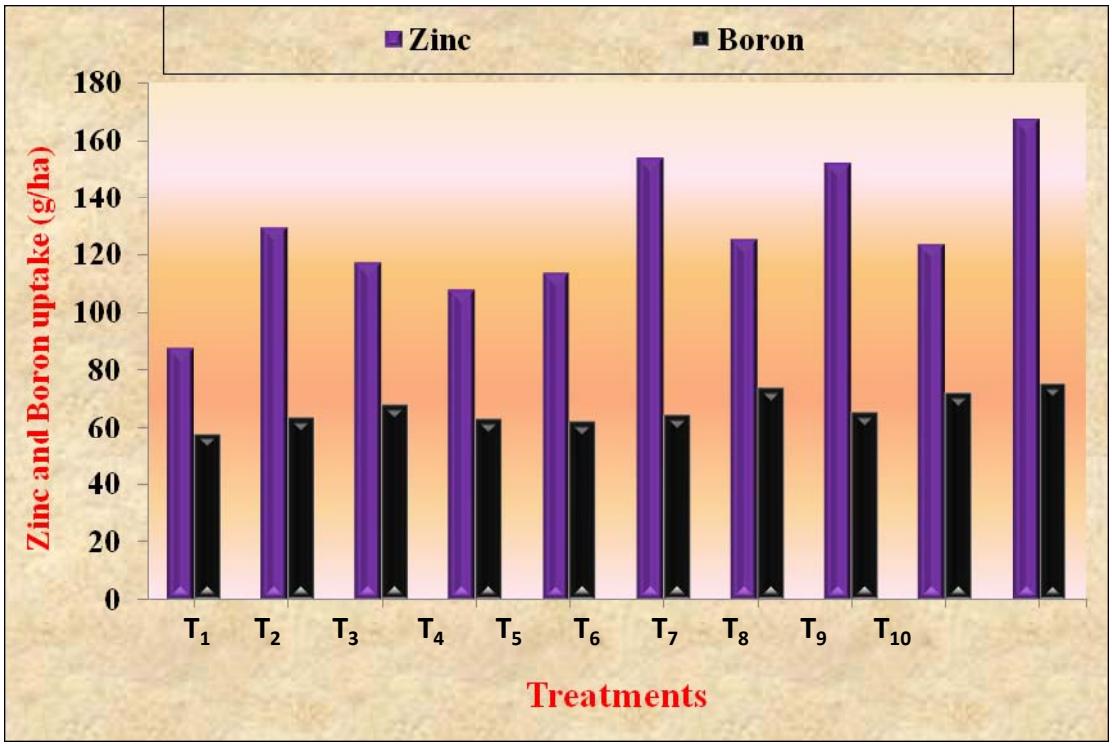


Fig. 46 : Total zinc and boron uptake of finger millet as influenced by application of zinc, boron and microbial inoculants

(2002) in finger millet who observed such increased N_2 uptake due to inoculation of *Azospirillum brasilense*. Furthermore, maximum uptake of nitrogen with dual inoculation of *Azospirillum* and VAM might be ascribed to their synergistic effect on nutrient uptake. Champawat and Pathak (1993) and Tewari *et al*. (1993) reported higher nitrogen uptake upon inoculation with VAM. The increase in nitrogen uptake under zinc application was primarily due to their increase in concentration coupled with more grain and straw yields. Similar increase in nitrogen uptake with application of zinc was reported by Venkateswarlu and Misra (1987) in rainfed wheat.

5.8.4.2 Effect of zinc, boron and microbial inoculants application on phosphorus uptake

Ion uptake by plant roots from soil is governed by transfer of ions through the soil and the absorbing power of the root. Some ions are poorly mobile in soil and they move by diffusion. The uptake of such ions depends on the movement of these ions to the root surface and then the absorbing capacity of the root. Phosphorus is one of the diffusion limited major plant nutrient. The soluble inorganic phosphorus occurring as primary orthophosphate and secondary orthophosphate are taken by plants. The rate in which plant roots absorb phosphorus from the soil solution is much faster than the rate in which phosphorus moves in soil solution by diffusion. This results in a phosphorus depletion zone around the root. Inoculation of VAM fungi has a significant role to play under this situation as it is in association with the roots of crop plants helps in mobilization of native and applied phosphorus. The hyphae of VAM fungi travel much beyond the phosphorus depletion zone and scavenge a large volume of soil and supply phosphorus to the plants. The phosphorus taken by the hyphae gets deposited in the arbuscules located in cortex of the host. Evidences

suggest that the phosphorus inflow rate in VAM hyphae was six times more compared to that of a non-mycorrhizal root (Bagyaraj, 2004).

In the present investigation also, significantly higher P uptake by finger millet grain (11.82 kg/ha), straw (9.73 kg/ha) and total P uptake (21.55 kg/ha) was recorded with the application of NPK + FYM + $ZnSO_4$ + borax + *A.brasilense* + VAM (T_{10}) as compared to control (Table 4.7.16 and Fig. 45). Chakraborty *et al.* (2002) reported higher phosphorus uptake upon inoculation with *A.brasilense* in finger millet, while, Bagyaraj and Manjunath (1980) and Tewari *et al.* (1993) noted an increase in phosphorus uptake upon inoculation with VAM in finger millet. Some of the reports of micronutrients suggested that increased uptake of phosphorus might be owing to increased yield of biomass due to zinc application. The results are in agreement with those of Soundara Rajan and Yassen (1981) in respect of phosphorus uptake due to zinc application.

5.8.4.3 Effect of zinc, boron and microbial inoculants application on potassium uptake

Application of zinc, boron with dual inoculation of *A.brasilense* and VAM along with recommended dose of NPK and FYM recorded significantly higher potassium uptake by finger millet grain (19.79 kg/ha), straw (68.88 kg/ha) and total potassium uptake (88.67 kg/ha) as compared to other treatments (Table 4.7.17 and Fig. 45). The increased potassium uptake was mainly on account of increased yield and nutrient content and also on account of its increased availability in the soil owing to external application of potassium. Present results are in confirmation with those of Chakraborty *et al.* (2002) in finger millet due to *Azospirillum* inoculation and Venkateswarlu and Misra (1987) due to zinc application in rainfed wheat.

5.8.4.4 Effect of zinc, boron and microbial inoculants application on zinc uptake

Zinc uptake was significantly influenced by the dual inoculation of *Azospirillum* and VAM along with micronutrients (Zn and B). Significantly higher zinc uptake by finger millet grain (102.20 g/ha), straw (65.02 g/ha) and total zinc uptake (167.21 g/ha) with the application of NPK + FYM + $ZnSO_4$ + borax + *A.brasilense* + VAM (T_{10}) as compared to other treatrments (Table 4.7.18 and Fig.46). Inoculation of *Azospirillum* along with micronutrients helped the micro-organism to produce more growth promoting substances and also helped the micro-organism to grow better and colonize in the finger millet roots. Thus there was an increase in root biomass which inturn helped in enhanced uptake of zinc and ultimately lead to higher yield of finger millet. Similar are the findings of Amitha Ganapathy and Savalgi (2006) in maize crop. In addition to *Azospirillum,* inoculation of VAM helps in mobilization of zinc resulted in higher available zinc pool in soil, which ultimately enhanced the zinc uptake. The findings are in line with the findings of Bagyaraj and Manjunath (1980) and Tewari *et al*. (1993) in respect of zinc uptake in finger millet due to VAM inoculation. The increase in zinc uptake might also be due to higher biomass production coupled with higher accumulation of zinc. Increased zinc uptake with application of $ZnSO_4$ has been documented by Indulkar and Malewar (1994) in sorghum and Duraisamy and Mani (2001) in millets.

5.8.4.5 Effect of zinc, boron and microbial inoculants application on boron uptake

Significant differences were observed in boron uptake due to zinc, boron and microbial inoculants application (Table 4.7.19 and Fig. 46). Application of NPK + FYM + $ZnSO_4$ + borax + *A.brasilense* + VAM (T_{10}) recorded significantly higher boron uptake by finger millet grain (21.02

g/ha), straw (53.95 g/ha) and total boron uptake by plant (74.96 g/ha) as compared to control. The increased boron uptake may be attributed to greater absorption of boron by the crop owing to increased yield of biomass. The uptake of boron was higher in finger millet straw than grain which reveals that the mobility of boron from straw to grain was rather poor. Nevertheless, the uptake of boron was more in the treatments where boron was applied externally in the form of borax. Increased boron uptake with the application of boron has been reported by Sinha *et al.* (1991) in different *kharif* and *rabi* crops, while Sakal *et al* (1999) noticed increase in boron uptake by grain and straw due to combined application of boron and FYM in maize and lentil crops. Further, the values of total uptake N, P_2O_5, K_2O, Zn and B were significantly and positively correlated with the grain yield (r = 0.831, 0.781, 0.752, 0.770 and 0.428, respectively) (Table 4.7.20).

5.9 Experiment-II(b) : RESPONSE OF FINGER MILLET-SOYBEAN ROTATION TO CONJUNCTIVE USE OF ZINC,BORONANDMICROBIAL INOCULANTS

Crop: **Soybean**

5.9.1 Effect of zinc, boron and microbial inoculants application on growth and growth parameters of soybean

Plant growth is dependent on the rate of accumulation of dry matter. The dry matter accumulation may reflect on the economic yield. In view of the fact that vegetative parts of plant serves as source whereas, grains are the sink. The need for the increased crop production is an outcome of a series of intermediate interaction of various biological events involving bio-chemical, physiological and morphological changes which takes place during its development in accordance with the supply of light, water, temperature and nutrients (Donald, 1962).

The results of the present investigation revealed that, application of NPK + FYM + $ZnSO_4$ + borax + *B. japonicum* + VAM (T_{10}) recorded significantly higher plant height at 30 (18 cm), 60 DAS (35.05 cm) and at harvest (39.75 cm) as compared to control (Table 4.8.1 and Fig. 47). However, it was found on par with the application of NPK + FYM + $ZnSO_4$ + *B. japonicum* (T_6). This increase in plant height was possibly attributed to internode elongation as a result of increased cell elongation and multiplication due to enhanced nutrient uptake by plants. This observation was in accordance with those of Balusamy *et al*. (1996) and Shirpurkar *et al*. (2005). Further, they also reported that application of zinc enhances the plant growth which may be attributed to the enhancement in auxin production and better nodulation. In addition, Kulkarni *et al*. (1989) also reported an improvement in the plant height due to application of zinc along with inoculation of *B. japonicum*, while Balachandar and Nagarajan (1999) and Tufenkci *et al*. (2006) noticed an increase in plant height due to inoculation of *B. japonicum* + VAM and VAM alone, respectively.

The dry matter production and its accumulation in different plant parts depend upon photosynthetic capacity of plants during the crop growth period. Photosynthetic capacity of plants depends upon dry matter accumulation in leaves and leaf area (Kulkarni *et al.*, 1989). Leaf area being photosynthetic surface plays an important role in determining the total biomass accumulation and quantity of photosynthates available for grain production. The higher values of leaf area (which is nothing but photosynthetic or chlorophyll apparatus) and leaf area index (which indicates amount of leaf surface area per unit land, which is exposed to solar radiation) indicates higher rate of photosynthesis and higher accumulation of photosynthates in different parts. In the present investigation, significantly higher leaf area and LAI was recorded with the application of NPK + FYM + $ZnSO_4$ + borax + *B. japonicum* + VAM (T_{10}) at

30 (480.30 cm^2/plant and 1.60, respectively), 60 DAS (1133 cm^2/plant and 3.78, respectively) and at harvest (107.9 cm^2/plant and 0.36, respectively) as compared to control (T_1). However, it was found on par with the application of NPK + FYM + $ZnSO_4$ + *B. japonicum* (T_6) (Table 4.8.3 and 4.8.4 and Fig. 47). This may be attributed to as *B. japonicum* treatment promotes nodulation whereas zinc is involved in nitrogen metabolism which inturn enhanced the vegetative growth and foliage cover of the crop. Soybean being self deciduous crop, leaf number and leaf area started decreasing towards the harvest. The higher leaf area and LAI with application of NPK + FYM + $ZnSO_4$ + borax + *B. japonicum* + VAM (T_{10}) was the consequence of higher number of leaves at 30 (10.25), 60 DAS (20.95) and at harvest (2.80) (Table 4.8.2). These results are in agreement with the earlier findings of Krishnamohan and Rao (1998), Praharaj and Dhingra (2001) and Nagar and Dadheech (2002) who reported an increase in LAI due to *B. japonicum* inoculation and Dash *et al.* (2005) and Shirpurkar *et al.* (2005) due to zinc application in soybean. Leaf area duration is a function of LAI and time of its persistence. The LAD was higher with the application of recommended NPK, FYM and micronutrients (Zn and B) along with microbial inoculants (*B. japonicum* and VAM) at 30-60 DAS (80.67 days) and 60 DAS – harvest (62.05 days) because of higher LAI and its persistence over a long period of time (Table 4.8.5 and Fig. 49).

Application of NPK + FYM + $ZnSO_4$ + borax + *B. japonicum* + VAM (T_{10}) recorded significantly higher number of branches at 60 DAS (4.87) and at harvest (6.15) as compared to other treatments. However, it was found at par with application of NPK + FYM + $ZnSO_4$ + borax + *B. japonicum* (T_6: 4.36 and 5.85 at 60 DAS and at harvest, respectively) (Table 4.8.5 and Fig. 49). This could be attributed to more availability of N and P due to fixation of atmospheric nitrogen by *B. japonicum* in addition to applied inorganic nitrogen and phosphorus. Further,

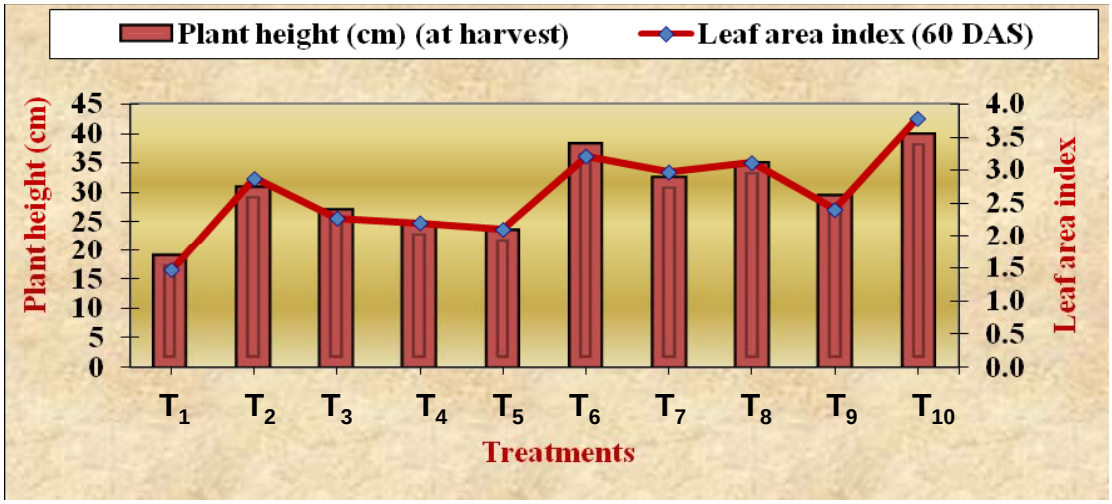


Fig.47: Plant height and leaf area index of soybean as influenced by application of zinc, boron and microbial inoculants

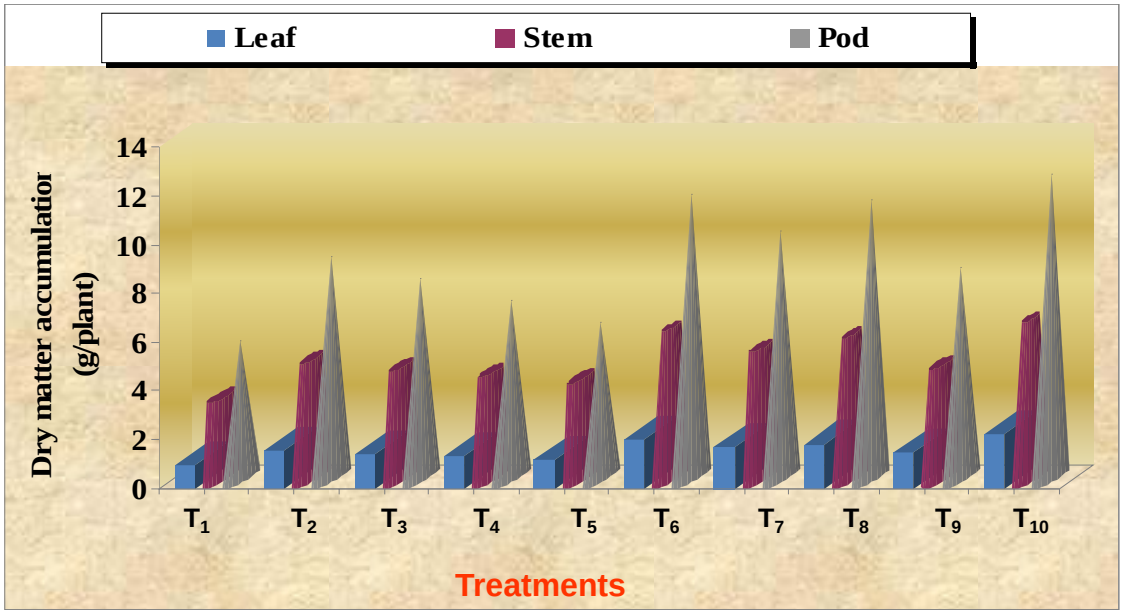


Fig.48: Dry matter accumulation in leaf, stem and pod of soybean at harvest of soybean as influenced by application of zinc, boron and microbial inoculants

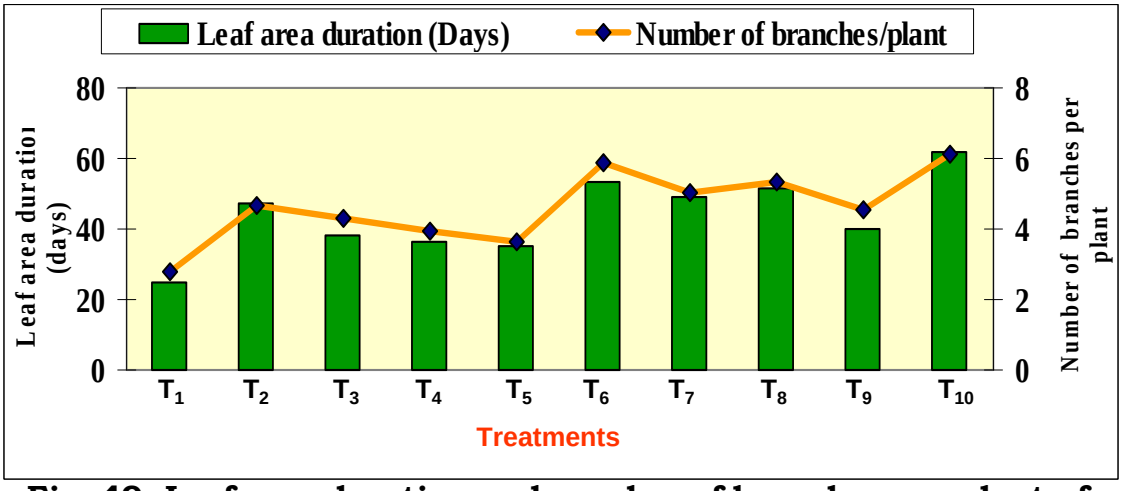


Fig. 49: Leaf area duration and number of branches per plant of soybean as influenced by application of zinc, boron and microbial inoculants

mobilization of native bound phosphorus by VAM lead to better plant development, thus leading to improved number of branches. The results are in accordance with the studies of Joshi *et al*. (2000), Dash *et al*. (2005) and Shirpurkar *et al*. (2005) who reported increased in number of branches due to micronutrients application in soybean, whereas Nagar and Dadheech (2002) and Kalhapure *et al*. (2003) noticed increase in number of branches due to *B. japonicum* inoculation.

Economic yield is a part of total biological yield of the crop and hence, the dry matter production is an important determinant of the economic yield (Donald, 1962). Generally, there was a significant improvement in the total dry matter accumulation at 30 (4.62 g/plant), 60 DAS (16.71 g/plant) and at harvest (21.12 g/plant) due to application of NPK + FYM + $ZnSO_4$ + borax + *B. japonicum* + VAM (T_{10}) as compared to other treatments (Table 4.8.6 to 4.8.8 and Fig. 48). The differences in total dry matter accumulation of soybean with dual inoculation of *B. japonicum* and VAM might be due to better nodulation in soybean (Table 4.8.9 and 4.8.10), owing to better availability of phosphorus. This improvement in nodulation with *B. japonicum* inoculation might have resulted in higher amount of nitrogen fixation and thereby better vegetative growth which leads to increase in growth components viz., plant height, number of branches and number of leaves thus increasing the total dry matter accumulation (Table 4.8.1, 4.8.2 and 4.8.5). Indeed, the supply of micronutrients at sowing itself helped the increased colonization of *B. japonicum* in the rhizosphere to form healthy viable nodules which will fix more nitrogen and reflect the crop growth. Similar results were also reported by Kumutha and Santhanakrishnan (1994), Saxena and Chandel (1997), Thiyageshwari and Ramanathan (1999), Deshmukh *et al*. (2004) and Tufenkci *et al*. (2006). The increase in TDMA may also be attributed to cumulative effect of the nutrients contribution from inoculants and micronutrients on higher dry matter distribution in

leaf, stem at 30 DAS and pods at 60 DAS and at harvest (Table 4.8.6 and 4.8.8).

Nutrition in soybean is somewhat more complex in respect of micronutrients as it affects survival and growth of rhizobia, infection, nodulation and functioning of nitrogen fixation process in nodules. Nodule being formed on the roots of soybean consists millions of *B. japonicum* cells which absorb atmospheric nitrogen and supply it to the plant.

In the present investigation, application of NPK + FYM + $ZnSO_4$ + borax + *B. japonicum* + VAM (T_{10}) recorded significantly higher number of nodules per plant at 45 (43.95), 60 (66.95) and 75 DAS (58.38)which was 158.53,101.65 and 152.18 per cent, respectively and higher nodule dry weight at 45 (1.02 g/plant), 60 (1.39 g/plant) and 75 DAS (1.20 g/plant) which was 218.75,167.30 and 192.68 per cent higher as compared to control (T_1). However, it was found on par with the application of NPK + FYM + $ZnSO_4$ + *B. japonicum* (T_6) (Table 4.8.9 and 4.8.10). Significant increase in nodulation could be attributed to the involvement of zinc, wherein, under adequate zinc supply the increased auxin production, root initiation and shoot elongation of plant caused stimulatory effect on the production and development of nodules. Further, the application of boron as borax to soil improved nodule number, as it is an essential micronutrient for cell division in the process of nodule formation. Evidences suggests that a synergistic interaction between VAM and *B. japonicum* could benefit the plant system by way of increased colonization of *B. japonicum* which induced an improvement in nodule number which was attributed to direct availability of phosphorus by VAM symbiosis (Kumutha and Santhanakrishnan, 1994). In line with the present study, Bhuiyan and Shivashankar (1993), Singh (1994), Bhuiyan *et al.* (1995), Mehasen *et al.* (2002) and Menaria and Pushpendra Singh

(2004) also reported similar results of enhanced nodulation of the crop due to the application of micronutrients and microbial inoculants.

5.9.2 Effect of zinc, boron and microbial inoculants application on yield and yield attributes of soybean

Seed yield is polygenic complex character and is determined by the interaction of a number of characters among themselves and with the environment. Application of micronutrients (Zn and B) along with microbial inoculants caused significant variations in the yield of soybean. In the present investigation, application of NPK + FYM + $ZnSO_4$ + borax + *B. japonicum* + VAM (T_{10}) recorded significantly higher seed yield (2081 kg/ha) as compared to other treatments (Table 4.8.13; Fig.53 and Plate 6). The magnitude of increase in the seed yield due to application of NPK + FYM + $ZnSO_4$ + borax + *B. japonicum* + VAM (T_{10}), NPK + FYM + $ZnSO_4$ + *B. japonicum* (T_6) and NPK + FYM + $ZnSO_4$ + VAM (T_8) was 46.55, 42.89 and 42.04 per cent over control (NPK + FYM). This increase in seed yield in these treatments may be due to higher number of pods per plant, and number of seeds per pod.

The higher seed yield might be attributed to rapid mineralization of N, P and K from inorganic fertilizers and steady supply of these nutrients from FYM, which might have met the nutrient requirement of crop at the critical stages in addition to the nutrient contribution from microbial inoculants increased the seed yield significantly. The beneficial influence of micronutrients on the yield of soybean on various enzymes and efficient utilization of applied nutrients resulted in increased yield components. The positive response of soybean to zinc application may be due to increased growth and yield components, due to increased availability and better uptake of nutrients. Zinc is known to increase the nodulation and fixation of atmospheric nitrogen by increased nitrogenase enzyme activity, thereby the availability of N increased in addition to

T_1: Control (NPK + FYM only)

T_6: NPK + FYM+ $ZnSO_4$+ *A.brasilense*

T_8: NPK + FYM + $ZnSO_4$+ VAM

T_{10}: NPK+FYM+ $ZnSO_4$+Borax+*A.brasilense*+VAM

Plate 6: Response of soybean to conjunctive use of zinc, boron and microbial inoculants (Expt. IIb)

nitrogen fixed by the crop. The increased seed yield might be further ascribed to application of boron which is known to activate the basic metabolic rate in plants and facilitates the synthesis of nucleic acids and hormones, which have enhanced the seed yield due to greater availability of nutrients and photosynthates. These results are in accordance with the Dwivedi *et al*. (1990), Saxena and Chandel (1997), Sakal *et al*. (1998), Sarkar *et al*. (1998), Thiyageshwari and Ramanathan (1999) Shelge *et al*. (2000) and Shirpurkar *et al*. (2006)who reported increase in seed yield of different legumes due to application of micronutrients. In addition to this, the dual inoculation of *B. japonicum* and VAM resulted in cumulative effects such as supply of nutrients to the crop besides their role in production of growth promoting substances like auxin, gibberellins and cytokinin. Therefore, the increased seed yield might be due to the positive role of microbial inoculants in presence of major and micronutrients. Hence, the supply of the required nutrients through organic and inorganic sources and microbial inoculants facilitated balanced nutrition of the crop, which resulted in enhanced seed yield. The results are in conformity with the findings of Tomar *et al*. (1991), Singh (1994), Balachander and Nagarajan (1999), Mehasen *et al*. (2002) and Anon. (2005a).

As stated earlier, the role of micronutrients and microbial inoculants applications exerted greater influence on haulm yield from 2496 kg per ha in control to 3304 kg per ha with application of NPK + FYM + $ZnSO_4$ + borax + *B. japonicum* + VAM (T_{10}) (Table 4.8.13 and Fig.53). The contributory parameters for such an enhancement were related to taller growth of plants, higher dry matter accumulation, LAI and LAD, which consistently showed higher significant differences in haulm yield due to application of micronutrients and microbial inoculants. Thiyageshwari and Ramanathan (1999) also recorded higher stover yield of soybean due to application of NPK + FYM + $ZnSO_4$ + borax,

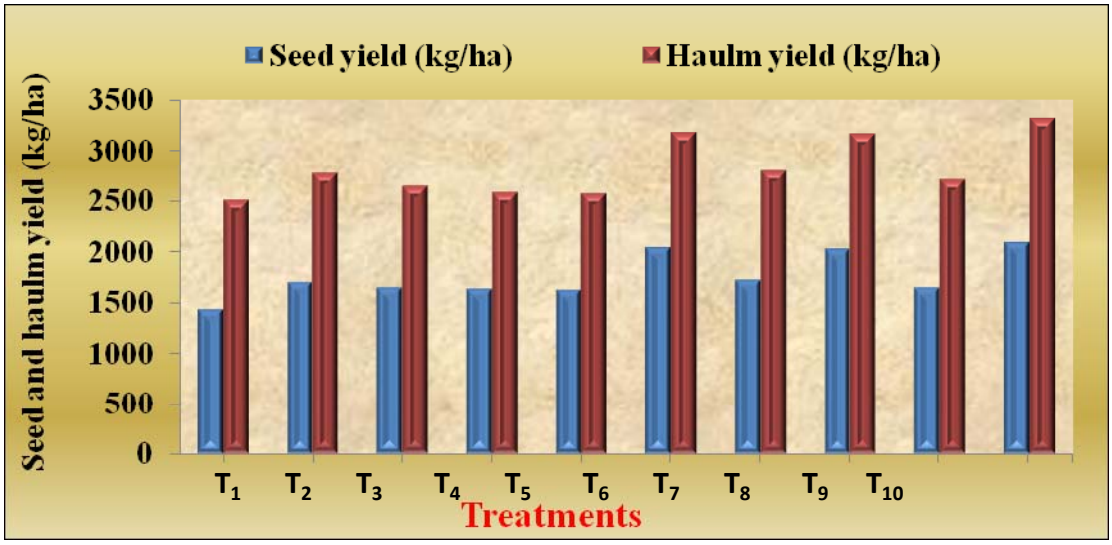


Fig. 53 : Seed yield and haulm yield of soybean as influenced by application of zinc, boron and microbial inoculants

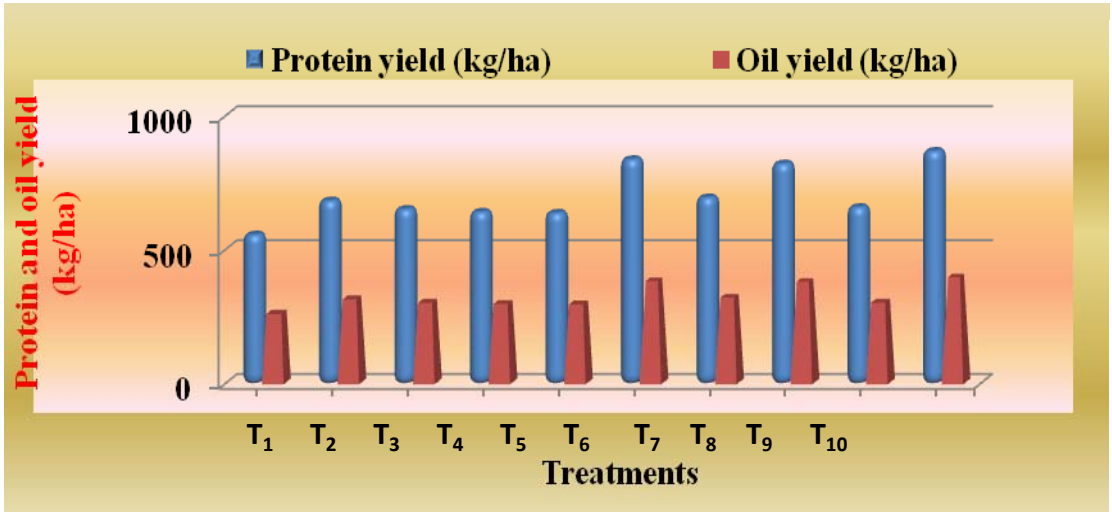


Fig. 54: Protein and oil yield of soybean as influenced by application of zinc, boron and microbial inoculants

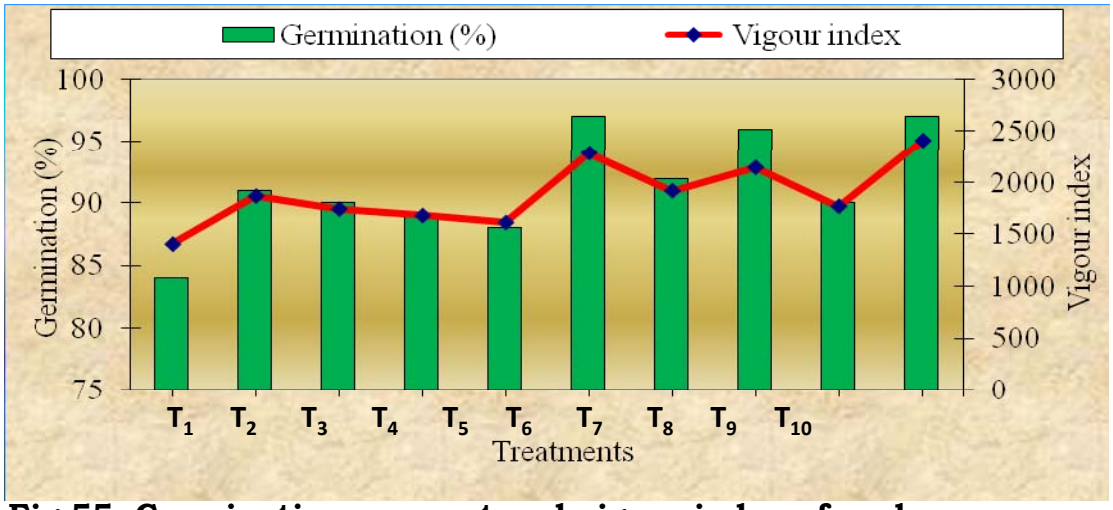


Fig.55: Germination per cent and vigour index of soybean as influenced by application of zinc, boron and microbial inoculants

while Sudesh Kumar *et al.* (1998) and Menaria and Pushpendra Singh (2004) noticed higher stover yield of soybean due to inoculation of *B. japonicum*.

The harvest index of soybean did not differ significantly among the different treatments (Table 4.8.13). It may be due to proportionate production of seed and haulm yields in soybean by different nutrient treatments which kept harvest index values almost constant

Seed yield is the manifestation of yield contributing characters. The main yield contributing characters that have direct impact on seed yield are number of pods per plant, number of seeds per pod, pod length, pod yield per plant, seed yield per plant and test weight. Application of NPK + FYM + $ZnSO_4$ + borax with dual inoculation of *B. japonicum* and VAM recorded significantly higher number of seeds per pod (3.15) which was 50 per cent higher as compared to control. This might be attributed to increased dry matter accumulation in the reproductive parts and formation of higher sink capacity. Similar increase in number of seeds per pod due to micronutrients and microbial inoculants was also reported by Tomar *et al.* (1991), Jht *et al.* (1998), Sailesh Kumar Mishra and Baboo (1999), Sudesh Kumar *et al.* (2001) and Ranjit Singh and Rai (2004).

Number of pods per plant (25.90) were significantly higher with the application of NPK + FYM + $ZnSO_4$ + borax + *B. japonicum* + VAM (T_{10}) as compared to rest of the treatments, but was found on par with the application of NPK + FYM + $ZnSO_4$ + *B. japonicum* (T_6 : 23.65) (Table 4.8.11 and Fig.50). Application of NPK + FYM + $ZnSO_4$ + borax + *B. japonicum* + VAM (T_{10}) and NPK + FYM + $ZnSO_4$ + *B. japonicum* (T_6) recorded 128.6 and 108.74 per cent higher number of pods per plant over control (NPK + FYM). This may be due to the interaction effect of microbial inoculants and N, P nutrition resulting in better vegetative

growth and photosynthetic activity which might have resulted in better translocation and partitioning of assimilates towards the pod. These results are in agreement with those of Tomar *et al.* (1991) and Balusamy *et al.* (1996) who reported increase in pod number per plant due to micronutrients application, while Kulhare *et al.* (1996), Ranjit Singh and Rai (2004) and Jalaluddin (2005) noticed increase in pod number per plant due to inoculation of *B. japonicum* and VAM.

Pod length was significantly higher with the application of NPK + FYM + $ZnSO_4$ + borax + *B. japonicum* + VAM (T_{10} : 6.03 cm) followed by NPK + FYM + $ZnSO_4$ + *B. japonicum* (T_6 : 5.72 cm) and NPK + FYM + $ZnSO_4$ + VAM (T_8 : 5.53 cm) (Table 4.8.11 and Fig. 51). This increase in length of pod may be due to better uptake of nutrients which increased the growth of plant. Similar results were reported by Mohan Kumar (2002) in soybean due to application of micronutrients and microbial inoculants.

The pattern of improvement in pod yield and seed yield per plant was similar to those reported earlier in case of seed yield (Table 4.8.12 and 4.8.13; Fig.51 and 52). Application of NPK + FYM + $ZnSO_4$ + borax + *B. japonicum* + VAM (T_{10}) recorded higher pod yield per plant (12.37 g/plant) and seed yield per plant (5.78 g/plant) over control (T_1). Similar results were reported by Jht *et al.* (1998), Sarkar *et al.* (1998) and Mehasen *et al.* (2002). This might be due to increased concentration of efficient and healthy strains of rhizobial bacteria in root nodules that inturn resulted in better utilization of atmospheric nitrogen. In addition to this, increased yield parameters due to the application of boron as borax might be attributed to the role of boron in the physiological process of plants such as cell maturation, tissue hydration and formation of reproductive organs and pollen germination. Further, boron helps in arresting the flower drop and improves the pod setting.

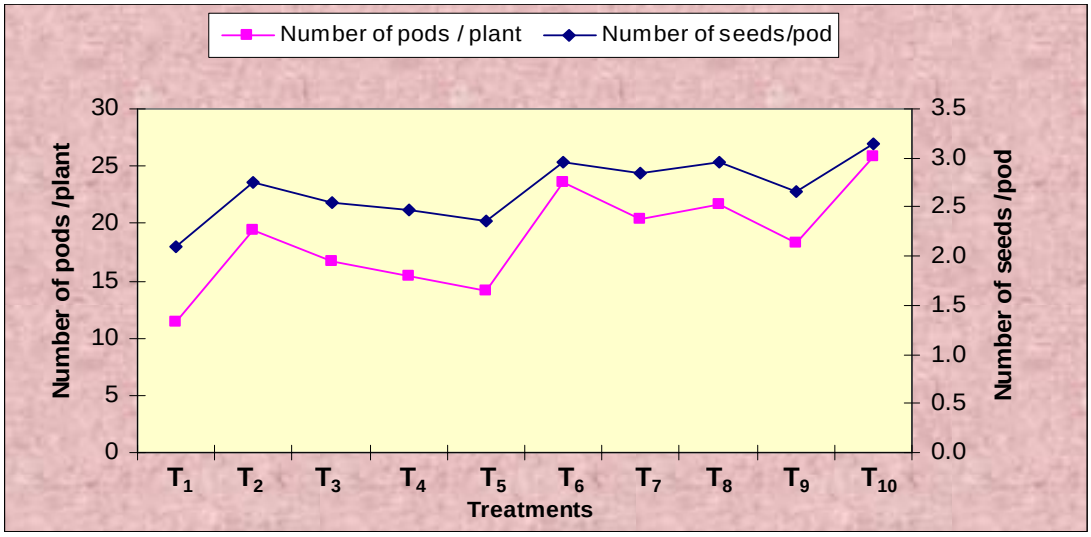


Fig.50: Number of pods per plant and number of seeds per pod of soybean as influenced by application of zinc, boron and microbial inoculants

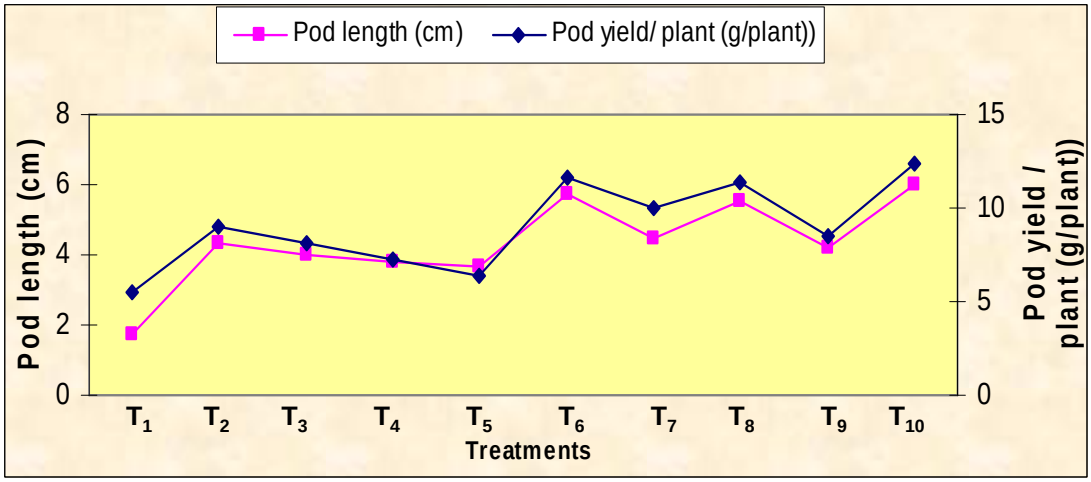


Fig.51: Pod length and pod yield per plant of soybean as influenced by application of zinc, boron and microbial inoculants

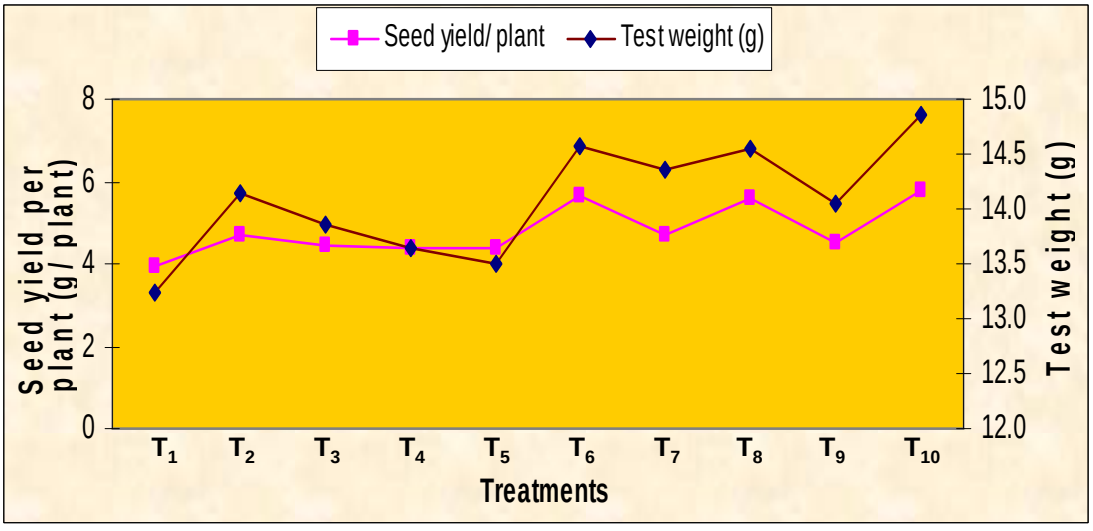


Fig.52: Seed yield per plant and test weight of soybean as influenced by application of zinc ,boron and microbial inoculants

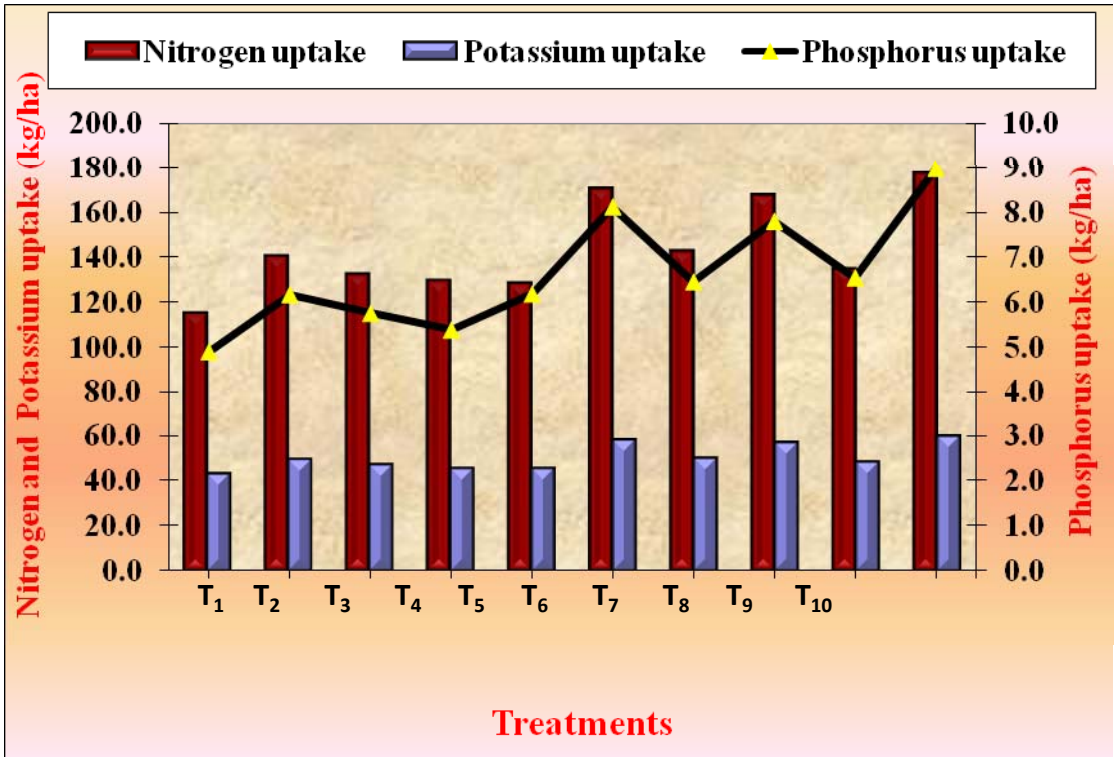


Fig.56: Total nitrogen, phosphorus and potassium uptake of soybean as influenced by application of zinc, boron and microbial inoculants

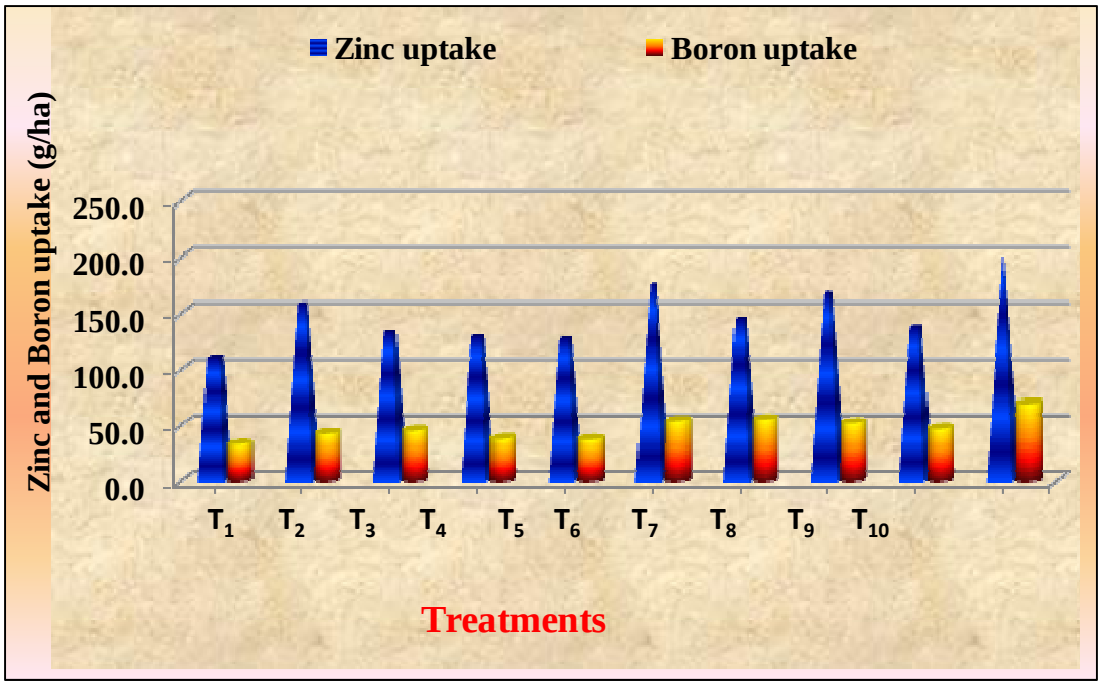


Fig. 57: Total zinc and boron uptake of soybean as influenced by application of zinc, boron and microbial inoculants

Test weight of soybean did not differ significantly due to micronutrients and microbial inoculants application (Table 4.8.12 and Fig.52).

These results have been further supported by significant and positive correlation between seed yield of soybean with growth parameters like TDM at harvest (r=0.723), leaf area at harvest (r=0.851) nodule number at 60DAS (r=0.698) and number of branches at harvest (r=0.796) and yield parameters like number of pods per plant (r = 0.753), number of seeds per plant (r = 0.750), pod length (r = 0.722), pod yield per plant (r = 0.699) and seed yield per plant (r = 0.803) (Table 4.8.21). Similar result was also reported by Ghatge and Kadu (1993) who had observed a significant and positive correlation of seed yield with growth and yield parameters in soybean.

Similarly, regression analysis indicated that 75 per cent of soybean seed yield was influenced by growth and yield parameters, as shown by the inter-relationship of source and sink in plant with the better uptake of nutrients by the conjunctive use of NPK + FYM + $ZnSO_4$ + borax with dual inoculation of *B. japonicum* and VAM (Table 4.8.21).

5.9.3 Seed quality parameters of soybean as influenced by zinc, boron and microbial inoculants application

Micronutrients like any other essential nutrient perform the primary function of transforming photo energy into chemical energy. They are indispensable for numerous enzymatic reactions. If the level of micronutrients falls below optimum, then metabolic efficiency of the plant is severely restricted. The resultant alteration in specific enzyme activities brings about qualitative change in plant constituents (Shankar *et al.*, 2005). Besides, micronutrients, microbial inoculants also known to influence the quality of seed through secretion of growth promoting

substances and enhance the availability of nutrients by way of fixation and mobilization (Tarafdar and Rao, 1997).

In the present investigation, quality parameters like protein and oil content of soybean seed did not differ markedly among different treatments (Table 4.8.14), whereas, significant differences in protein and oil yield was recorded due to application of micronutrients and microbial inoculants. Protein yield was significantly higher with application of NPK + FYM + $ZnSO_4$ + borax + *Rhizboium* + VAM (T_{10} : 870.10 kg/ha) over rest of the treatments (Table 4.8.14 and Fig.54). Higher protein yield in these treatments might be due to higher seed yield. The role of zinc and boron in synthesis of amino acids leading to formation of protein molecule is well established (Mengel and Krikby, 1984). The increase in protein content by the application of Zn, B, *B. japonicum* and VAM culture may be attributed to the increased number of nodules which ultimately enhanced the symbiotic nitrogen fixation. Increase in nitrogen content of the soil increased the protein content of soybean. Similar results were also reported by Shukla *et al.* (1983), Sudarshan and Ramaswami (1993) in groundnut and Bhuiyan *et al.* (1995), Bisht and Chandel (1996) in soybean due to micronutrients application, whereas Mehasen *et al.* (2002) reported increase in protein yield due to dual inoculation of *B. japonicum* and VAM.

The oil yield of soybean was significantly higher with the application of NPK + FYM + $ZnSO_4$ + borax + *Rhizboium* + VAM (T_{10} : 396.05 kg/ha) followed by NPK + FYM + $ZnSO_4$ + *Rhizboium* (T_6 : 382.09 kg/ha) and NPK + FYM + $ZnSO_4$ + VAM (T_8 : 379.36 kg/ha) (Table 4.8.14 and Fig.54). Higher oil yield in these treatments might be due to higher seed yield. The role of zinc in increasing the activation of NADPH dependent dehydrogenase involved in fat synthesis is well established (Gupta and Vyas, 1994). Further, the values of protein and oil yield were

significantly and positively correlated with seed yield(r=0.953 and 0.946,respectively((Table 4.8.21)

Seed inoculation with *B. japonicum* and soil inoculation with VAM caused considerable and significant increase in oil yield. It might be due to enhanced uptake of nitrogen and phosphorus by the plants from the soil solution where the amount of these nutrients is increased because of biological fixation through *B. japonicum* and VAM, respectively. Evidences suggests that increased uptake of phosphorus along with other nutrients is very essential for energy transformation process which might have resulted in increased conversion of phosphorylated plant constituents into fatty acids and ultimately increased the oil content. Similar increase in oil content was reported by Shukla *et al*. (1983) and Sudarshan and Ramaswami (1993) in groundnut due to zinc and boron application.

Application of micronutrients (Zn and B) with dual inoculation of *B. japonicum* and VAM caused significant variation in germination, dry weight of root and shoot and seed vigour index. Significantly higher germination (97%), shoot and root dry weight (24.90 mg) and seed vigour index (2417) was observed with the application of NPK + FYM + $ZnSO_4$ + borax + *Rhizboium* + VAM (T_{10}) as compared to control (T_1) (Table 4.8.15; Fig.55 and Plate 7). Improvement in nutritional condition of seed under NPK + FYM + $ZnSO_4$ + borax + *Rhizboium* + VAM (T_{10}) application seems to be due to the congenial environment for seed growth because of adequate supply of metabolites and nutrients. This was reflected in increased weight of individual seed and ultimately higher germination and dry weight of shoot and root. Further, an increase in the vigour index under this treatment may be due to availability of nutrients and photosynthates to seeds leading to healthy growth and development of seeds resulting in accumulation of balanced nutrients and carbohydrates

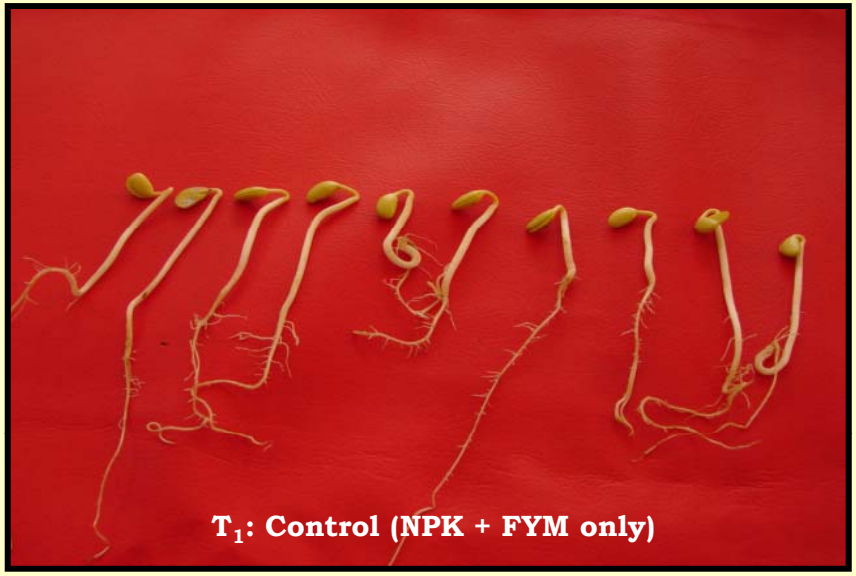


Plate 7: Seed vigour of soybean as influenced by zinc, boron and microbial inoculants

in the seed. Similar increase in shoot and root dry weight of soybean was reported by Bhuiyan *et al*. (1995) due to application of PKS + Zn with inoculation of *B. japonicum* and Barakah and Heggo (1998) due to dual inoculation of *B. japonicum* and VAM along with phosphorus, while Shankar *et al*. (2005) reported increase in germination shoot and root dry weight and vigour index of soybean due to zinc and boron application.

5.9.4 EFFECT OF ZINC, BORON AND MICROBIAL INOCULANTS APPLICATION ON NUTRIENTS UPTAKE BY SOYBEAN

5.9.4.1 Nitrogen uptake by soybean seed, haulm and total plant uptake

Application of NPK + FYM + $ZnSO_4$ + borax + *Rhizboium* + VAM (T_{10}) recorded significantly higher nitrogen uptake by soybean seed (139.23 kg/ha), haulm (37.59 kg/ha) and total nitrogen uptake (176.82 kg/ha) as compared to rest of the treatments (Table 4.8.16 and Fig.56). This is because zinc and *B. japonicum* involved in biological nitrogen fixation and translocation in plant parts and higher dry matter accumulation. Higher nitrogen absorption may also be due to stimulatory effect of boron in N uptake. Similar increase in nitrogen uptake by soybean plant was reported by Katiyar and Pant (1993), Sarkar and Tripathi (1996), Barakah and Heggo (1998) and Sonboir and Sarawgi (2000).

5.9.4.2 Effect of zinc, boron and microbial inoculants application on phosphorus uptake

Phosphorus is one of the major plant nutrients which play a key role in balanced nutrition of plants. Major part of water soluble hosphorus in fertilizers becomes insoluble and unavailable to the growing crops within short period due to its chemical fixation in soils. Hence solubilization of fixed soil phosphorus through the use of

microorganisms coupled with organics (*i.e.,* FYM) is a viable option to augment the availability of phosphorus in easily assimilable form by the crops(Poonam Gautam *et al.,* 2003).In the present investigation, phosphorus uptake was found to be significantly higher with application of NPK + FYM + $ZnSO_4$ + borax + *Rhizboium* + VAM (T_{10}) in soybean seed (4.42 kg/ha), haulm (4.56 kg/ha) and total (8.98 kg/ha) as compared to control (T_1) (Table 4.8.17 and Fig.56) which could be attributed to higher availability of phosphorus due to mobilization of native and bound phosphorus by VAM in addition to external application through fertilizer which ultimately resulted in better root growth and increased physiological activity of roots to absorb phosphorus. The results are in agreement with the findings of Kumutha and Santhanakrishnan (1994), Barakah and Heggo (1998) due to dual inoculation of *B. japonicum* and VAM in soybean.

5.9.4.3 Effect of zinc, boron and microbial inoculants application on potassium uptake

As an essential nutrient, potassium is known to have several functions inside the plant body and it has been associated with such roles as an enzyme activator, food former, root booster, stalk strengthner, breathing regulator, water strecher and starch transporter, protein builder, wilt reducer, disease retarder, crop quality improver, chemical traffic policeman and so on (Singh and Singh, 1994). Therefore, its uptake by plant will definitely boost up the yield of the soybean crop. In the present investigation, application of NPK + FYM + $ZnSO_4$ + borax + *Rhizoboium* + VAM (T_{10}) recorded significantly higher uptake of potassium by soybean seed (10.45 kg/ha), haulm (49.77 kg/ha) and total potassium uptake (60.22 kg/ha) as compared to control (T_1) (Table 4.8.18). This might be due to the fact that better plant growth leading to higher uptake of nutrients and also due to stimulatory effect of P, Zn and B in absorption of potassium. Evidences suggest that the

stimulatory effect of inoculation of *B. japonicum* and VAM on potassium absorption might be due to their indirect solubilizing effect of potassium bearing minerals. Moreover, it increased the N content of the soil by fixation of atmospheric nitrogen which has synergistic effect on potassium absorption (Vedram *et al.*, 2002a). These results are in conformity with the findings of Tufenkci *et al.* (2006) due to soil inoculation of VAM in soybean.

5.9.4.4 Effect of zinc, boron and microbial inoculants application on zinc uptake

Application of NPK + FYM + $ZnSO_4$ + borax + *B. japonicum* + VAM (T_{10}) recorded significantly higher zinc uptake by soybean seed (134.39 g/ha), haulm (70.47 g/ha) and total zinc uptake (204.86 g/ha) as compared to rest of the treatments (Table 4.8.19 and Fig.57). This may be due to involvement of applied zinc in activating the enzymatic system helped the translocation of zinc to other plant parts. Further, dual inoculation of *B. japonicum* and VAM showed significant influence on the uptake of zinc. This might be due to the role of VAM in acquiring mineral nutrients from soil especially immobile elements such as phosphorus and zinc (Vyas, 2006) while, *B. japonicum* indirectly helped in zinc uptake by way of biological nitrogen fixation, wherein the nitrogen concentration in the soil increased, which had stimulating effect on zinc uptake. Similar increase in zinc uptake have been reported by Devarajan and Palaniappan (1995) due to zinc application while, Krishna *et al.* (1981), Vejsadova *et al.* (1992) and Tufenkci *et al.* (2006) noticed increased zinc uptake due to VAM inoculation.

5.9.4.5 Effect of zinc, boron and microbial inoculants application on boron uptake

Application of NPK + FYM + $ZnSO_4$ + borax + *Rhizboium* + VAM (T_{10}) recorded significantly higher boron uptake by soybean seed (28.35

g/ha), haulm (41.22 g/ha) and total boron uptake (69.57 g/ha) as compared to rest of the treatments (Table 4.8.20 and Fig.57). This may be due to better availability of applied and native boron in the soil. The increased supply of boron to the crop, as well as indirect effect resulting from the formation of boron-diol complexes reduced loss of boron which ultimately resulted in higher boron uptake. These findings are in line with those reported by Mohan Kumar (2002) and Sumangala (2003) who observed higher boron uptake due to borax application in soybean and groundnut respectively. Further, the values of total uptake N, P_2O_5, K_2O, Zn and B were significant and positively correlated with the seed yield (r = 0.892, 0.854, 0.849, 0.851and 0.807, respectively) (Table 4.8.21). Vedram *et al.* (2002b) also recorded positive correlation between total uptake of NPKS and Zn with grain yield in mungbean.

5.10 EFFECT OF ZINC, BORON AND MICROBIAL INOCULANTS APPLICATION ON POPULATION OF SOIL MICRO-ORGANISMS AND SOIL ENZYMES ACTIVITY IN FINGER MILLET-SOYBEAN AND SOYBEAN-FINGER MILLET BASED CROPPING SYSTEM

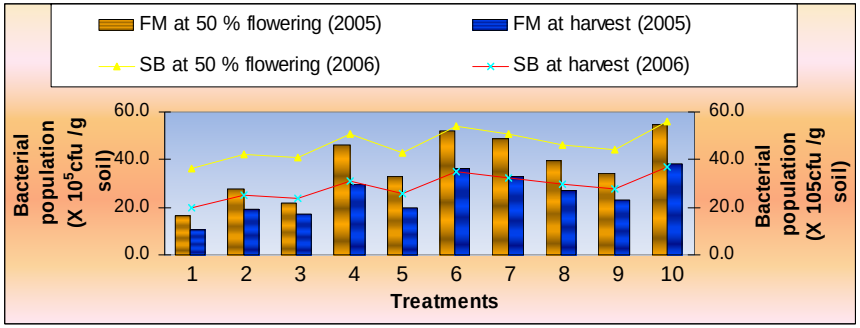
The soil in contact with root surface comprises an area of intense microbial activity. The environment under root zone becomes highly favourable for multiplication and activity of microorganisms due to the presence of vast array of compounds in the form of root exudates (Arshad and Frankenberger, 1993). Important processes like mineralization, nitrification, phosphorus recycling etc., are dependent much on the balanced equilibrium existing among various groups of organisms in soil. Many of the processes occurring in the soil are mediated by enzymes produced by proliferating microorganisms. These enzymes are substrate specific and act from either inside or outside the living cell. Any threat to microbiological activity is reflected in the rate of enzymatic transformations occurring in soil.

5.10.1 Effect of zinc, boron and microbial inoculants application on soil microorganisms

Population of diversified microflora (Table 4.9.1 and 4.9.2) was greatly influenced at 50 per cent flowering stage in comparison to harvest due to zinc, boron and microbial inoculants application. In the present investigation, irrespective of cropping systems, application of micronutrients (Zn and B) and recommended dose of NPK + FYM along with dual inoculation of *Azospirillum* / *B. japonicum* and VAM significantly influenced the population of microbes.

5.10.1.1 Bacterial population

The bacterial population differed significantly due to zinc, boron and microbial inoculants application with an increasing trend at 50 per cent flowering followed by a decline at harvest (Table 4.9.1 and 4.9.2 and Fig.58). In the present study, it was observed that, the population of bacteria was found to be higher with the application of NPK + FYM + $ZnSO_4$ + borax + *A.brasilense* / *B. japonicum* + VAM (T_{10}) which was followed by NPK + FYM + $ZnSO_4$ + *A.brasilense* / *B. japonicum* (T_6) in both finger millet-soybean and soybean-finger millet based cropping system. The higher bacterial population may be due to greater availability of nutrients (N and P) with the application of microbial inoculants (*A.brasilense / B. japonicum* and VAM) which seem to help in the multiplication of bacterial population. Similar increase in the bacterial population was reported by Chouksey *et al*. (1995) due to application of NPK + FYM; Sumangala (2003) due to application of RDF + Zn + B + Mo + *B. japonicum* + PSB + VAM in groundnut and Anon. (2007) reported an increase in bacterial population due to NPK + Zn + B application in finger millet –soybean and soybean-finger millet cropping system.



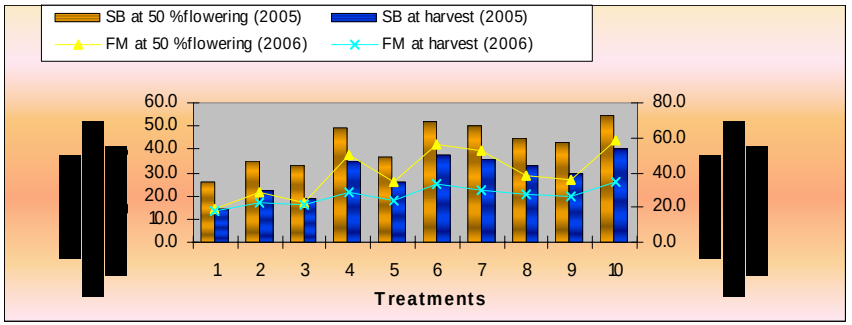
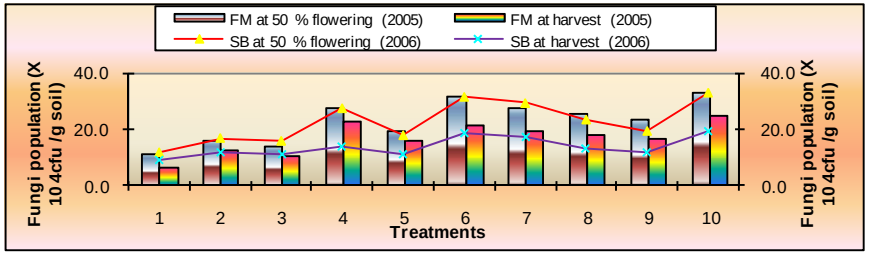


Fig.58: Bacterial population at 50 % flowering and at harvest of finger millet and soybean as influenced by zinc, boron and microbial inoculants nutrition in finger millet –soybean and soybean –finger millet based cropping system



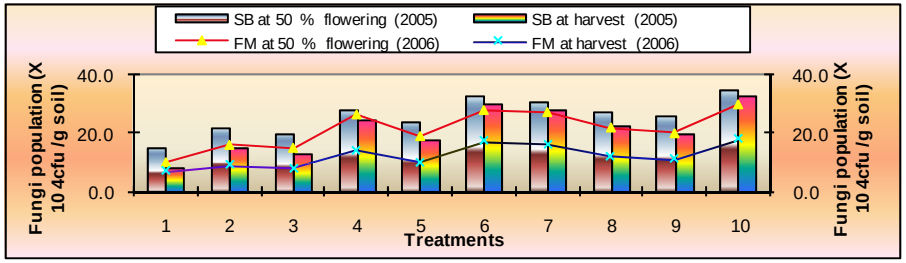
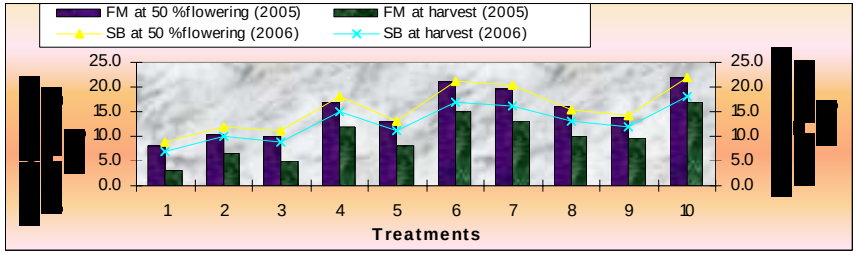


Fig.59: Fungal population at 50 % flowering and at harvest of finger millet and soybean as influenced by zinc, boron and microbial inoculants nutrition in finger millet –soybean and soybean –finger millet based cropping system



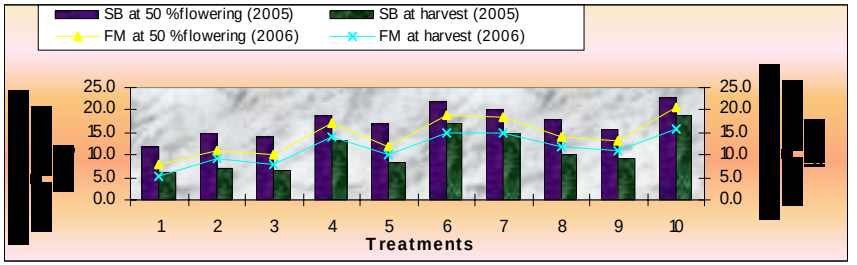


Fig.60: Actinomycetes population at 50 % flowering and at harvest of finger millet and soybean as influenced by zinc, boron and microbial inoculants nutrition in finger millet –soybean and soybean –finger millet based cropping system

5.10.1.2 Fungal population

Significantly higher population of fungi was observed at 50 per cent flowering and at harvest of crops due to zinc, boron and microbial inoculants application along with recommended NPK + FYM over control in both the cropping systems (Table 4.9.1 to 4.9.2 and Fig.59). This could be due to increased availability of nutrients particularly the positive interaction of VAM with *A.brasilense* and *B. japonicum*. VAM fungus are known to increase the availability of immobile micronutrients such as Fe, Zn, Cu and Mn along with major nutrient phosphorus through mobilization process. This could results in better growth of plants which inturn resulted in more release of root exudates which acts as a source of carbon and energy for microorganisms. These results are in accordance with findings of Chouksey *et al*. (1995), Rajender Reddy *et al*. (1999), Vedram *et al*. (2002b), Sumangala (2003) and Anon. (2007) who observed increased fungal population due to application of organics, inorganic fertilizers and microbial inoculants while working on different crops.

5.10.1.3 Actinomycetes population

In the present investigation at 50 per cent flowering and at harvest of finger millet and soybean crops, significantly higher population of actinomycetes was observed due to application NPK + FYM + $ZnSO_4$ + borax + *A.brasilense / B. japonicum* + VAM (T_{10}) as compared to control (T_1) in both the cropping systems(Table 4.9.1 to 4.9.2 and Fig.60). This increased actinomycetes population might be attributed to increased availability of macro and micronutrients during the crop growth period due to addition of organic manure along with micronutrients and microbial inoculants. Nitrogen fixation through *B. japonicum* and mobilization of P and micronutrients along with addition of leaf litter and crop residues into the soil during reproductive stage might have favoured

increased population of actinomycetes. Similar results were reported by Anon. (2007) due to application of NPK + Zn + B.

The higher population of rhizosphere micro-organisms due to dual inoculation of *A.brasilense / B. japonicum* and VAM might be due to synergistic relationship between them. The physiological plant promotion characteristics such as N_2 fixation, phosphorus mobilization, phytohormone production also play a very important role (Hoflich *et al.*, 1995). Another probable reason may be the availability of N and P which appears to have encouraged the multiplication of the organisms (Saha *et al.*, 1985). Mobilization of phosphorus and micronutrients have resulted the vigorous root growth. The increased root metabolic activity has resulted, probably due to increased availability of nutrients. The increased root growth indirectly influenced the microbial population by increasing the root area for colonization. Moreover, the population of microorganisms was higher under soybean than finger millet due to the fact that as soybean being a legume, its cultivation play an important role in the recuperation of soil health and improving sustained soil productivity (Vedram *et al.*, 2002a) which ultimately helped in improved microflora. Further, the population of micro-organisms was higher at 50 per cent flowering and declined thereafter at harvest. This could be due to the influence of plants as root exudates, that stimulated the multiplication of beneficial groups compared to control and decreased at harvest, which could be due to the fact that as plants enter into reproductive stage, photosynthates are diverted towards development of reproductive parts and release of less of root exudates.

The changes assessed in the present investigation for microbial population in response to crop rotation and application of organics, micronutrients, NPK fertilizers and microbial inoculants had a positive effect on microbial buildup and ultimately crop yields.

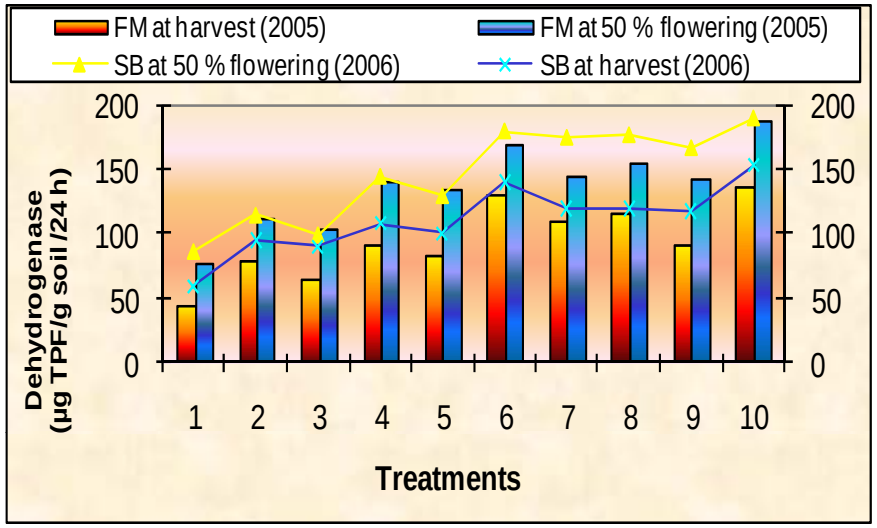
5.10.2 Effect of zinc, boron and microbial inoculants application on soil enzymatic activity at 50 per cent flowering and at harvest of the crops

Some indication of potential capacity of soil to carryout biological processes may be gained by determining the activities of different enzymes. Also the enzymes would reflect on component micro-organisms present in soil material (Kiss *et al.*, 1975).

In the present investigation, the activity of different enzymes like dehydrogenase, urease, acid and alkaline phosphatase in soil was influenced significantly due to zinc, boron and microbial inoculants application at 50 per cent flowering and at harvest of crops (Table 4.9.3 and 4.9.4).

5.10.2.1 Dehydrogenase activity in soil

Biological oxidation of organic compounds is a dehydrogenation process and these are mediated by dehydrogenases that are highly specific. Dehydrogenase activity is an index of the average activity of active microbial population (Skujins, 1976), the variation in the activities are attributed to the diversities in vegetation, cropping history, soil available nutrients, soil fauna and environmental factors (Tabatabai, 1982). In the present study, dehydrogenase activity was significantly higher with the application of NPK + FYM + $ZnSO_4$ + borax + *A.brasilense* / *B. japonicum* + VAM (T_{10}) as compared to other treatments. However, it was found on par with the application of NPK + FYM + $ZnSO_4$ + *A.brasilense* /*B. japonicum* (T_6). A least activity of dehydrogenase was observed in control (T_1). This could be due to presence of higher microbial load in NPK + FYM + $ZnSO_4$ + borax + *A.brasilense* /*B. japonicum* + VAM (T_{10}) as compared to control (Table 4.9.3 to 4.9.4 and Fig.61) Also the decrease in dehydrogenation during later stage i.e., at harvest could be due to the decreased microbial population. Similar



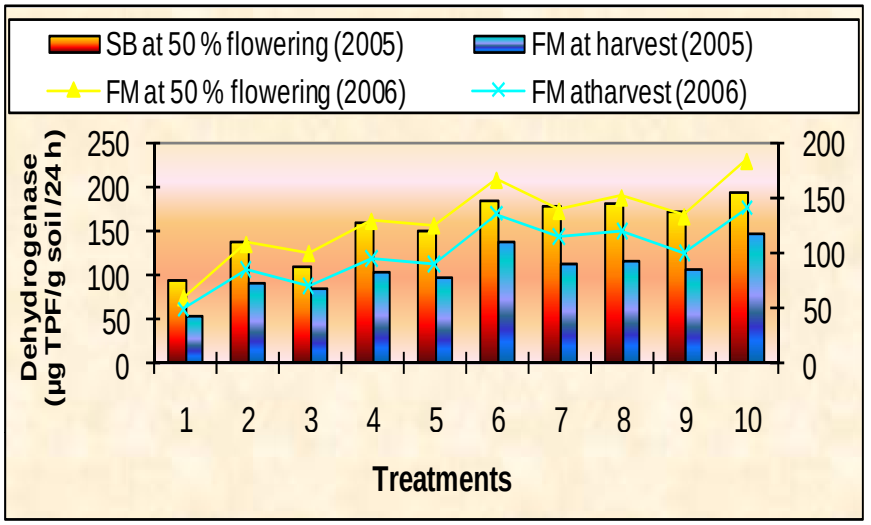
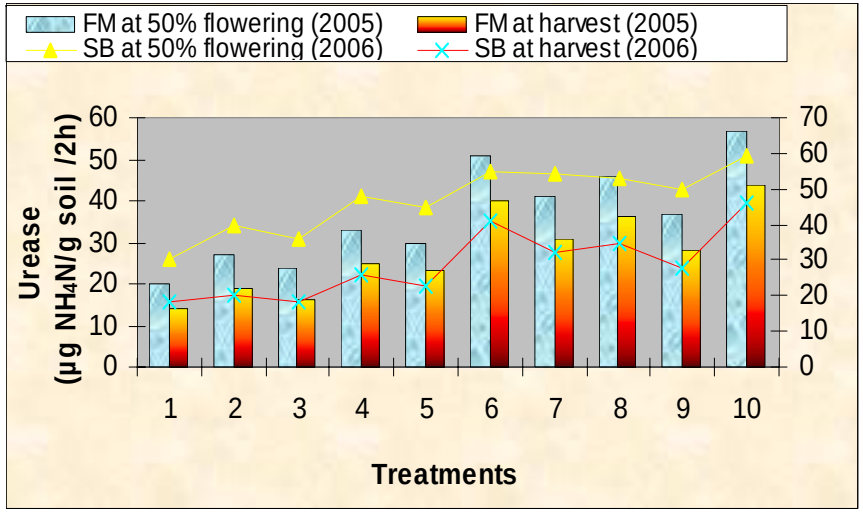


Fig. 61 : Dehydrogenase activity in soil at 50 per cent flowering and at harvest of finger millet and soybean as influenced by zinc boron and microbial inoculants nutrition in finger millet –soybean and soybean –finger millet based cropping system



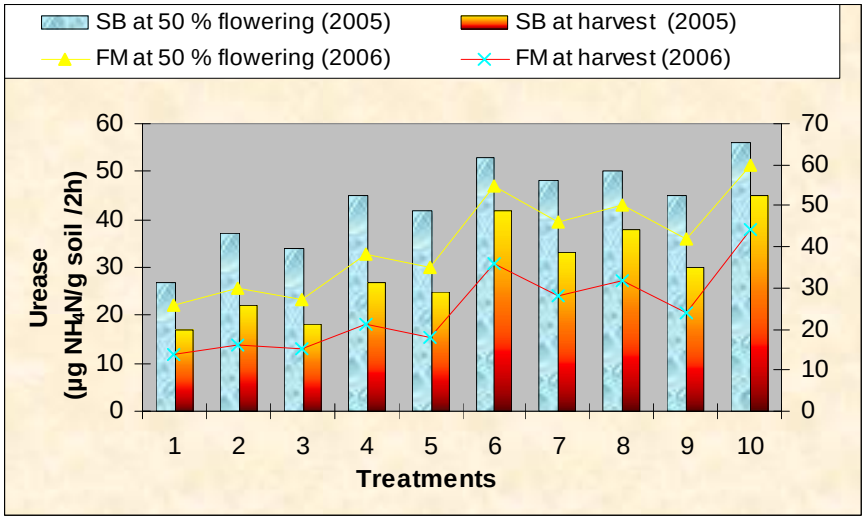


Fig. 62 : Urease activity in soil at 50 per cent flowering and at harvest of finger millet and soybean as influenced by zinc, boron and microbial inoculants nutrition in finger millet –soybean and soybean –finger millet based cropping system

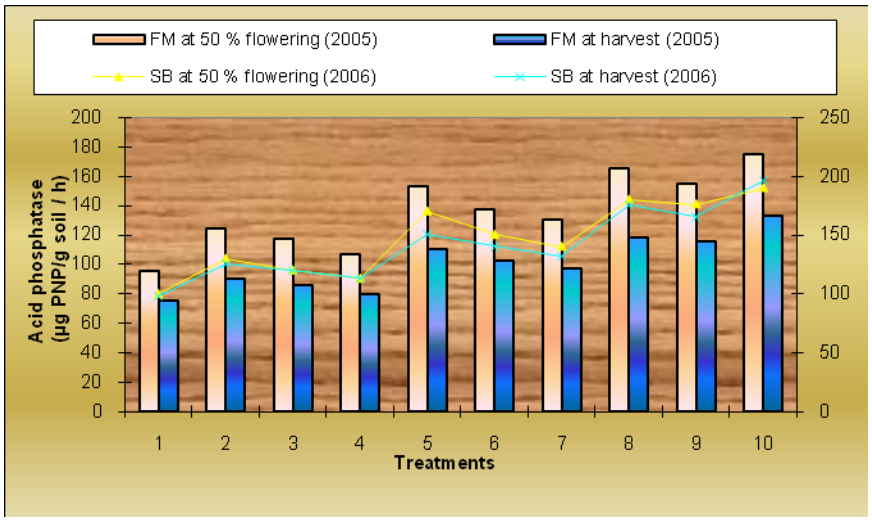
results of higher dehydrogenase activity in soil have been reported by Manna *et al.* (1996), Singaram and Kamalakumari (1995), Anon. (1997a) and Anon. (2007).

5.10.2.2 Urease activity in soil

Urease is of much importance as it hydrolyses urea. It was revealed from the data that the urease activity was found to be higher with application of NPK + FYM + $ZnSO_4$ + borax + *A.brasilense* /*B. japonicum* + VAM (T_{10}) as compared to other treatments. However, it was found on par with application of NPK + FYM + $ZnSO_4$ +*A.brasilense* / *B. japonicum* (T_6) (Table 4.9.3 to 4.9.4 and Fig. 62). This might be due to increase in the available nitrogen content of soil as influenced by biological nitrogen fixation by *B. japonicum* and associative fixation of nitrogen by *A.brasilense*. The higher activity of urease in soil was due to application of NPK + FYM + Zn + B has been reported by Anon. (2007).

5.10.2.3 Acid phosphatase activity in soil

The enzyme acid phosphatase is involved in mineralization of organic phosphorus and is important because it converts organic phosphorus into forms in which plants can utilize. The impact of organic manure, microbial inoculants and micronutrients has shown that maximum activity at 50 per cent flowering stage with a decreasing trend at harvest (Table 4.9.3 to 4.9.4 and Fig.63). This might be due to higher availability of phosphorus in soil as influenced by VAM. Meanwhile, there was also a higher microbial activity due to addition of FYM. These results are in agreement with the findings of Singaram and Kamalakumari (1995) and Anon. (2007) due to application of FYM and NPK + FYM + Zn + B respectively.



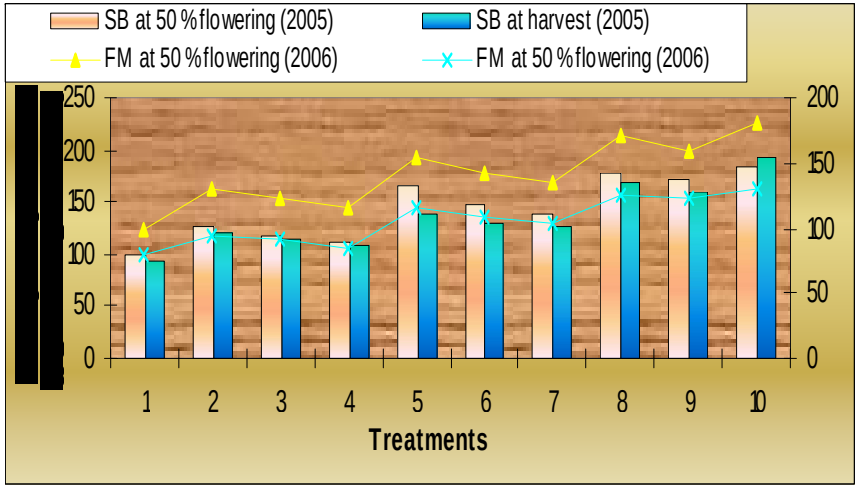
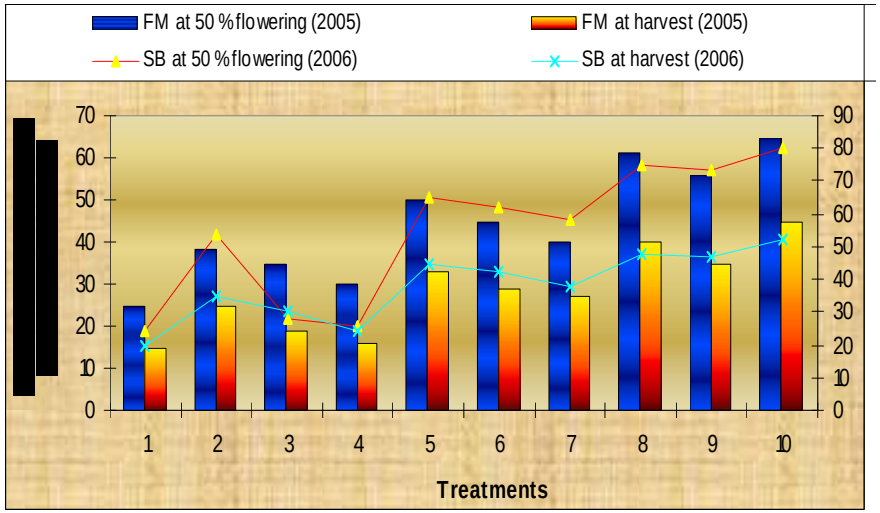


Fig. 63 : Acid phosphatase activity in soil at 50 per cent flowering and at harvest of finger millet and soybean as influenced by zinc, boron and microbial inoculants nutrition in finger millet –soybean and soybean –finger millet based cropping system



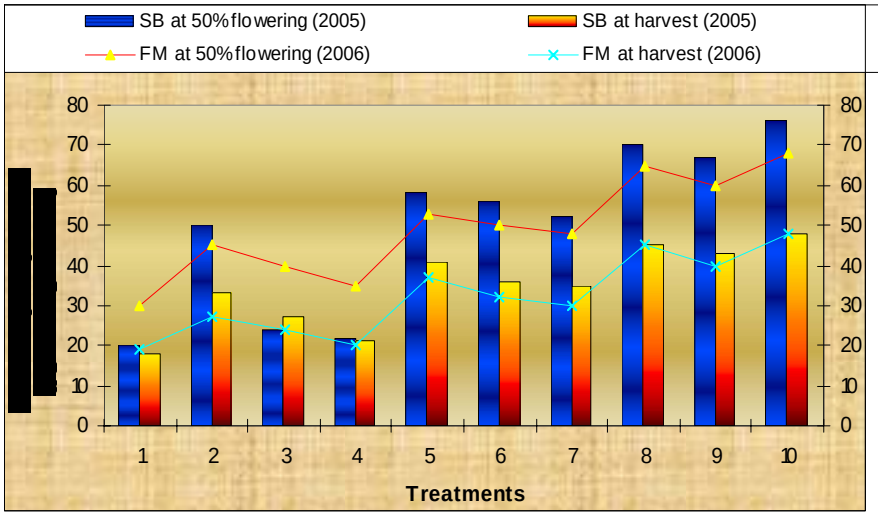


Fig. 64 : Alkaline phosphatase activity in soil at 50 per cent flowering and at harvest of finger millet and soybean as influenced by zinc boron and microbial inoculants nutrition in finger millet –soybean and soybean –finger millet based cropping system

5.10.2.4 Alkaline phosphatase activity in soil

Application of NPK + FYM + $ZnSO_4$ + borax + *A.brasilense* /*B. japonicum* + VAM (T_{10}) recorded significantly higher alkaline phosphatase activity in both the crops as compared to control (Table 4.9.3 to 4.9.4 and Fig. 64). This might be due to the higher activity of microbial population. The major contributors of soil enzyme pool are mainly microorganisms. The increase in alkaline phosphatase activity might also due to higher availability of organic phosphorus from FYM and mobilizing activity of VAM. Chhonkar and Tarafdar (1984) observed significant positive correlation between alkaline phosphatase activity and organic phosphorus content of soil.

5.11 EFFECT OF ZINC, BORON AND MICROBIAL INOCULANTS APPLICATION ON AVAILABILITY OF NUTRIENTS IN SOIL IN FINGER MILLET-SOYBEAN AND SOYBEAN-FINGER MILLET BASED CROPPING SYSTEM

5.11.1 Available nitrogen in the soil

A significant difference in available N status of soil was observed due to zinc, boron and microbial inoculants application (Table 4.10.1 and Fig. 65) in both cropping systems. Significantly higher available nitrogen in soil was recorded in control (T_1: NPK + FYM) after harvest of finger millet (225.55 kg/ha) and soybean (199.46 kg/ha). Similar trend was noticed in soybean-finger millet cropping system. This might be owing to lower uptake of nitrogen in NPK + FYM. Lower available nitrogen status was registered in NPK + FYM + $ZnSO_4$ + borax + *A.brasilense* /*B. japonicum* + VAM (T_{10}) after harvest of finger millet and soybean in both the cropping systems. This might be due to higher uptake of nitrogen as influenced by interactive behaviour of Zn and B; VAM and *A.brasilense* / *B. japonicum* which increased the mobilization of atmospheric nitrogen in the soil along with external supply of nitrogen through inorganic and

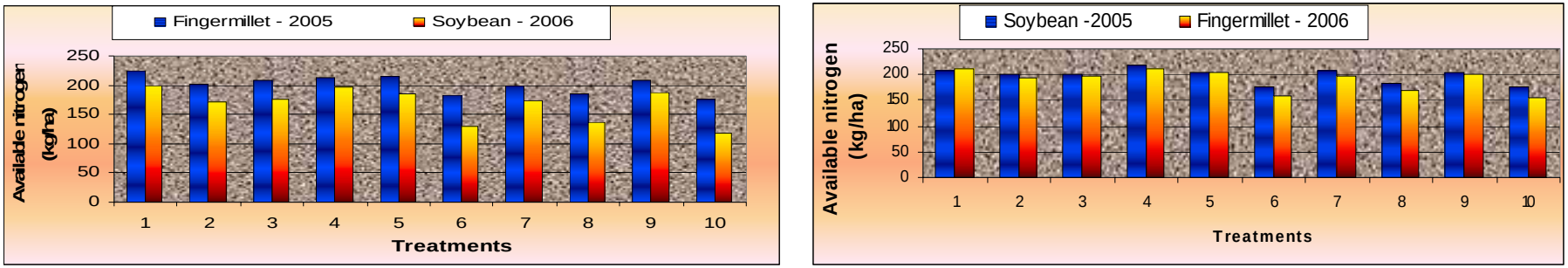


Fig. 65 : Available nitrogen status in soil after harvest of finger millet and soybean as influenced by zinc, boron and microbial inoculants nutrition in finger millet –soybean and soybean –finger millet based cropping system

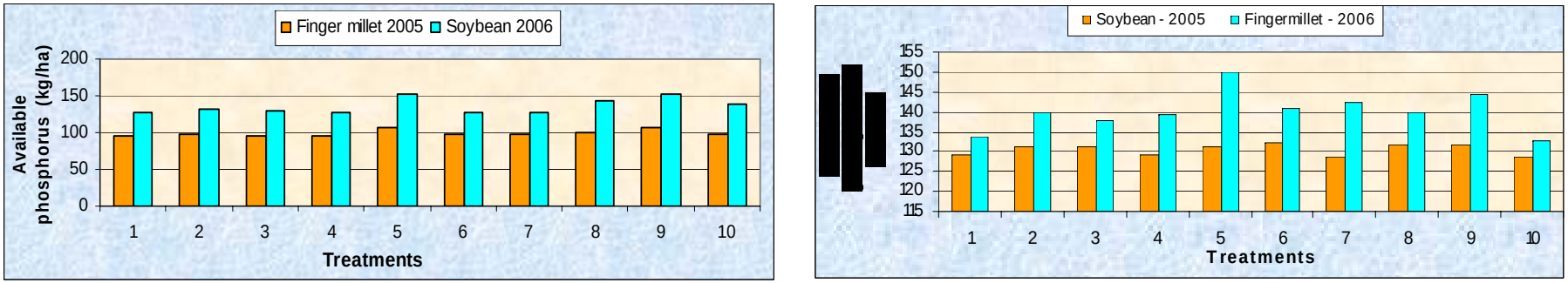


Fig. 66 : Available phosphorus status in soil after harvest of finger millet and soybean as influenced by zinc, boron and microbial inoculants nutrition in finger millet –soybean and soybean –finger millet based cropping system

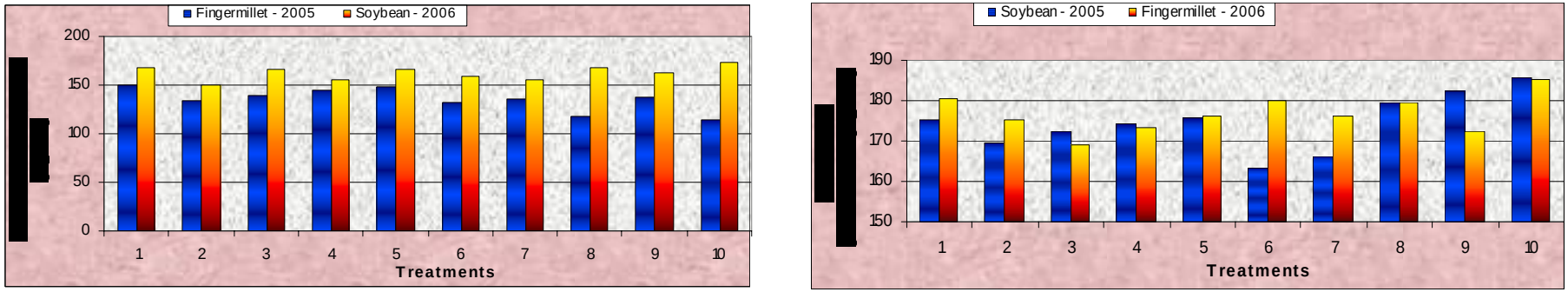


Fig. 67: Available potassium status in soil after harvest of finger millet and soybean as influenced by zinc, boron and microbial inoculants nutrition in finger millet –soybean and soybean –finger millet based cropping system

organic sources. Further, increased microbial activity in soil was exhibited because of conjunctive use of FYM along with micronutrients and dual inoculation of inoculants also contributed nitrogen to the available nitrogen pool which ultimately reflected in the grain/seed and straw/haulm yields. The results are in accordance with the studies of Gajanana *et al.* (2000) in finger millet and Singh (1991) in soybean who reported increased available N status due to application of NPK and FYM.

5.11.2 Available phosphorus in the soil

The available phosphorus in the soil after harvest of finger millet and soybean in soybean-finger millet based cropping system and after harvest of finger millet in finger millet-soybean based cropping system did not differ significantly due to different treatments. However, significantly higher available phosphorus status in the soil after harvest of soybean in finger millet-soybean cropping system was recorded with application of NPK + FYM + borax + VAM (T_9) followed by NPK + FYM + $ZnSO_4$ + VAM (T_8), NPK + FYM + $ZnSO_4$ + borax + *B. japonicum* + VAM (T_{10})(Table 4.10.1 and Fig. 66). The higher available phosphorus status in the soil might be due to mineralization of organic and inorganic reserves by the mobilizing action of VAM (Bagyaraj, 2004).

5.11.3 Available potassium in the soil

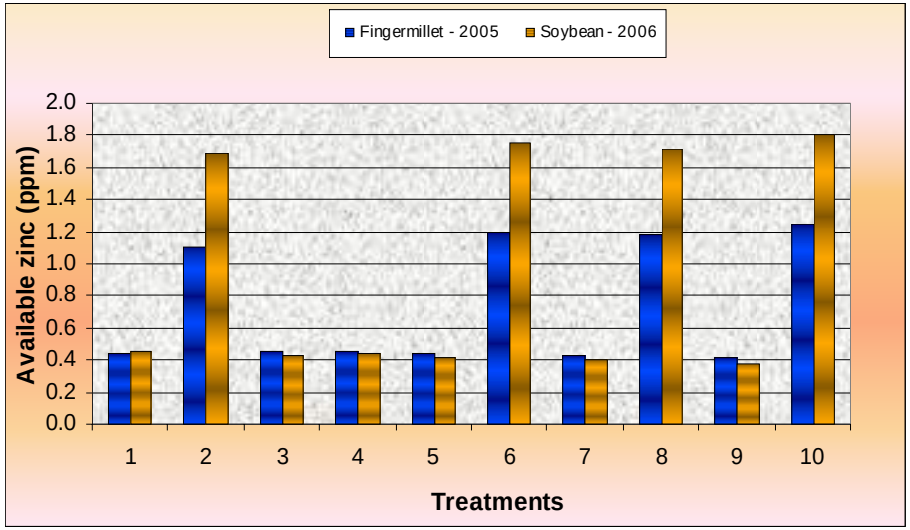
The available potassium status in the soil after harvest of crops did not differ significantly due to different treatments in both the cropping systems except after harvest of finger millet in finger millet-soybean cropping system (Table 4.10.1 and Fig. 67). Significantly higher available potassium in soil after harvest of finger millet was recorded in control (T_1). This might be due to less uptake of potassium in control.

5.11.4 Available zinc in soil

Available zinc status in soil after the harvest of crops differed significantly due to micronutrients and microbial inoculants application (Table 4.10.2 and Fig. 68). Significantly higher available zinc status in soil after harvest of crops was noticed with application of NPK + FYM + $ZnSO_4$ + borax + *A.brasilense* /*B. japonicum* + VAM (T_{10}) followed by NPK + FYM + $ZnSO_4$ + VAM (T_8), NPK + FYM + $ZnSO_4$ + *A.brasilense* (T_6) and NPK + FYM + $ZnSO_4$ (T_2). This might be due to the fact that addition of FYM and microbial inoculants resulted in enhanced activity of microbes in the soil. These microbes in consequence released the complex organic substances (chelating agents) which could have prevented micronutrient-zinc from precipitation, fixation oxidation and leaching. Further, addition of FYM also contribute zinc to the soil pool (Bellakki and Badanur,1997) Above results are in agreement with the findings of Mohan Kumar (2002) in soybean and Sumangala (2003) in groundnut who reported increase in available zinc status due to application of $ZnSO_4$ along with RDF, B, M_0 and inoculation of Phosphate solubilising bacteria and VAM.

5.11.5 Available boron in soil

Available boron content in post harvest soil was higher with application of NPK + FYM + $ZnSO_4$ + borax + *A.brasilense* / *B. japonicum* + VAM (T_{10}) as compared to control (T_1) in both the cropping systems. However, it was found on application of NPK + FYM + borax+ VAM (T_9), NPK + FYM + borax + *A.brasilense* / *B. japonicum* (T_7) and NPK + FYM + borax (T_3) (Table 4.10.2 and Fig. 69). This might be due to the beneficial effect of FYM which was applied along with boron and microbial inoculants. Application of FYM in conjunction with boron forms boron–diol complexes with the breakdown products of FYM. On a weight basis, FYM retains more boron than mineral soil constituents (Sakal *et al.*, 1999). Further, evidence suggests that microorganisms secrete



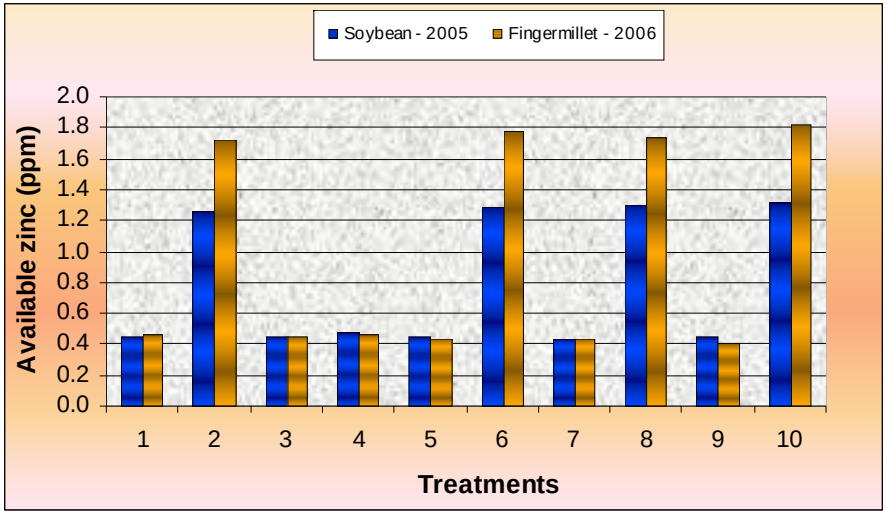
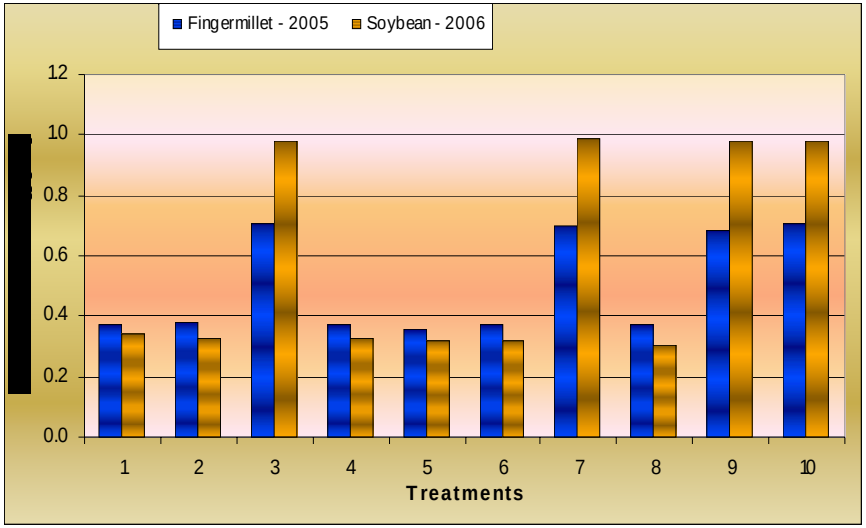


Fig. 68: Available zinc status in soil after harvest of finger millet and soybean as influenced by zinc, boron and microbial inoculants nutrition in finger millet –soybean and soybean –finger millet based cropping system



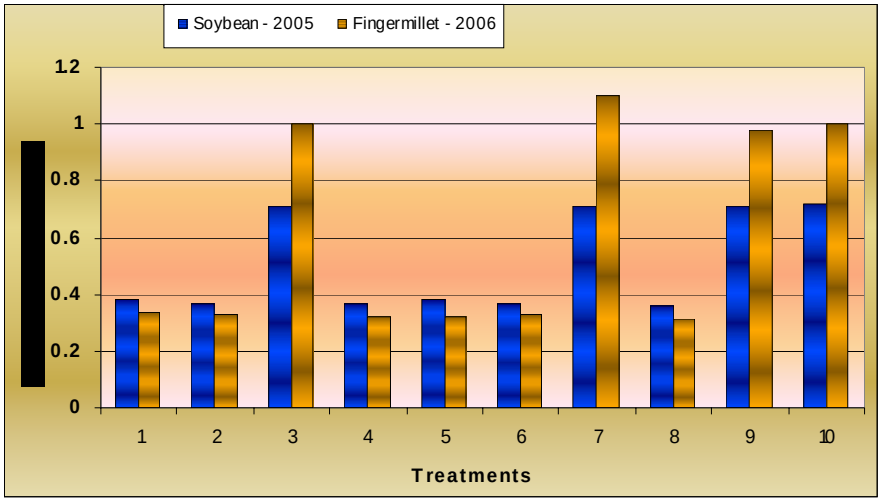


Fig. 69: Available boron status in soil after harvest of finger millet and soybean as influenced by zinc, boron and microbial inoculants nutrition in finger millet –soybean and soybean –finger millet based cropping system

phytohormones and build up organic status of soil, leading to increase in the availability of nutrients (Mishra and Patjoshi, 1996). These findings are in agreement with those of Mohan Kumar (2002) and Sumangala (2003).

5.12 Nutrients balance in finger millet-soybean and soybean-finger millet based cropping systems as influenced by zinc, boron and microbial inoculants application

The knowledge about the balance amount of soil nutrients is necessary for evaluating the impact of modern system of agriculture on sustained crop production.

5.12.1 Nitrogen balance

Balance sheet of nitrogen in finger millet-soybean based cropping system revealed that, there was a negative balance of nitrogen noticed after harvest of finger millet, while a positive balance was observed after the harvest of soybean (Table 4.11.1). The range of nitrogen loss was from 35.53 to 40.95 kg N per ha after harvest of finger millet, whereas a net gain of nitrogen after harvest of soybean from 20.96 to 50 kg N per ha was noticed in different treatments. The negative balance after harvest of finger millet might be ascribed to the fact that the preceding crop before sowing of finger millet was finger millet. The positive balance after soybean is because, soybean being a leguminous crop fixes higher atmospheric nitrogen besides leaf fall contributing significant N addition (Table 4.11.1).

In soybean-finger millet based cropping system, net gain of nitrogen after harvest of soybean (35.69 to 66.23 kg/ha) and net loss of nitrogen after harvest of finger millet (5.20 to 26.30 kg/ha) was observed (Table 4.11.2). But the net loss of nitrogen was less after the harvest of finger millet in soybean-finger millet based cropping system. Application

of NPK + FYM + $ZnSO_4$ + borax + *A.brasilense*/*B. japonicum* + VAM recorded higher gain of nitrogen (66.23 kg/ha) after harvest of soybean and less loss of nitrogen after harvest of finger millet (5.20 kg/ha). This trend confirmed that nutrient status of soil is favorably affected by cultivation of legume crops in the cropping system. Similar improvement in N status of soil after legume-cereal crop rotation was reported by Shrivastava *et al.* (2003). In line with the present study, Pawar and Jadhav (1995) also reported that the legumes such as groundnut, greengram and soybean provided additional N to sorghum through fixation and mineralization of their biomass.

5.12.2 Phosphorus balance

The phosphorus balance in soil in both the cropping systems are presented in Table 4.11.3 to 4.11.4. In general, there was net loss of phosphorus was observed in all the treatments irrespective of the cropping systems. Lower negative balance of phosphorus was noticed with the application of NPK + FYM + $ZnSO_4$ + borax + *A.brasilense* / *B. japonicum* + VAM (T_{10}) in both the cropping systems. This might be due to higher uptake of phosphorus leading to increased plant growth and yield. Higher negative balance of phosphorus was noticed in control. This may be due to the fixation of available phosphorus in soils ultimately resulted in net loss of available phosphorus. The results are in accordance with the studies of Thimma Reddy (1987) in finger millet, Mohan Kumar (2002) and Sumangala (2003) in soybean and groundnut respectively who observed negative balance of phosphorus due to application of RDF.

Further, it is interesting to note that the available phosphorus status of the soil improved over the initial status in all the treatments with a higher values in the treatments where the recommended NPK fertilizers were applied along

with FYM, micronutrients and microbial inoculants. This improvement over the initial status with application of *A.brasilense* / *B. japonicum* and VAM might be attributed to the solubilization, mobilization and mineralization of phosphorus from applied sources with slow and steady availability and thereby sustaining even after harvest of crops. The finding confirms those of Duraisamy and Mani (2000) and Ranjit Singh and Rai (2004).

5.12.3 Potassium balance in soil

On perusal of the data on potassium balance it reveals that there was a net loss of potassium observed after harvest of finger millet in finger millet-soybean cropping system. The higher negative balance in potassium was probably due to high potassium demand by finger millet crop for vegetative growth and grain formation. Higher depletion of soil potassium under cereal based systems has been recorded by Prasad *et al.* (2000) (Table 4.11.5 and 4.11.6). However, potassium balance was positive after the harvest of soybean in both the cropping systems. This might be due to the fact that the fixed potassium might have been made available by the soybean in the sequences and enriched the soil, resulting in a positive balance of potassium observed in soybean-finger millet cropping system, which is unique in nature.

Contrary to earlier net loss of potassium after harvest of finger millet, there was a positive balance of potassium observed in soybean-finger millet based cropping system.

The positive balance of potassium after the harvest of finger millet in soybean-finger millet cropping system might be ascribed as fixed potassium might have been made available by soybean in the sequence and enriched the soil, resulting in a positive balance.

Further, it is important to state that the treatment receiving combined application of inorganic fertilizers, FYM, microbial inoculants along with micronutrients registered higher available potassium in the soil over the initial status in soybean-finger millet cropping system. This might be due to the favourable effect of soybean. Further, the evidence suggests that the roots of leguminous crops secret organic acids and hydroxyanion (Ae *et al.*, 1991). These root exudates not only enrich organic matter but also enhance the available potassium in soils by reducing its fixation. Similar improvement in potassium status was observed under groundnut-sorghum sequence (Pawar and Jadhav, 1995).

5.12.4 Zinc balance in soil

Components of balance sheet of zinc (Table 4.11.7 and 4.11.8) revealed that, a negative balance of zinc was noticed in finger millet-soybean and soybean-finger millet based cropping systems. The higher negative balance of zinc was observed with the application of NPK + FYM + $ZnSO_4$ + borax + *A.brasilense* / *B. japonicum* + VAM (T_{10}) in both the cropping systems. This might be because of higher crop growth and removal of higher amount of zinc. Both loss and availability of zinc was more, when it was applied through $ZnSO_4$. This could be due to the fact that in addition to external application of zinc as $ZnSO_4$, FYM has also supplemented zinc to the tune of 22 ppm. Besides, the FYM mobilizes the native zinc through chelation and complex formation with organic ligands. Since the utilization of fertilizer zinc by the crops seldom exceeds 2 per cent, most of the added zinc remains unutilized which resulted in maximum buildup of available zinc in the soil. The results are in agreement with Jha and Chandel (1987); Singhal and Rattan (1999) who reported significant increase in DTPA extractable zinc left at harvest of soybean with increased zinc rates.

5.12.5 Boron balance in soil

On perusal of data presented in Table 4.11.9 and 4.11.10 indicated that there was a net loss of boron noticed in both the cropping systems. The net loss of boron was more in the treatments where borax was added externally. However, the available boron status of the soil improved over the initial status in the treatments where boron was applied through borax in both the cropping systems. This might be due to the beneficial effect of FYM when applied in conjunction with boron which resulted in formation of boron- diol complexes with the breakdown products of FYM and has been suggested as the possible mechanism for boron retention. Association of boron with organic matter prevents its leaching (Sakal *et al.*, 1999). Lower negative balance of boron was observed with the application of NPK + FYM which may be attributed to the poor plant growth and yield which has resulted in lower uptake of boron. Similar results have been reported by Mohan Kumar (2002) and Sumangala (2003) in soybean and groundnut, respectively.

The results on balance of zinc and boron status in soil largely indicate that the crops fertilized with zinc and boron utilizes only fraction of zinc and boron which implies that single time application will leave residual effect for succeeding crops and regular applications to each crop may build up their status up to harmful limits since the range between deficiency and toxicity limits of zinc and boron is quite narrow for most of the field crops. Therefore, the frequency of zinc and boron application in cropping systems should be decided after careful appraisal of deficiency.

5.13 Influence of crop rotation system on yield, nutrient balance and economics of finger millet and soybean cultivation

The adoption of improved production technology and change over to appropriate cropping system paved the way to shun away with age-old yield barrier, providing new dimensions to agricultural production. The

nutrient input needed to be increased several times with the introduction of high yielding, nutrient responsive varieties. This led to rapid turnover of nutrients in soil-plant systems. The crops grown in a particular sequence need differential requirement of nutrients than those growing individually (Joshi and Billore, 2004). Application of nutrients in excess results in their reduced use efficiency (Huggins *et al.*, 1989). This is more accountable in sequential cropping systems especially when a cereal crop is preceded by a legume (Prasad *et al.*, 2000). There are sufficient evidences to indicate that legumes such as soybean by virtue of their ability to fix atmospheric nitrogen leave enriched soil with nitrogen when incorporated in a particular cropping sequence and such nitrogen may be utilized by succeeding non-legume crops (Saxena and Chandel, 1986).

However, in the present investigation because of lower amount of rainfall received during 2006 the effect of legume (soybean) on yield of finger millet was not realized.

Nevertheless, there was appreciable effect of preceding legume (soybean) on nutrients balance as observed before transplanting of finger millet especially nitrogen and potassium. There was a net gain of nitrogen after the harvest of soybean in both the cropping systems. The positive balance of N might be attributed to the addition of large quantity of crop residue such as roots, stubbles, leaves, nodules and rhizobia rich in nitrogen by soybean and its higher biomass compared to finger millet. The net loss of nitrogen was less after the harvest of finger millet in soybean-finger millet based cropping system (Table 4.5.1, 4.5.2, 4.11.1 and 4.11.2). The possible reason for this may be due to the fact that the root portion of soybean left after harvesting is having a narrow C : N ratio which serves as a source of proliferation for microbes, which helps in greater mineralization of nitrogen in the soil system. Similar results of

positive balance of nitrogen was reported by Ghosh and Singh (1994) in summer legumes – maize sequence.

There was a negative balance of phosphorus noticed in both the cropping systems. However, the phosphorus status of soil improved over its initial status with a higher magnitude in soybean-finger millet cropping system (Table 4.5.3, 4.5.4, 4.11.3 and 4.11.4). This may be attributed to increased availability of soil phosphorus owing to decomposition of additional organic matter added through soybean root residues and leaf fall besides root exudates might have contributed to the solubilization of native and applied P_2O_5. The root system of legume has the capacity to solubilize soil phosphorus through excretion of amino acids and encourage the growth and multiplication of microbes. This might have been possible owing to enhanced supply of readily available food and energy to microbes. Similar results were reported by Subba Rao (1986).

On perusal of data it indicated that there was a positive balance of potassium noticed in both the cropping systems except after the harvest of finger millet in finger millet-soybean cropping system owing to high potassium demand by finger millet (Table 4.5.5, 4.5.6, 4.11.5 and 4.11.6). The positive balance of potassium was due to the fixed potassium might have been made available by the legumes (soybean) which was included in rotation and enriched the soil. The findings confirms those of Pawar and Jadhav (1995).

The balance sheet of micronutrients indicates that a negative balance of zinc and boron was noticed in both the cropping systems. However, the available zinc and boron were higher after the harvest of finger millet in soybean-finger millet cropping system as compared to finger millet-soybean cropping system (Table 4.5.7 to 4.5.10 and 4.11.7 to 4.11.10). This might be due to legume effect.

Maximum net returns (Table 4.6.1, 4.6.2, 4.12.1 and 4.12.2) was obtained in soybean-finger millet cropping system as compared to finger millet-soybean based cropping system.

Similar trend in grain yield, nutrient balance and economics was also observed in experiment No. 1. The integrated use of chemical fertilizers with micronutrients was more pronounced in the treatments where farm yard manure was applied. As such, organic manure besides supplying nutrients to the first crop often leaves substantial residual effect on succeeding crops not only on account of its own effect but also by helping to retain nutrients added.

On the basis of the study, it may be affirmed that adopting legume based crop rotations along with integrated nutrient supply involving chemical fertilizers, organic manures microbial inoculants along with micronutrients increases crop productivity by improving soil nutrients pool, economics and can prove a boon in fighting for food security.

5.14 Economics of finger millet-soybean and soybean-finger millet based cropping system as influenced by zinc, boron and microbial inoculants application

Economics is the main parameter which finally decides the adoption levels at farming situations of any new introduced technology by the farmers. It should be technically and economically viable. Therefore, the economic analysis of the results is very important.

Assessment of treatments in terms of economic traits in finger millet-soybean based cropping system revealed that maximum net returns was realized due to the application of NPK + FYM + $ZnSO_4$ + *A.brasilense* / *B. japonicum* + VAM (T_6: Rs. 50,753/ha) followed by application of NPK + FYM + $ZnSO_4$ + borax + *A.brasilense* / *B. japonicum* + VAM (T_{10} : Rs.50,637/ha). This might be due to higher economic yields

obtained in these treatments. Lower net returns was recorded in control (T_1 : Rs. 28,695/ha) (Table 4.12.1and Fig. 70). The B : C ratio was found to be higher with application of NPK + FYM + $ZnSO_4$ + *A.brasilense* / *B. japonicum* (T_6 : 2.13) followed by application of NPK + FYM + $ZnSO_4$ + VAM (T_8 : 1.95). The control treatment recorded lower B : C ratio (1 : 30). These differences may be due to differences in yield of the crops and cost of cultivation of respective treatments.

In soybean-finger millet cropping system, application of NPK + FYM + $ZnSO_4$ + *A.brasilense* / *B. japonicum* + VAM (T_6) recorded maximum net returns (Rs. 53,629/ha) followed by NPK + FYM + $ZnSO_4$ + borax + *B. japonicum* / *A.brasilense* + VAM (T_{10} : Rs. 53,585/ha) (Table 4.12.2 and Fig. 71). This may be attributed to higher yields of the crops obtained in these treatments, whereas lower net returns was recorded in control (T_1 : NPK + FYM) (Rs. 33,949/ha) due to lower yields. The B : C ratio was found to be higher with application of NPK + FYM + $ZnSO_4$ + *B. japonicum / A. brasilense* (T_6 : 2.25) followed by NPK + FYM + $ZnSO_4$ + VAM (T_8 : 2.06) as compared to NPK + FYM + $ZnSO_4$ + borax + *A.brasilense / B. japonicum* + VAM (T_{10}: 2.05). This might be due to increased cost incurred on application of different nutrients. The above results are in accordance with the studies of Mohan Kumar (2002) who reported higher net returns and B : C ratio due to application of NPK + S + Zn + B + Mo along with dual inoculation of *B. japonicum* and PSB in soybean.

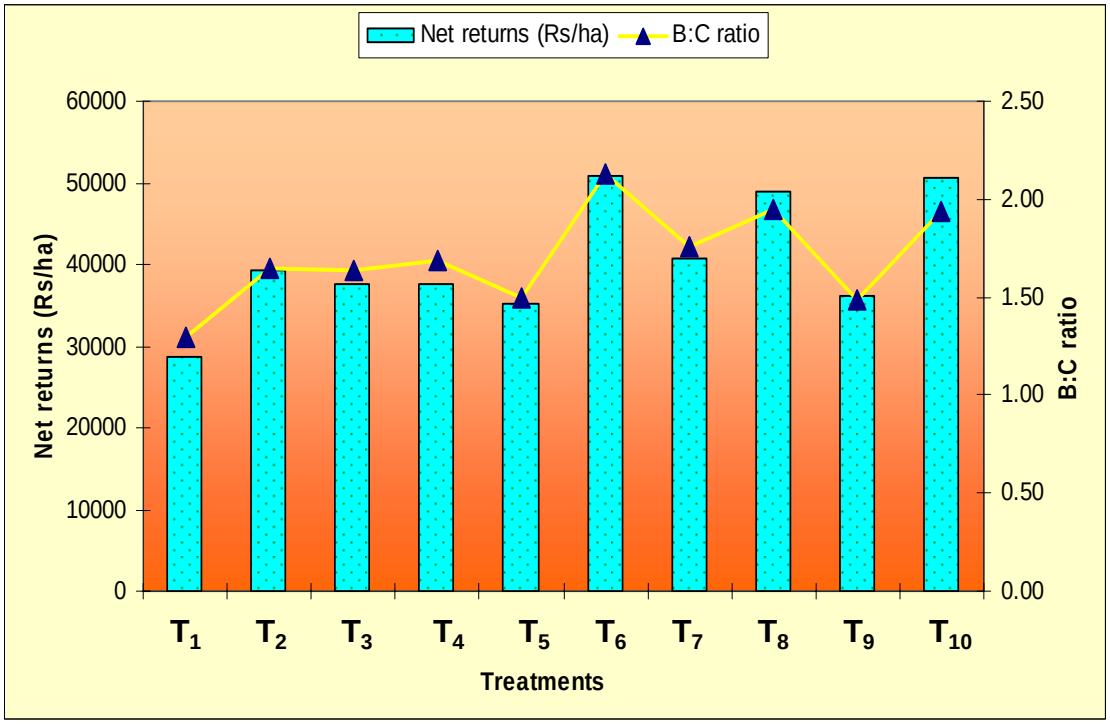


Fig.70 : Net returns and B:C ratio of finger millet –soybean based cropping system as influenced by application of zinc, boron and microbial inoculants

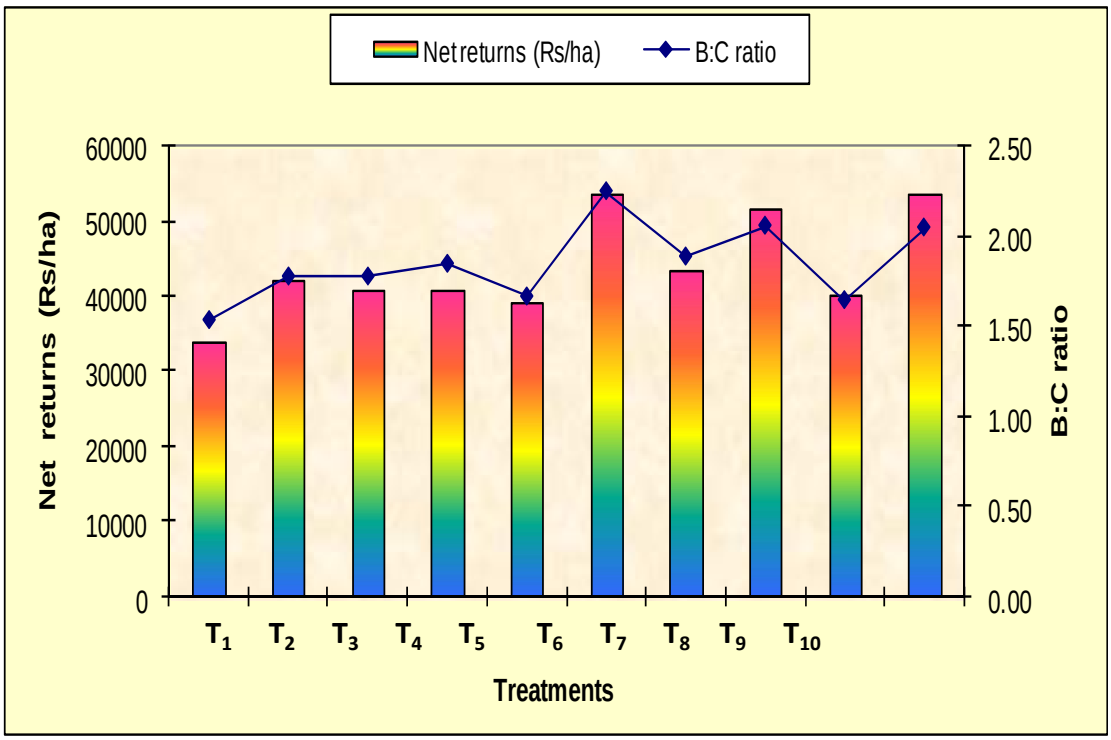


Fig.71 : Net returns and B:C ratio of soybean – finger millet based cropping system as influenced by application of zinc, boron and microbial inoculants

5.15 Practical utility of the results

Any genuine innovation is rendered useless, if it has no practical utility. The adoption of technology by farmers being the main objective, a technology can be more easily adopted, if the farming community is convinced about its benefits. The results obtained in the present investigation revealed the following practical utilities in promoting the use of micronutrients and microbial inoculants in improving the performance of finger millet-soybean rotation.

- The results on grain/seed and biomass productivity revealed that the application of micronutrients (Zn and B) under the umbrella of recommended dose of major nutrients with FYM increased yields of both the crops over their applications in the absence of FYM.

- Conjunctive use of recommended dose of NPK, FYM along with Zn and B with dual inoculation of *A.brasilense/B. japonicum* and VAM is best for getting higher grain/seed yield as compared to other treatments.

- Nutritionally better quality of finger millet and soybean seeds could be obtained with conjunctive use of micronutrients, microbial inoculants along with recommended dose of fertilizers and FYM.

- Under rainfed condition, soybean-finger millet rotation is an effective cropping system as compared to finger millet-soybean in order to improve the soil fertility and crop productivity.

- Application of NPK (50:40:25 kg/ha for finger millet and 25:60:25 kg/ha for soybean + FYM (7.5 t/ha for finger millet and 6.25 t/ha for soybean) + $ZnSO_4$ (12.5 kg/ha) + *A. brasilense* (1 kg in 10 litres of water) / *B. japonicum* (375 g/ha) + VAM (10 kg/ha) is best treatment for getting maximum net returns and B:C ratio.

5.16 Future research frontiers

- Developing appropriate integrated micronutrient supply and management systems, using organic, microbial inoculants and non-conventional industrial and mine refuse *etc.,* with adequate care for improving nutrient use efficiency, considering potential availability of these materials in local and regional perspective.

- Role of micronutrients in improving food quality vis-à-vis human health.

- Developing models for predicting crop response and rate of depletion of micronutrient reserves in soils.

- Studies on increasing micronutrient use efficiency with innovative technologies such as enriching or fortifying with available organic manures.

- Co-ordinating micronutrient research by agronomists with breeders, soil scientists, physiologists, biotechnologists, pathologists and microbiologists besides animal and human nutrition scientists is the need of the hour.

SUMMARY

VI. SUMMARY

Agronomic investigations on "Relative response of finger millet-soybean rotation to application of zinc, boron and microbial inoculants" was carried out at All India Co-ordinated Research Project for Dryland Agriculture Centre, UAS, GKVK, Bangalore during *kharif* seasons of 2005 and 2006, which comprised of two field experiments. A brief summary of the findings is presented below:

Experiment-I (a): Response of finger millet-soybean rotation to zinc and boron nutrition

In the present investigation, experiment was laid out in a randomized complete block design (RCBD) with three replications. In the present study, nine treatments using recommended dose of fertilizer (50 : 40 : 25 kg N, P_2O_5 and K_2O/ha, respectively), $ZnSO_4$ @ 12.5 kg per ha, borax @ 10 kg per ha along with or without farm yard manure @ 7.5 t per ha were tried. The experiment consisted of nine treatments *viz.,* control, NPK only, NPK + FYM, NPK + $ZnSO_4$, NPK + borax, NPK + $ZnSO_4$ + borax, NPK + FYM + $ZnSO_4$, NPK + FYM + $ZnSO_4$ + borax. The crops were rotated between plots in the second year of experimentation. During the course of investigation, different growth and yield parameters were recorded at different stages of crop growth. The data on seed quality parameters *viz.,* protein and oil content in seeds of soybean, germination and vigour index of seeds of both crops were recorded. Nutrient uptake (N, P, K, Zn and B) by crop and soil nutrient status (N, P, K, Zn and B) after harvest of the crop and nutrient balance was recorded. The population of microbes (bacteria, fungi and actinomycetes) and activity of enzymes (dehydrogenase, urease, acid and alkaline phosphatase) were observed at 50 per cent flowering and at harvest of both the crops. Economic analysis was carried out to know the profitability of cropping systems under different nutrient management systems. Correlation and

regression study was undertaken to measure the mutual relationship between characters.

Finger millet

- Application of NPK + FYM + $ZnSO_4$ + borax recorded significantly higher growth parameters *viz.,* plant height, number of tillers per hill, number of green leaves per hill, leaf area, leaf area index, leaf area duration and dry matter accumulation and its distribution among plant parts at different stages of crop growth.

- The yield parameters *viz.,* number of productive tillers per hill (5.13), number of fingers per ear head (6.95), ear head length (8.76 cm), finger length (6.71 cm), grain yield per plant (10.84 g), 1000-grain weight (3.72 g) and threshing per cent (81.04) were also higher with the application of NPK + FYM + $ZnSO_4$ + borax as compared to control.

- Application of NPK + FYM + $ZnSO_4$ + borax recorded significantly higher grain yield (3613 kg/ha) and straw yield (5566 kg/ha) as compared to control. The increase in grain yield due to application of NPK + FYM + $ZnSO_4$ + borax was 315 per cent over control.

- The seed quality parameters of finger millet were significantly influenced by micronutrients application. Significantly higher germination (98%), dry weight of shoot and root (4.9 mg) and seed vigour index (478) was recorded with conjunctive use of zinc sulphate and borax along with recommended NPK and FYM as compared to control.

- Application of NPK + FYM + $ZnSO_4$ + borax recorded significantly higher uptake of nitrogen (90.70 kg/ha), phosphorus (17.40 kg/ha),

potassium (72.63 kg/ha), zinc (137.38 g/ha) and boron (73.89 g/ha) as compared to control.

- The grain yield was significantly and positively correlated with growth parameters such as TDM at harvest (r = 0.920), leaf area at harvest (r = 0.857) and number of tillers at harvest (r = 0.842), yield parameters such as number of productive tillers at harvest (r = 0.901), number of fingers per earhead (r = 0.789), earhead length (r = 0.820), finger length (r = 0.845), grain yield per plant (r = 0.925), test weight (r = 0.870), threshing per cent (r = 0.668) and total uptake of N, P_2O_5, K_2O, Zn and B nutrients (r = 0.930, 0.919, 0.933, 0.913 and 0.893). The variation in the grain yield due to growth, yield parameters and total uptake of nutrients was about 93 per cent as explained by the linear regression equation.

Soybean

The growth parameters of soybean *viz.,* plant height, number of green leaves per plant, leaf area, LAI, LAD, dry matter accumulation and its distribution in different plant parts, number of branches, nodule number and nodule dry weight were significantly higher with application of NPK + FYM + $ZnSO_4$ + borax.

- The yield contributing parameters of soybean like number of pods per plant (23.65), number of seeds per plant (2.85), pod length (4.75 cm), pod yield (10.83 g/plant), seed yield (5.22 g/plant) and test weight (14.35 g) were significantly higher with application of NPK + FYM + $ZnSO_4$ + borax and was on par with application of NPK + FYM + $ZnSO_4$.

- Seed and haulm yield was significantly higher with the application of NPK + FYM + $ZnSO_4$ + borax (1936 and 3152 kg/ha, respectively) as compared to control. However, it was found on par with the

application of NPK + FYM + $ZnSO_4$ and NPK + FYM + borax. The magnitude of increase in the yield due to application of NPK + FYM + $ZnSO_4$ + borax, NPK + FYM + $ZnSO_4$ and NPK + FYM + borax was 131.03, 127.68 and 123.75 per cent over control, respectively.

- Seed quality parameters of soybean *viz.,* protein yield (792.95 kg/ha), oil yield (362.04 kg/ha), germination (97.00%) and vigour index (2397) were significantly higher with the application of NPK + FYM + $ZnSO_4$ + borax as compared to control.

- Significantly higher uptake of nitrogen, phosphorus, potassium, zinc and boron were recorded with the application of NPK + FYM + $ZnSO_4$ + borax as compared to control.

- Significant and positive correlation was observed between growth, yield parameters and uptake of nutrients with grain yield.

- Application of NPK + FYM + $ZnSO_4$ + borax recorded significantly higher population of bacteria, fungi and actinomycetes at 50 per cent flowering and at harvest of crops in both the cropping systems. Similarly the activity of dehydrogenase, urease activity, acid and alkaline phosphatase enzymes were also higher with the application of NPK + FYM + $ZnSO_4$ + borax as compared to control.

- Significantly higher available nitrogen (231.04 and 226.32; 211.74 and 192.46 kg/ha, respectively), phosphorus (110.69 and 106.46; 110.25 and 109.79 kg/ha, respectively), potassium (154.55 and 170 kg/ha; 189.86 and 179.45 kg/ha, respectively) was observed in soil with the application of NPK + FYM after harvest of finger millet and soybean in finger millet-soybean and soybean-finger millet based cropping system. Application of NPK + FYM + $ZnSO_4$ + borax recorded

significantly higher available zinc and boron as compared to control in both the cropping systems

- The micronutrient use efficiency (additional yield produced per kg of micronutrient applied) was higher with the application of NPK + FYM + borax (54.9 and 33.0 in finger millet and soybean, respectively) in finger millet-soybean cropping system and (30.0 and 48.5 in soybean and finger millet, respectively) in soybean-finger millet cropping system.

- In nutrient balance, there was a net loss of nitrogen observed after the harvest of finger millet, both in finger millet-soybean (30.95 to 59.39 kg/ha) and soybean-finger millet (5.50 to 10.50 kg/ha) based cropping system. A positive balance of nitrogen was observed after harvest of soybean both in finger millet-soybean (22.84 to 65.17 kg/ha) and soybean-finger millet (7.64 to 50.65 kg/ha) based cropping system.

- The loss of phosphorus ranged between 18.17 to 36.25 kg per ha in finger millet and 4.62 to 67.35 kg per ha in soybean among the different treatments in finger millet-soybean cropping system, while the loss of phosphorus ranged between 16.71 to 63.15 kg per ha in soybean and 4.13 to 29.97 kg per ha in finger millet among the different treatments in soybean-finger millet based cropping system.

- The gain of potassium ranged from 8.87 to 41.06 in soybean in finger millet-soybean based cropping system and 4.0 to 15.13 kg per ha in soybean and 3.20 to 38.87 kg per ha in finger millet, in finger millet-soybean based cropping system except after harvest of finger millet in finger millet-soybean based cropping system. The net loss of potassium was noticed which ranged from 2.30 to 15.40 kg per ha.

- There was a net loss of zinc and boron noticed among different treatments in both the cropping systems.

- A higher net income of Rs. 44,138 and 47,825 per ha was realized due to application of NPK + FYM + $ZnSO_4$ and NPK + FYM + $ZnSO_4$ + borax, in finger millet-soybean and soybean-finger millet based cropping system, respectively. The higher B : C ratio of 2.14 and 2.29 were obtained with the application of NPK + $ZnSO_4$ + borax in finger millet-soybean and soybean-finger millet based cropping system, respectively.

Experiment-II: Response of finger millet-soybean rotation to conjunctive use of zinc, boron and microbial inoculants

The experiment-II was conducted at AICRPDA Centre, UAS, GKVK, Bangalore during *kharif* 2005 and 2006 to elucidate the information on conjunctive use of zinc, boron and microbial inoculants application on growth, yield and quality of finger millet and soybean crops. The VAM (*Glomus fasciculatum*) was applied as soil application at the rate of 10 kg per ha. Finger millet seedlings were root dipped in the slurry of *Azospirillum brasilense* @ 1 kg per ha in 10 litres of water before transplanting. Soybean seeds were inoculated with *Bradyrhizobium japonicum* @ 375 g per ha. Besides, the uptake of nutrients in crops, status of soil nutrients before sowing and after harvest of crops, microbial and enzymatic studies and economic analysis were also studied. Summary of the investigation carried out is presented below:

Finger millet

- The growth parameters of finger millet like plant height, number of tillers per hill, number of green leaves per hill, leaf area, LAI, LAD and dry matter accumulation and its distribution in different plant parts

were higher with the application of NPK + FYM + $ZnSO_4$ + borax + *A.brasilense* + VAM.

- The yield parameters *viz.,* number of productive tillers per plant, number of fingers per ear head, ear head length, finger length, grain yield per plant, 1000-grain weight were also higher with the application of NPK + FYM + $ZnSO_4$ + borax + *A.brasilense*.

- Application of NPK + FYM + $ZnSO_4$ + borax + *A.brasilense* + VAM recorded significantly higher grain (4143 kg/ha) and straw yield (6467 kg/ha) of finger millet over rest of the treatments. The increase in grain yield due to application of NPK + FYM + $ZnSO_4$ + borax + *A.brasilense* + VAM, NPK + FYM + $ZnSO_4$ + *A.brasilense* and NPK + FYM + $ZnSO_4$ + VAM was 45.31, 41.80 and 40.93 per cent over control.

- Application of NPK + FYM + $ZnSO_4$ + borax + *A.brasilense* + VAM registered significantly higher germination (99%) and seed vigour index (561%) as compared to control.

- The uptake of nutrients *viz.,* nitrogen, phosphorus, potassium, zinc and boron (110.59, 21.55, 88.67 kg/ha, 167.21 and 74.96 g/ha, respectively) was significantly higher with the application of NPK + FYM + $ZnSO_4$ + borax + *A.brasilense* + VAM as compared to control.

- Significant and positive correlation was observed between grain yield and growth, yield parameters and uptake of nitrogen, phosphorus, potassium, zinc and boron nutrients. The growth, yield and uptake of nutrients have indicated a predictability of 73 per cent of the finger millet yield due to the above factors.

Soybean

- Soybean growth parameters like plant height, number of green leaves per plant, leaf area, LAI, LAD, number of branches, dry matter accumulation and its distribution in different plant parts, nodule number and nodule dry weight at different growth stages were significantly higher with the application of NPK + FYM + $ZnSO_4$ + borax + *B. japonicum* + VAM as compared to control.

- Application of NPK + FYM + $ZnSO_4$ + borax + *B. japonicum* + VAM recorded significantly higher number of pods per plant (25.90), number of seeds per plant (3.15), pod length (6.03 cm), pod yield per plant (12.37 g/plant) and seed yield per plant (5.78 g/plant). However, it was found on par with the application of NPK + FYM + $ZnSO_4$ + *B. japonicum*.

- Significantly higher seed and haulm yield of soybean (2081 and 3304 kg/ha, respectively) was recorded with the application of NPK + FYM + $ZnSO_4$ + borax + *B. japonicum* + VAM as compared to other treatments. However, it was found on par with the application of NPK + FYM + $ZnSO_4$ + *B. japonicum* and NPK + FYM + borax + *B. japonicum.*

- Seed quality parameters of soybean *viz.,* protein yield (870.10 kg/ha), oil yield (369.05 kg/ha), germination (97%) and vigour index (2417) were significantly higher with the application of NPK + FYM + $ZnSO_4$ + borax+ *B. japonicum* + VAM as compared to control.

- Uptake of plant nutrients by soybean crop was significantly higher with the application of NPK + FYM + $ZnSO_4$ + borax + *B. japonicum* + VAM (176.82, 8.98, 60.22 kg N, P, K per ha, 204.86 and 69.57 g Zn and B per ha, respectively) as compared to control.

- Increased seed yield was significant and positively correlated with growth, yield and uptake of nutrients. Variation in the seed yield of soybean due to growth, yield and total uptake of nutrients was about 95 per cent as explained by the multiple linear regression equation.

- Significantly higher population of bacteria, fungi and actinomycetes was observed with the application of NPK + FYM + $ZnSO_4$ + borax + *A.brasilense* / *B. japonicum* + VAM at 50 per cent flowering and at harvest of finger millet and soybean in both the cropping systems.

- The activity of dehydrogenase, urease activity, acid and alkaline phosphatase was higher with the application of NPK + FYM + $ZnSO_4$ + borax + *A.brasilense* / *B. japonicum* + VAM at 50 per cent flowering and at harvest of finger millet and soybean in both the cropping systems.

- Significantly higher available nitrogen in soil after harvest of crops was recorded in control (NPK + FYM) in both the cropping systems. The available phosphorus in soil was higher with the application of NPK + FYM + VAM in both the cropping systems except after harvest of soybean in soybean-finger millet cropping system. The available potassium was higher with the application of NPK + FYM + $ZnSO_4$ + borax + *A.brasilense / B. japonicum* + VAM in both the cropping system except after harvest of finger millet in finger millet-soybean cropping system. The available Zn and boron status after harvest of crops was higher with application of NPK + FYM + $ZnSO_4$ + borax + *A.brasilense / B. japonicum* + VAM in both the cropping systems.

- In nutrient balance, the net loss of nitrogen after harvest of finger millet and net gain of nitrogen after harvest of soybean was observed in both the cropping systems. The loss of phosphorus varied between 15.25 to 39.86 kg per ha and 5.87 to 25.87 kg per ha after harvest of

finger millet and between 14.28 to 31.86 and 29.62 to 38.95 after harvest of soybean, respectively in finger millet-soybean and soybean-finger millet based cropping system. The gain of potassium ranged from 9.77 to 57.63 kg per ha, after harvest of soybean in finger millet-soybean based cropping system, 4.88 to 36.05 kg per ha after harvest of soybean and 2.62 to 39.69 kg per ha after harvest of finger millet in soybean-finger millet based cropping system. The net loss of potassium ranges from 7.85 to 20.68 kg per ha was observed after harvest of finger millet in finger millet-soybean based cropping system. There was a negative balance of zinc and boron noticed after harvest of crops in both the cropping systems.

- Application of NPK + FYM + $ZnSO_4$ + *A.brasilense* / *B. japonicum* + VAM recorded higher net returns of Rs. 50,753 per ha and B:C ratio (2.13) in finger millet-soybean based cropping system. Similarly, in soybean-finger millet cropping system higher net returns was recorded with the application of NPK + FYM + $ZnSO_4$ + *B. japonicum* /*A. brasilense* + VAM (Rs. 53,629/ha). The B : C ratio was also higher (2.25) with the application of NPK + FYM + $ZnSO_4$ + *B. japonicum / A.brasilense.*

- Under rainfed condition, soybean-finger millet rotation is an effective cropping system as compared to finger millet-soybean in order to improve the soil fertility and crop productivity.

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* Original not seen

APPENDIX

APPENDIX

Price of inputs and outputs used in experiment

Sl. No.	Particulars	Price (Rs.) /unit
I. Inputs		
1.	Finger millet seeds (GPU-28)	12.00/kg
2.	Soybean seeds (KB-79)	38.00/kg
3.	**Fertilizers**	
	a. Urea	4.85/kg
	b. DAP	9.34/kg
	c. MOP	4.50/kg
	d. Zinc Sulphate ($ZnSO_4$)	67.00/kg
	e. Borax	45.00/kg
4	Farm Yard Manure (tonnes)	300/t
5	**Biofertlizers (kg)**	
	a. *Azospirillum brasilense*	75.00/kg
	b. *Rhizobium japonicum*	75.00/kg
	c. VAM	70.00/kg
6	**Plant protection chemicals**	
	a. Nuvacron (Liter)	800.00
7	**Labour wages (per day)**	
	a. Men	60.00
	b. Women	60.00
8	Tractor rent (per hour)	200.00
9	**Miscellaneous**	
	a. Land revenue (per season/ha)	1000
	b. Marketing and handling 2 % of gross returns	1000
II Outputs		
1.	Finger millet grain produce (Quintal)	650.00
2.	Straw (tonnes)	1400.00
3.	Soybean seed produce (Quintal)	2000.00
4.	Haulm (tonnes)	200.00