INTEGRATED NUTRIENT MANAGEMENT SYSTEM FOR PRODUCTIVITY POTENTIAL OF SORGHUM-WHEAT SEQUENCE UNDER IRRIGATED CONDITION

By

MADHUKAR BHIMRAJ DHONDE

Reg. No. 9804

A Thesis submitted to

MAHATMA PHULE KRISHI VIDYAPEETH,
RAHURI-413 722, DIST. AHMEDNAGAR
Maharashtra State (India)

in partial fulfilment of the requirement

for the degree

of

DOCTOR OF PHILOSOPHY (AGRICULTURE)

in

AGRONOMY

DEPARTMENT OF AGRONOMY,
POST GRADUATE INSTITUTE,
MAHATMA PHULE KRISHI VIDYAPEETH,
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2002

DEDICATION

AFFECTIONATELY

DEDICATED

TO

MY BELOVED

PARENTS.

.... MADHUKAR

CANDIDATE'S DECLARATION

*I hereby declare that the thesis entitled, "**Integrated nutrient management system for productivity potential of sorghum-wheat sequence under irrigated condition**" or part thereof has not been previously submitted by me or other person to any other University or Institution for a degree or diploma.*

Place : Rahuri

Dated : 6 / 6 /2002

(Madhukar B. Dhonde)

Dr. S. H. Shinde
M.Sc. (Agri.), Ph.D.
Associate Dean,
College of Agriculture,
KOLHAPUR

CERTIFICATE

This is to certify that the thesis entitled, **"INTEGRATED NUTRIENT MANAGEMENT SYSTEM FOR PRODUCTIVITY POTENTIAL OF SORGHUM-WHEAT SEQUENCE UNDER IRRIGATED CONDITION"**, submitted to the Faculty of Agriculture, Mahatma Phule Krishi Vidyapeeth, Rahuri-413 722, Dist. Ahmednagar, Maharashtra State, India, in fulfilment of the requirement for the degree of **DOCTOR OF PHILOSOPHY (AGRICULTURE)** in **AGRONOMY**, embodies the results of a piece of *bona fide* research work carried out by **Mr. MADHUKAR BHIMRAJ DHONDE,** under my guidance and supervision and that no part of the thesis has been submitted for any other degree or diploma.

The assistance and help rendered during the course of this investigation have been duly acknowledged.

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Date : / /2002

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CERTIFICATE

This is to certify that the thesis entitled, "**INTEGRATED NUTRIENT MANAGEMENT SYSTEM FOR PRODUCTIVITY POTENTIAL OF SORGHUM-WHEAT SEQUENCE UNDER IRRIGATED CONDITION**", submitted to the Faculty of Agriculture, Mahatma Phule Krishi Vidyapeeth, Rahuri-413 722, Dist. Ahmednagar, Maharashtra State, India, in fulfilment of the requirement for the degree of **DOCTOR OF PHILOSOPHY (AGRICULTURE)** in **AGRONOMY,** embodies the results of a piece of *bona fide* research work carried out by **Mr. MADHUKAR BHIMRAJ DHONDE,** under the guidance and supervision of **Dr. S. H. Shinde,** Associate Dean, College of Agriculture, Kolhapur. It is sufficiently high standard to warrant its submission to the University for the award of the said degree. No part of the thesis has been submitted for any other degree or diploma.

Place : Rahuri,
Date : 6 / 6 /2002

(**D. M. Sawant**)
Associate Dean (PGI)

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(Madhukar B. Dhonde)

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LIST OF ABBREVIATIONS

Symbol		Reference
@	:	At the rate of
C.D.	:	Critical difference
cm	:	Centimeter (s)
cm hr^{-1}	:	Centimeter per hour
Cu	:	Copper
°C	:	Degree celcius
DAS	:	Days after sowing
dm^2	:	Square decimeter (s)
DMP	:	Dry matter production
dSm^{-1}	:	Deci Siemen's per meter
DTPA	:	Diethyl Triamine Penta Acetic Acid
EC	:	Electrical conductivity
et al.	:	(et alibi) meaning and others
Fe	:	Iron
Fig.	:	Figure
FYM	:	Farm Yard Manure
g	:	Gram (s)
GLM	:	Gliricidia leaves manure
INMS	:	Integrated Nutrient Management System
ha	:	Hectare
i.e.	:	That is (id est)
K	:	Potassium
K_2O	:	Potash
kg	:	Kilogram
kg ha^{-1}	:	Kilogram (s) per hectare
mg kg^{-1}	:	Milligram per kilogram
Mn	:	Manganese
MOP	:	Muriate of Potash
N	:	Nitrogen
nm	:	Nano meter
No.	:	Number
NS	:	Non-significant
P	:	Phosphorus
q ha^{-1}	:	Quintal per hectare
RDF	:	Recommended dose of fertilizer
Rs.	:	Rupee (s)
SEm	:	Standard error of means
SYI	:	Sustainability yield index
viz.	:	Namely
WCS	:	Wheat cut straw
Wt.	:	Weight
/	:	Per
%	:	Per cent

ABSTRACT

"INTEGRATED NUTRIENT MANAGEMENT SYSTEM FOR PRODUCTIVITY POTENTIAL OF SORGHUM-WHEAT SEQUENCE UNDER IRRIGATED CONDITION"

By

M. B. DHONDE

A candidate for the degree
of
DOCTOR OF PHILOSOPHY (AGRICULUTURE)
in
AGRONOMY
MAHATMA PHULE KRISHI VIDYAPEETH,
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2002

Research Guide	:	Dr. S. H. Shinde
Department	:	Agronomy

An experiment on integrated nutrient management system for productivity potential of sorghum-wheat sequence under irrigated condition was carried out at the Main Centre for Cropping System Research Project, M.P.K.V., Rahuri for two consecutive years during 1999-2000 and 2000-2001. Ten treatments comprised of use of chemical fertilizers alone and in conjunction with different organic manures viz., farm yard manure (FYM), wheat cut straw (WCS) and gliricidia leaves were laid out in randomized block design. An attempt was made to develop appropriate integrated nutrient management system (INMS) involving balance proportion of chemical fertilizers and organic manures as the main components for sustaining crop productivity on long term basis. The experiment was conducted on the same

site without changing the randomization of treatments to assess the residual effect of fertilizers on crop yield after 17[th] cycle of crop rotation.

The soil of experimental plot was clayey in texture with low in available nitrogen (153 kg ha^{-1}), medium in available phosphorus (14.0 kg ha^{-1}) and rich in available potash (496.0 kg ha^{-1}) with slightly alkaline in reaction (pH 8.2).

The results revealed that all growth parameters in sorghum were highest with the application of 50 per cent recommended dose of fertilizers in conjunction with organic manures at 25 to 50 per cent N substitution through FYM and *gliricidia leaves to sorghum. Consequently sorghum grain and* fodder yields were the highest with 50 per cent N substituted through FYM coupled with 50 per cent recommended dose of fertilizers and were at par with 100 per cent recommended dose of chemical fertilizers i.e. 120:60:60 kg NPK ha^{-1}. Among the organic sources viz., gliricidia ranked second in respect of yield of sorghum.

All the growth characters of wheat were significantly higher in treatment 100 per cent recommended dose of fertilizers (i.e. 120:60:60 kg NPK ha^{-1}) over 75 per cent recommended dose of fertilizers (RDF) and control. Nitrogen management strategy showed remarkably increment in growth attributes of wheat. As a result, the maximum and significantly higher grain and straw yields were obtained by the 100 per cent RDF applied to wheat preceded by 50 per cent RDF + 50 per cent N through FYM applied to sorghum.

Addition of FYM in combination with chemical fertilizers had pronounced positive effect on mean grain productivity of sorghum and wheat in sorghum-wheat crop sequence over years. Comparable productivity was also found due to application of 100 per cent NPK dose of fertilizers and 50 per cent N substituted either through gliricidia leaves or wheat cut straw to sorghum. Sustainability yield index (SYI) and mean grain productivity on pooled mean basis in sorghum and wheat crop emanated the necessity of use of FYM, gliricidia leaves and wheat cut straw along with chemical fertilizers to sustain crop and soil productivity in long run.

The highest uptake of NPK by plant and available NPK status in soil were observed in application of sub-optimum levels of inorganic fertilizers in combination with organic manures for 50 per cent N substitution or optimum level of chemical fertilizer alone. The trend in sustaining the residual fertility due to organic sources was in order of FYM > gliricidia leaf manure > wheat cut straw.

Available N, P and K balance in sorghum-wheat crop sequence was influenced by conjoint use of organic and inorganic fertilizers as well as inorganic fertilizers alone and magnitude of reduction was decreased with increased levels of fertilizers.

Incorporation of FYM, wheat cut straw and gliricidia leaves for 25 to 50 per cent N substitution in conjunction with balanced dose of NPK fertilizers increased the infiltration rate, water stable aggregates and organic matter content of soil and decreased the bulk density due to improvement in structural status of soil. On the other hand, there was adverse effects due to continuous application of inorganic fertilizers alone on bulk density and soil structure.

Micronutrient content in soil improved due to integrated nutrient management system, however, continuous cropping with reduced levels of RDF brought their level below.

ABST. CONTD..

The microbial biomass and population in soil obtained was significantly more due to application of FYM for substitution of 50 per cent N alongwith 50 per cent RDF for sorghum and 100 per cent RDF for wheat followed by use of gliricidia leaves used for substitution of nitrogen. However, it was reduced due to use of only inorganic fertilizers without organic manures.

The profitability of sorghum-wheat sequence under integrated nutrient management system, the organic sources viz., FYM coupled with 50 per cent RDF applied during *kharif* season to sorghum and 100 per cent RDF applied to wheat brought out significant increase in total net monetary returns (Rs. ha^{-1}) and Benefit:Cost ratio followed by 100 per cent RDF to both the crops during both the seasons.

The energy balance and energy use efficiency of sorghum-wheat crop sequence indicated the superiority of the treatment comprising of 50 per cent RDF + 50 per cent N through FYM applied during *kharif* season to sorghum and 100 per cent RDF applied to wheat crop.

Thus, it could be safely recommended that in the crop sequence of sorghum-wheat where both the crops are exhaustive feeders, it is necessary to incorporate the organic manures such as FYM, gliricidia leaves or wheat cut straw as per availability in substitution of N to the extent of 25 to 50% in order to have not only the reasonably high sustainability, profitability of the productivity of sequence but also for maintaining the soil fertility and microbial activity in the soil.

Pages : 1 to 348

INTRODUCTION

1. INTRODUCTION

India is the largest country next to China in respect of population on the earth and by the year 2030, the country will have over 1350 million people. The current food availability per capita is about 190 kg. At this level the food availability per person for energy intake is low compared to energy need as recommended by World Health Organization. If this increment in population is maintained at current population growth @ 1.8% per annum, the total food production has to reach 350 million tonnes by 2030. To meet out demands of food grains of ever increasing population of our country, it is necessary to improve the productivity and production of the country. . India, with 2.4 per cent of the global area supports more than 15 per cent of the world's human population and nearly 17 per cent of cattle population. Interestingly, in a country like India, more than 70 per cent of population is dependent upon agriculture in one form or the other. Out of 328.73 million ha geographical area of the country at present about 43.20 per cent of the area is made available for cultivation to sustain 1000 million people and further area increase is not being visualised. In order to increase production further there is no other option except to pay greater emphasis on increasing productivity and enhancing the cropping intensity by using available resources most efficiently. System approach is applied to agriculture for efficient utilization of all resources, maintaining stability in production and obtaining higher returns. Cropping system is the most important component in the integrated farming system management. Adoption of cropping system by the farmers is greatly influenced by various factors including profit, household needs, resource base, market, input supply and so on. it is very important to give a basket of multiple choice in cropping systems to suit the need of the individual farmer. Maximizing and stabilizing food production per unit area per unit time is the need of the day, to meet the requirement of rapidly ever increasing population. It is necessary to make the best use judiciously not only of land, labour and capital but also of the natural resources like temperature, radiant energy, soil moisture and soil nutrients by employing suitable technologies in most effective way.

Sustainable agriculture involves successful management of resources for increased agricultural production to satisfy changing human needs, while maintaining or enhancing the environment and natural resources (FAO, 1989). To realise sustainable agriculture, it is important to maintain the soil health by back up of precision farming. Apply chemical fertilizers in conjunction with biosolids (FYM, crop residues, industrial and urban wastes) and biofertilizers in such a way that crop yield and nutrient use efficiency get maximized without any deterioration of soil, water and air quality.

The area under *kharif* sorghum occupies 13.11 mha in India with production of 12.96 million tonnes. The major sorghum growing states are Maharashtra, Andhra Pradesh, Karnataka, Gujrat, Rajsthan and Tamil Nadu, while wheat growing states are Punjab, Haryana, Uttar Pradesh, Bihar, Maharashtra, Gujrat and part of Andhra Pradesh and Karnataka. Out of 18.97 mha arable area of the Maharashtra state, approximately, 40.19 per cent of area comes under the jurisdiction of Mahatma Phule Krishi Vidyapeeth, Rahuri. The area under *kharif* sorghum in Maharashtra is 28.8 per cent which ranks first in *kharif* crops. The per cent of the *kharif* sorghum in the region to the state acreage comes to 22.80 per cent. Among the *rabi* cereals, the *rabi* sorghum (3.60 mha) ranks first followed by wheat. The area under wheat in Maharashtra state is 8.815 lakh ha. The percentage of wheat in the region to the state acreage comes to 46.40 per cent. About 62 per cent of the area under wheat is in irrigated condition followed after sorghum, pearl millet or some of the *kharif* pulses.

Sorghum-wheat cropping system has become very important production system and contributes to about one third of cereal production. Research conducted at various research stations suggested that among the various crop sequences tested, sorghum-wheat in irrigated uplands was the most productive and profitable sequence. About 1/3rd of the irrigated wheat is taken under sorghum-wheat sequence i.e. an area of about 1.81 lakh ha is under this system. The sorghum-wheat system has been very popular among the farmers owing to the fact that these two cereals are highly productive with advent of new hybrids in sorghum and dwarf high yielding varieties in wheat. The farmers are aware of the new hybrids and the dwarf varieties require higher doses of fertilizer to get high yields. Because of the high productivity of both these crops in this system, the average monetary returns are also high. New technologies which could help to achieve a quantum jump in productivity and production are yet to sight.

With introduction of high yielding cultivars and multiple cropping system, the demand for fertilizers has gone up manifold. As such the production of fertilizers may not cope up with the demand for many years to come while the use of mineral fertilizers is the quickest and surest way to boosting crop production, their cost and other constraints frequently prevent farmers from using them in recommended quantities and in balanced proportions. As a consequences of this and other constraints there seems to be no option but to fully exploit potential alternative sources of plant nutrients. Complementary use of available renewable sources of plant nutrients (organic/

biological) alongwith the mineral fertilizers is of great importance for the maintenance of soil productivity i.e. soil structure, soil bio-activity, soil exchange capacity and water holding capacity. Results from various cropping systems and ecologically illustrate that positive interactions result from the integrated use of mineral fertilizers and organic/biological sources of plant nutrients within the framework of integrated nutrition system (Roy and Ange, 1991).

There is quite a bit of accumulated information on crop yield and soil fertility emanating from several long term field trials conducted during the past, wherein certain notable changes in the nutritional status of the soil have resulted after decades of experimentation because of low intensity of cropping and fertilizer use. While the findings are no doubt of great value they would fail to meet the requirement of the present system of intensive agriculture involving the raising of high yielding varieties in multiple cropping system with high levels of fertilizer input (Ghosh, 1976). Fertilizer use recommendations which were hitherto single crop oriented are now being developed for the cropping systems. The available data on effects of organic manures on crop yield suggest that balanced combination of organic manures and chemical fertilizers are required for sustained soil productivity (Gaur, 1982; and Hesse and Misra, 1984). The organic matter content of soil, in general, determines soil productivity. This is attributed to the ability of some of the organic fractions to modify the physical and chemical properties of soil in a desirable manner, and partly to the fact that organic matter serves as nutrient source to both micro-organisms and higher plants.

Judicious use of fertilizer is no doubt, the king-pin in agricultural production under different agro-climatic as well as farming situations. Use of fertilizers in an unbalanced way leads to reduce productivity and enhance the deficiency of other plant nutrients. It is, therefore, necessary to supply various types of fertilizers in balanced proportion to meet the nutrient demands of the crops and also sustain the soil fertility on perpetual basis. The persistent nutrient depletion and its gap is a great threat to sustainable agriculture. This gap could be minimized through combined use of all possible sources of nutrients with their scientific management for optimum growth, yield and quality of different crops and cropping systems, although neither the organic manures nor the chemical fertilizers alone could achieve the objective under intensive farming where the nutrient removal in the soil-plant system has been extensive (Biswas and Benbi, 1989). The use of organic manures, crop residues and green manuring with chemical fertilizers is receiving greater attention in the intensive farming under integrated nutrient management system concept.

The shift in the emphasis from yield per unit area for each crop to yield per unit area per unit time and per unit of input has resulted in an intensive cropping progamme which rapidly depletes the soil of it's nutrients and thus decreases crop production. It has now become amply clear that there should be judicious use of organics and inorganics material to restore soil fertility. Combined use of fertilizers with manures, crop residues and green manuring is known to stimulate mineralization and immobilization of organic nitrogen and can influence the forms and availability of phosphorus and potassium in soil in many ways.

Continuous use of fertilizers and manures gives rise to various nitrogenous compounds in soil. About 92-96 per cent of the total N present in soil is in organic forms, which are mainly derived from plant and animal residues. Prasad and Rokima (1991) reported that exchangeable NH_4-N was dominant form of N contributed directly or indirectly to nitrogen nutrition of crops.

Since, various crops behave differently with respect to removal and to form of P present in soil, it is desirable to choose crop and crop rotations in such a way that they play a complementary role in making better utilization of different forms of P from depletion and accumulation by growing crops. Rokima and Prasad (1991) studied the transformation of P added in combination with organic manures and reported that addition of FYM enhanced the build up of all forms of inorganic P that contributed most either directly or indirectly towards available P and its subsequent utilization by cereal crops in rotation.

The importance of potassium management in cropping systems will certainly increase with cropping intensity, crop productivity etc. Prasad and Singh (1987) reported that water soluble, exchangeable and non-exchangeable K increased with increasing amount of K and organic manures and were correlated significantly with K uptake and yield of wheat. Prasad and Rokima (1991) also indicated increase in water soluble, exchangeable and non-exchangeable K with the application of FYM over chemical fertilizer alone under integrated nutrient management in calcareous soil.

Some of the micronutrient problems are likely to be faced in multiple cropping systems. Marked differences in micronutrient requirements of crops to be grown in succession in multiple cropping make the micronutrient fertilization problem. Prasad and Singh (1980) observed that continuous use of FYM and NPK fertilizers over a period of 20 years has helped in maintaining and improving the available Zn and Fe status of soil. Also, the application of

FYM for the last eight years was effective in maintaining available micronutrient level and build up of availability of Zn was favoured due to organic manures (Trehan and Grewal, 1983).

The augumental microbial activity can tap the inert nitrogen gas from the atmosphere, reduce the leaching losses and regulate the supply of phosphorus. In a microbial study, the response of microflora varied with the type of characteristics of soil and organics used. Application of organics influenced bacterial population to a greater extent than fungi and actinomycetes (Gaur *et al.*, 1984).

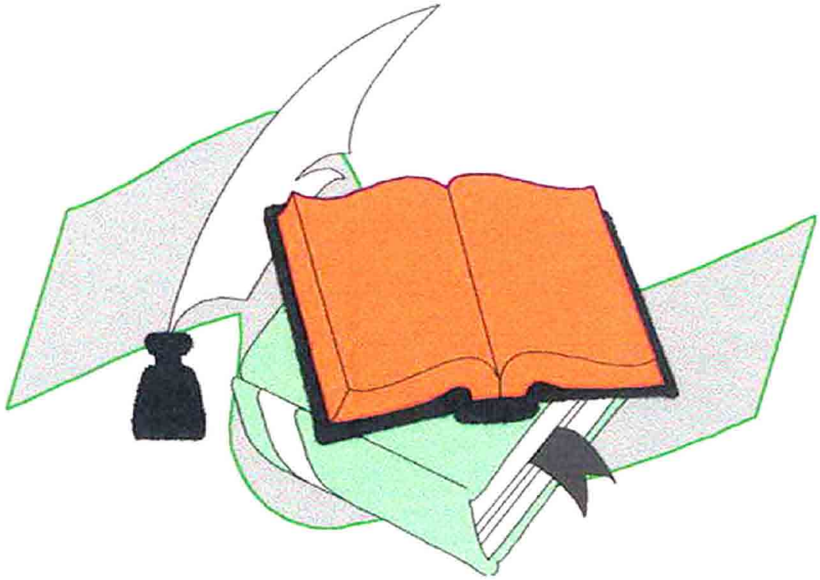
Several studies carried out in India have shown the beneficial effects of addition of organic manures on the soil physical properties. Biswas *et al.* (1971) reported that the treatments consisting of the inorganic fertilizers alone and in various combinations with organic manures at different levels, the structural status, water retention and bulk density of the soil were significantly improved by the treatments with organic manures. The decrease in bulk density and increased water stable aggregates were also observed under long term use of chemical fertilizers in combination with organic manures in a permanent manurial experiment by Singh and (1980).

It is apparent that there is a need to generate more information on integrated nutrient recommendations for cropping systems as a whole, taking into account balanced plant nutrition through the complementry synergistic effect of combined use of both mineral and organic sources for sustained crop production through increased soil productivity in long term experiments. The information on the effects of continuous added fertilizers and manures in calcareous soils under sorghum-wheat cropping is quite meagre.

Several researchers have reported the use of nitrogen incorporation through different organic sources and their effect on crop productivity and soil fertility. The frame plot experiment at Main Centre for Cropping Systems Research Project (AICARP), Mahatma Phule Krishi Vidyapeeth, Rahuri (Maharashtra), is being conducted since *kharif* 1984-85 on Typic Chromustert (Otur soil series) with different treatments consisting chemical fertilizers alone and in conjunction with organic sources viz., farm yard manure, wheat straw and gliricidia leaves, using sorghum-wheat sequence on a fixed site, which provided an opportunity for studying their effects.

The present study on effect of integrated nutrient management on the yield potential, economics and nutrient availability in sorghum-wheat-sequence under irrigated condition in vertisol is proposed with the following objectives.

1. To investigate the long term effects of organic and inorganic sources of fertilizers on the productivity of sorghum and wheat.
2. To assess the availability of nutrient status in the soil.
3. To estimate nitrogen economy in sorghum-wheat crop sequence.
4. To develop suitable integrated nutrient supply system for higher productivity of sorghum-wheat crop sequence with better soil health.



REVIEW OF LITERATURE

2. REVIEW OF LITERATURE

The fertility status of soil is an important factor in crop production especially in cereal crops. Cereal crops need large amount of nutrients to achieve high productivity. Complementary use of available renewable sources of plant nutrients (organic/biological) along with mineral fertilizers is of great importance for the maintenance of soil productivity, that is soil structure, soil bioactivity, soil exchange capacity and water holding capacity. The appropriate combination of mineral fertilizers, organic manures, crop residues, compost or N-fixing crop varies according to the system of land use and ecological, social and economic conditions. To implement this effectively, a lot of basic information on the selection of suitable cropping system, the correlation of their yield with different soil nutrient forms and available nutrients and their relative importance in plant nutrition etc. have to be thoroughly explored. Keeping this in view, the literature pertaining to the above aspects with reference to N, P, K, micronutrients and physical properties of soil alongwith crop productivity, economics and energy studies of the sequence are reviewed in this chapter under following subheads.

2.1 Effect of integrated nutrient management on crop growth characters and yield attributes of sorghum

2.1.1 Plant height

A significant improvement in height of sorghum was recorded with application of nitrogen (Waghmare and Singh, 1984; Devasenapathy and Subbarayalu, 1986; Kumar, 1993; Deshmukh *et al.*, 1996 and Barik *et al.*, 1998).

Likewise, application of phosphorus also improved the plant height (Khot and Narkhede, 1970; Govil and Prasad, 1972; Meghwanshi, 1992).

On the other hand, the plant height was not influenced either by nitrogen (Krishnamurthy *et al.*, 1975 and Korikanthimath and Palaniappan, 1984) or by phosphorus application (Hons *et al.*, 1986; Hirpara *et al.*, 1992).

While, Raut and Ali (1987) and Meghvanshi (1992) observed significant influence of both nitrogen and phosphorus application on plant height of sorghum. However, Jadhav (1994) observed the significant increase in plant height with full dose of fertilizers (75 kg N + 50 kg P_2O_5 /ha) as compared to half dose of fertilizers (37.5 kg N + 25 kg P_2O_5 /ha).

The increase in plant height with NPK fertilization may be due to increase in cell division (Rajput *et al.*, 1983).

At Jhanshi (U.P.), Gangwar and Singh (1992) reported that plant height of sorghum was increased by 35.33 per cent with recommended level of fertilizer over control. While the studies of Mohammed *et al.* (1995) revealed that fertility variation treatments did not influence the plant height of sorghum on alfisol of southern Telengana region of Andhra Pradesh.

A maximum of 73% reduction in plant height in CVS 15 and minimum of 49% in CSH-14 sorghum were observed (Revuru and Garud, 1998). Mean plant height of sorghum was maximum when fertilizers applied for 60 q/ha yield target and was reduced with higher fertilization. However, fodder yield and plant height was increased significantly due to higher plant density at 3.33 lakh/ha (Tambe and Bhoi, 1999).

Application of FYM at 6 t/ha increased plant height of sorghum by 17.81 per cent over control, on sandy clay soil at Jhanshi (Gangwar and Singh, 1992). Bangar (1994) reported that the height of sorghum plant was affected due to utilization of available N for decomposition of straw through soil microbes. While at Durgapura (Jaipur), application of 20 t FYM/ha increased the plant height by 5.84 per cent over control (Kumar, 1993).

2.1.2 Photosynthetic parameters

Increase in LAI at 60 DAS by 16.10 per cent with application of 40 kg N/ha over control was recorded at IARI, New Delhi (Balyan and Singh, 1985). At Junagarh, application of 120 kg N/ha profoundly increased LAI at harvest by 43.3 per cent over control (Hirpara *et al.*, 1992). The dry matter accumulation and leaf measurements are the two major indices of plant growth, and ultimately provide a basis for grain yield potential. Nitrogen application increases number of leaves per plant (Kumar, 1993; Dashora, 1998) and thus increases LAI (Balasubramanian and Ramamoorthy, 1996; Kumawat and Bansal, 1996 and Barik *et al.*, 1998).

Studies conducted at Udaipur revealed that application of 80 kg N/ha registered significantly higher LAI by 7.14 and15.38 per cent over 40 kg N/ha and control, respectively (Kumawat and Bansal, 1996). Dashora (1998) observed that application of 120 kg N/ha increased LAI and chlorophyll content at flowering by 14.5 per cent and 13.6 per cent, over 40 kg N/ha, respectively.

Phosphorus application upto 40 kg P_2O_5 /ha also resulted in an increase in LAI and chlorophyll content at 60 DAS of sorghum (Meghwanshi, 1992).

Application of 30 to 60 kg N and 30 kg P_2O_5 /ha to rainfed sorghum grown on vertisol increased the leaf area (Raut and Ali, 1987). Kandiannan and Rangasamy (1990) concluded that when fertilizer application (40 kg N + 20 kg P_2O_5) was withdrawn, the LAI was reduced to 4.87 as compared to 6.67 with all technologies. Increase in LAI with N and P_2O_5 application was also reported by Singh *et al.* (1993).

Oleksenko and Krasenkov (1988) observed that application of NPK increased chlorophyll contents, net photosynthetic productivity and leaf area duration. Similarly, an increase in number of leaves per plant and leaf area was noted with application of NPK fertilizers (Chaudhary and Khade, 1991).

On the contrary, Mohammed *et al.* (1995) reported that fertility variation did not influence the number of leaves per plant significantly and only 5.03 per cent increase with application of full dose of fertilizer as compared to half dose of fertilizer was noticed.

While working at Durgapura (Jaipur), Kumar (1993) reported that application of 20 t FYM/ha increased the leaf area by 2.90 per cent over control.

2.1.3 50% flowering

In the opinion of Shrivastava and Singh (1970), the physiological effect of nitrogen on early maturity was attributed to the development of leaves to the full potential, which resulted in accelerated photosynthesis, consequently the reproductive phase started earlier in hybrid sorghum. Number of days to attain 50 per cent flowering was significantly reduced with high N fertilization (120 kg N/ha) over nitrogen application at 60 kg N/ha (Krishnamurthy *et al.*, 1975). A significant reduction in days to bloom with increasing levels of nitrogen was noted (Devasenapathy and Subbarayalu, 1986; Poonia, 1997 and Dashora, 1998).

Phosphorus application also reduced days to flowering (Govil and Prasad, 1972). Similarly, Sahrawat *et al.* (1995) reported that days to 50 per cent flowering and physiological maturity were significantly reduced by phosphorus application on vertisol in Andhra Pradesh.

2.1.4 Dry matter accumulation

The extent of increase reported varies widely, depending upon soil and climatic conditions. An increase in dry matter accumulation following application of 80-90 kg N/ha was reported by Carvalho *et al.* (1982). Balyan and Singh (1985) noted increase in dry matter by 9.3 per cent with 40 kg N/ha over control at IARI. Nitrogen application increases dry matter accumulation in sorghum at all stages of crop growth (Kud somannar *et al.*, 1980). Further increase in dose upto 130 kg N/ha had no significant effect. Hons *et al.* (1986) noticed greater response of high energy sorghum (HES) to applied N compared to other cultivars. They further recorded an improvement in biomass by 40 and 60 per cent with 84 and 168 kg N/ha, respectively over control. At Rajendranagar (A.P.), shoot dry matter was found to increase upto 100 kg N/ha (Reddy *et al.*, 1988). In Gujrat, increasing rate of N from 40 to 120 kg/ha enhanced biomass by 16 per cent (Raj and Patel, 1989). Positive response of nitrogen application upto 120 kg N/ha on dry matter production was also reported by Malik *et al.* (1992); Kumar (1993) and Dashora (1998).

Application of phosphorus reduced the lodging under heavy nitrogen application due to increase in strongness of stem and enhanced dry matter accumulation (Khot and Narkhede, 1970). While Hons *et al.* (1986) and Ogunlela (1988) found that dry matter accumulation was not affected by phosphorus application. Bishnoi and Singh (1990) and Das *et al.* (1996) also reported increase in dry matter accumulation with application of phosphorus.

Raut and Ali (1987) observed that application of nitrogen at 30 to 60 kg/ha and phosphorus at 30 kg/ha increased dry matter production of rainfed sorghum. The studies of Niranjan and Arya (1992) at Jhansi revealed that dry matter yield of sorghum was the highest with application of 100 per cent recommended dose of N and P (60 kg N + 40 kg P_2O_5 /ha). Meghwanshi (1992) reported from Udaipur that application of 80 kg N/ha and 40 kg P_2O_5 /ha significantly increased dry matter accumulation per plant. Increase in dry matter accumulation by 26.9 per cent with 100 kg N + 50 kg P_2O_5/ha over 20 kg N + 10 kg P_2O_5/ha was reported by Singh *et al.* (1996). Palaniswamy *et al.* (1998) noted that contribution of leaves, stem and panicle weight towards total dry matter production at harvest was 10.15, 36.45 and 30.41 per cent in different cultivars.

Similarly, Chaudhary and Khade (1991) reported that application of NPK fertilizer increased dry matter production.

Gangwar and Niranjan (1991) have also reported increase in dry matter yields due to application of FYM. Chaudhari (1992) reported that there were significant genotypic differences in photosynthetic rates (AGR) and total dry matter accumulation at harvest. Hybrid CSH-5 and CSH-9 showed significant superiority over PJ8K in total dry matter accumulation. Application of FYM @ 6 t/ha increased dry matter accumulation of sorghum by 29.93 per cent over control, on sandy clay soil at Jhansi (Gangwar and Singh, 1992) and 20.04 per cent over control with 20 t FYM/ha at Durgapura (Jaipur) (Kumar, 1993). A maximum dry matter production was recorded with application of Zn + Mn during 35, 65 and 115 days of growth period. The soil application of micronutrient was found to be superior to foliar application in increasing dry matter/plant (Khapre *et al.*, 1994).

2.1.5 Yield attributes

Application of nitrogen from 0 to 120 kg/ha increased grain weight per panicle as well as test weight (Roy and Wright, 1973b). However, further increase in dose upto 180 kg did not improve the yield (Krishnamurthy *et al.*, 1975). In hybrids, the response to nitrogen application was recorded upto 150 kg N/ha (Kudsomannawar *et al.*, 1980). Various scientists noted favourable effect of nitrogen fertilization on yield component (Shukla and Seth, 1976; Panwar, 1982; Singh *et al.*, 1986; Bhoseker and Raikhelkar, 1990; Kumawat and Bansal, 1996; Kushwaha and Chandel, 1997 and Dashora, 1998). Increasing rates of N upto 150 kg/ha improved panicle weight, grains/panicle and test weight by 100, 118 and 20 per cent, respectively over control (Basavaraju and Bommegowda, 1982). At IARI (New Delhi), N application upto 80 kg/ha failed to alter test weight (Balyan and Singh, 1985). Applications of 150 kg N/ha recorded the highest grain yield of 42 q/ha at Hissar (Singh *et al.*, 1986). At Parbhani, (Maharashtra), Byale *et al.* (1987) recorded average response of 18.3 kg grain/kg N when crop was fertilized upto 120 kg N/ha compared to 8.7 kg grain/kg N with 40 kg N/ha. Grain yield of sorghum was found to increase linearly from 26 to 42 q/ha with increasing levels of nitrogen from 0 to 150 kg N/ha, but decreased after that with 200 kg N/ha (Singh *et al.*, 1987). Some other workers reported response of sorghum upto 90 kg N/ha (Gupta *et al.*, 1986; Ali and Rao, 1987 and Jayakumar *et al.*, 1987). However, Singh *et al.* (1987) failed to observe significant effect of N on earhead/ha but recorded improvement in grain yield/earhead upto 80 kg N/ha. Thus, the response of increasing levels of nitrogen was found curvilinear (Locke and Hons, 1988). The response per kg of N at 50, 100 and 150 kg N/ha was 12.4, 10.8 and 9.4 kg grain/ha, respectively (Thakre *et al.*, 1989). Porwal and Singh (1989) noted increase in grain weight per earhead by 33 per cent at 80 kg N/ha over no N at AICSIP, Udaipur. Significant linear increase in earhead length from 18.2 to 23.3 cm and test weight from 25.3 to 30.7 g with increasing nitrogen levels from 0 to 150 kg/ha was reported (Thakre *et al.*, 1989). Field experiment conducted under AICSIP, Udaipur, revealed that application of 80 kg N/ha recorded maximum grain yield (35.05 q/ha) which was higher by 14 per cent and 57 per cent over 40 kg N/ha and no nitrogen (Anonymous, 1990). In other locations, sorghum has shown its response upto 120 kg N/ha (Mahakulkar *et al.*, 1992; Kushwaha and Chandel, 1997 and Barik *et al.*, 1998). However, at Bellary (Karnataka), Ramamohan Rao *et al.* (1995) failed to record any influence of N on yield attributes. Kumawat and Bansal (1996) recorded 28, 43 and 10 per cent increase in grains per earhead, grain weight and test weight with application of 80 kg N/ha, over control, respectively. Similarly, application of 80 kg N/ha increased grain and fodder yield of sorghum by 56 and 40 per cent over control on clay loam at the same location (Kumawat and Bansal, 1996).

The increase in grain and fodder yield of sorghum with application of 60 kg N/ha was reported by Savithri *et al.* (1997) and Balasubramanian *et al.* (1986). Further, Poonia (1997) noted that crop fertilized with 80 kg N/ha produced maximum grain yield (18.2 q/ha), while fodder yield was the highest (45.2 q/ha) with 120 kg N/ha. Dashora (1998) observed similar results. Earhead weight and grain yield per earhead was increased significantly with application of 80 kg N/ha. However, successive increase in N dose did not alter 1000 grain weight (Dashora, 1998).

Khot and Narkhede (1970) reported that phosphorus application upto 80 kg/ha significantly increased the grain weight per earhead. Likewise, Shrivastava (1971) also found that application of phosphorus upto 100 kg/ha increased the earhead weight and grain weight per panicle compared to no phosphorus application. The increase in weight per panicle, number of grains per panicle, 1000 grain weight and panicle length by 12.85, 33.70, 11.80 and 10 per cent, respectively with application of 26 kg P_2O_5/ha over control was also observed by Roy and Wright (1973b) at IARI (New Delhi). Phosphorus improves the harvest index by partitioning greater portion of dry matter into grain (Lanjewar and Khot, 1978) and, therefore, increases number of grains and weight per panicle, but its effect on increasing 1000 grain weight is much smaller (Turkhade and Prasad, 1980; Ogunlela, 1988 and Singh *et al.*, 1996). Under rainfed conditions, Singh *et al.* (1993) suggested a mean optimum level of 40 kg P_2O_5 /ha of sorghum. The response of sorghum to phosphorus application have been extensively reported and thus P application is generally recommended (Anonymous, 1982). However, the quantum of response of sorghum to phosphorus application varies with soil, genotype and initial soil fertility status. Bishnoi *et al.* (1983) reported significant response of applied phosphorus to sorghum on 10 sites at cultivator's field in Ludhiana district and found that increase in yield due to applied P decreased at higher level of P.

Jadhav *et al.* (1983) noted significant increase in grain yield of sorghum with 60 kg P_2O_5 /ha and fodder yield with 90 kg P_2O_5 /ha. However, the per cent utilization of P decreased with increase in rates of P_2O_5. The economic dose of phosphorus was 25 kg P_2O_5 /ha. On medium black soil of Indore, Raghuwanshi *et al.* (1988) observed that application of 40 kg P_2O_5 /ha increased grain yield (32.92 q/ha) significantly over control (29.2 q/ha). Gill *et al.* (1988) found that the optimum dose of phosphorus to be applied to sorghum was 59 and 57 kg P_2O_5/ha on low and medium soil, respectively and response was 0.44 and 0.41 kg dry matter per kg of P_2O_5 applied in respective soils.

Durais-amy *et al.* (1990) found that application of P_2O_5 had no effect on grain yield of sorghum at Coimbatore. Shrivastava and Siddique (1992) and Mahakulkar *et al.* (1992) noted response of sorghum to applied P upto 60 kg/ha. An increase in grain, fodder and biological yield with application of 40 kg P_2O_5 /ha was also reported by Meghwanshi (1992). Sorghum . responded even to higher doses of phosphorus upto 80 kg P_2O_5 /ha on alfisols (Donagle *et al.*, 1993) and upto 90 kg P_2O_5 /ha on vertisols (Sahrawat *et al.*, 1995).

Zade *et al.* (1995) observed that application of 30 kg P_2O_5 /ha increased average sorghum yield from 20.5 to 26.68 q/ha. However, higher rates did not further increase grain yield. Singh *et al.* (1996) reported higher yield attributes with increasing application of phosphorus except for 1000 grain weight.On clay soil at Indore (Madhya Pradesh), Sharma *et al.* (1998) noted increase in 1000 grain weight and number of grains per panicle due to phosphorus application at 110 kg/ha.

In a long term field experiment at New Delhi involving multiple cropping with high yielding pearl millet-wheat-cowpea (fodder) on slightly alkaline alluvial sandy loam it was observed that application of N and P significantly increased the yield of all the crops (Swarup and Ghosh, 1979). Increase in sorghum yield by 15.9 per cent with application of 60 kg N + 60 kg

P_2O_5 /ha over control (48.8 q/ha) was recorded by Oleksenko (1988). The utilization of fertilizer N and P was 22-36 and 9-24 per cent, respectively. In Gujrat, sorghum cv. GJ-37 produced significantly higher grain yield (41.1 q/ha) with application of 80 kg N + 40 kg P_2O_5 /ha (Patel *et al.*, 1989). While working at Ludhiana, Brar *et al.* (1990) reported that grain yield of sorghum was enhanced upto 80 kg N and 20 kg P_2O_5 /ha, however, higher fertility rate did not give further increase in grain yield. A favourable improvement in yield attributes *viz.*, grain yield per plant and test weight were observed with application of N and P at Junagadh, Gujrat (Hirpara *et al.*, 1992). At Udaipur, Meghwanshi (1992) reported that yield attributes, *viz.*, grains/panicle, grain weight/panicle and 1000 grain weight were improved significantly with application of 80 kg N and 40 kg P_2O_5 /ha. At Jhansi (Uttar Pradesh) maximum dry matter yield was recorded (52.7 q/ha) with application of 100 per cent recommended level of N and P (60 kg N + 40 kg P_2O_5 /ha) (Niranjan and Arya, 1992). Tomar and Raghu (1993) also observed similar results. At Pantnagar, application of 100 kg N + 50 kg P_2O_5 /ha produced significantly higher grain and stover yields of sorghum (Singh *et al.*, 1996 and Pal *et al.*, 1996).More *et al.* (1994) obtained a higher grain yield of sorghum with 50 kg N and 25 kg P_2O_5 /ha as compared to 50 kg N/ha alone.

Jadhav (1994) reported that the important yield components of sorghum viz., length of earhead, weight of earhead, weight of grains per earhead and 1000 grain weight were significantly increased with full dose of fertilizers (75 kg N + 50 kg P_2O_5 /ha), as compared to half of the recommended dose. Mohammed *et al.* (1995) concluded that the test weight improved from 18.7 to 22.6 g with increase in fertilizer rates from 20 + 10 to 80 + 40 kg N + P_2O_5 /ha and grain yield per plant significantly increased from 45.6 to 84.2 g in response of increasing fertilizer rates from 20 + 10 to 100 + 50 kg N + P_2O_5 /ha, whereas, panicle length was not influenced by fertility variation treatments. At Pantnagar, Singh *et al.* (1996) noted that application of 100 kg N +50 kg P_2O_5 recorded an average 30.4, 14.5 and 22.3 per cent higher panicle weight per plant, grains per panicle and grain yield per plant, respectively over 20 kg N + 10 kg P_2O_5 on light silty clay loam soil having medium available phosphorus. In addition to the effect of fertilization on growth and development, its real effect is being reflected on the grain and fodder yield.

Minhas and Mehta (1984) reported that under wheat-maize rotation, the grain yield of both the crops increased with higher levels of fertilizer application and the effect was significant as well as consistent. Rana *et al.* (1984) observed that under constraints of fertilizers and irrigation, a reduction in fertilizer dose from 100 per cent of the recommended amounts of N and P to 75 and 50 per cent levels resulted in an overall decrease in grain yield of crops under maize-wheat-greengram rotation. Singh and Nambiar (1986) revealed that balanced fertilization with NPK at 100 per cent based on the initial soil test values produced an average grain yield of 6.02 to 10.2 t ha^{-1} over years in maize-wheat, soybean-wheat, rice-rice and rice-wheat cropping systems. Incorporation of FYM at 10-15 t ha^{-1} along with optimal dose of N, P and K enhanced the grain yield by 0.8 to 1.2 t ha^{-1} over optimal nutrients inputs.

Lal and Mathur (1988) reported that fertilizers alone increased the yields of maize and wheat upto 15^{th} years but sharp reduction was observed in the subsequent two years under N, NP and NPK treatments. Organic manure alone or in combination with fertilizers maintained yield of both the crops over years. Results from a experiments on rice-wheat sequence with graded levels of fertilizers, indicated that continuous application of recommended dose of NPK could sustain high yields of both the crops and very little scope of reducing or skipping any amount of NPK dose (Soni *et al.*, 1988). The grain yield of sorghum is highly associated with panicle weight that has maximum positive direct effect on yield (Nimbalkar *et al.*, 1988 and Jayaprakash *et al.*, 1997).

According to Kandiappan and Rangaswamy (1990), the contribution of fertilizer was the highest in increasing the sorghum yield. Application of 100 kg N + 60 kg P_2O_5 + 40 kg K_2O/ha produced significantly higher grain yield (21.3 q/ha) of sorghum over 50 kg N + 30 kg P_2O_5 + 20 kg K_2O/ha (15.85 q/ha) (Raghuwanshi *et al.*, 1990). Dakore and Mungikar (1991) noted an increase in dry matter yield with application of NPK fertilizers. Similarly, Chaudhary and Khade (1991) also observed a progressive increase in grain yield with increasing rates of NPK. A linear increase in grain yield of sorghum cv. CSH-9 was noted with 50, 75 and 100 per cent recommended dose of fertilizers (120 kg N + 60 kg P_2O_5 + 60 kg K_2O/ha) (Kasole *et al.*, 1994). Raghuwanshi and Umat (1994) observed that fertility level of 120 kg N + 60 kg P_2O_5 + 40 kg K_2O/ha gave maximum grain yield (42.97 q/ha) as compared to control (14.81 q/ha). The studies of Jadhav (1994) at Pune (Maharashtra) revealed that grain and fodder yield of sorghum decreased respectively, by 16.74 and 12.03 per cent when fertility level was reduced to half. While studying the effect of continuous use of balanced fertilization, Bhatia and Sikarwar (1995) found a decreasing trend for sorghum-wheat production with the application of nitrogen alone indicating a need of a P application in addition to nitrogen for sustaining crop production. They concluded that continuous application of 120 kg N + 80 kg P_2O_5 + 40 kg K_2O/ha could sustain the yield without serious depletion in soil fertility. Balasubramanian and Ramamoorthy (1996a) concluded that 120 kg N + 60 kg P_2O_5/ha was the optimum dose for getting higher yields of sorghum. Every corresponding rise in fertility levels to 50, 75 and 100 per cent recommended dose to sorghum significantly enhanced the grain production upto the highest level of 100 kg N + 60 kg P_2O_5 + 40 kg K_2O/ha (Dubey *et al.*, 1997). Mahakulkar *et al.* (1998) also concluded that recommended dose of fertilizer proved productive and profitable than the other nutrient treatments tried in sorghum based cropping system at Akola. In Kolhapur district of Maharashtra, the response-fertilizer ratio was maximum (7.29) at recommended level of 120 kg N + 60 kg P_2O_5 + 60 kg K_2O/ha under irrigated conditions. The same ratio was obtained at 50 per cent of this recommended dose under rainfed conditions (Sharma *et al.*, 1999).

Pardhi (1976) found non-significant effect of FYM in improving the growth and yield attributes of sorghum at Akola. Rahate *et al.* (1979) reported that application of normal dose of fertilizers used in combination with a small dose of 5 t ha^{-1} of FYM over a long period of 11 years gave 25 to 30 per cent higher crop yields than those obtained by use of fertilizers alone. Helkiah *et al.* (1981) compared organic and inorganic sources of fertilizers on a black soil and reported that organic sources at different levels in combination with inorganic fertilizers significantly increased the grain and straw yields of hybrid sorghum. Prasad and Sinha (1981) also observed that increasing levels of fertilizers in combination with organic manures in a long term manure and fertilizer experiment conducted for 8 years at Ranchi, reported the highest yield in intensive cropping.

Bhatia and Shukla (1982) reported that continuous application of FYM for five years helped in maintaining and improving yield of maize as compared to application of chemical fertilizers alone in a permanent manurial trial. Kulkarni and Kulkarni (1982) observed that in many situations under long term effect studies with various cropping sequences, FYM plus NPK was better than NPK alone upto 90:45:45 level. But at 120:60:60 level of fertilizers, FYM had a little effect. Mandal *et al.* (1983) reported increasing fibre yield after eight years of intensive cropping and manuring in an annual rotation of jute-rice-wheat. The increase in fibre production due to 100 per cent NPK dose over 50 per cent NPK was significant.

Narkhede and Ghugare (1987) found that addition of leucaena loppings caused an increase in yield of winter sorghum in drylands. In a five years study, on nutrient management in cotton-wheat rotation on sandy loam soils, no residual and cumulative effects of N and P were observed in cotton and wheat, however growing cowpea for green manuring after wheat increased the yields of both the crops. Devarajan *et al.* (1987) concluded that application of 10 t FYM/ha increased grain yield of sorghum from 34.8 q/ha to 43.2 q/ha. Grain yield did not increase further with application of 20 t FYM/ha. In the same gesture, application of 4, 5 and 6 tonnes FYM per hectare increased grain yield of sorghum by 27.5 per cent at Indore (Sharma, 1987), 9.82 per cent at Dharwar (Goudreddy *et al.*, 1989) and 37.11 per cent at Parbhani (Bhosekar and Raikhelkar, 1990), respectively. Acharya and Bishnoi (1988) observed that the treatments receiving FYM and 100 per cent of the recommended NPK dose gave significantly higher crop yields than the other treatments after 13 years of continuous cropping and manuring. Application of FYM increased yield attributes viz., number of grains per panicle and 1000 grain weight (Goudreddy *et al.*, 1989 and Bhosekar and Raikhelkar, 1990). However, Duraisamy *et al.* (1990) opined that application of 5 or 10 t FYM/ha had no effect on yield of sorghum on red non-calcareous sandy loam soil at Coimbatore.

Muthuswami *et al.* (1990) observed that grain and straw yield of ragi, maize and cowpea, receiving the same fertilizer levels over a period of 16 years showed significant differences in yield of crops. Balanced application of NPK fertilizer, based on soil test in conjunction with FYM produced the highest yield of all the three crops. And when the dose of NPK was half of the fertilizer level, yield decreased. But at 150 per cent level, significant yield increase was recorded. Badanur *et al.* (1990) reported that incorporation of *Leucaena leucocephala* (Subabul) loppings @ 5 t ha^{-1} gave significantly higher sorghum grain yield as compared to sunhemp, sorghum stubbles and sunflower stalks. Udaysoorian (1990) found that among the organic manure treatments glyricidia leaf manure (GLM) recorded the highest grain yield in *kharif* and summer under rice-rice cropping system. Under continuous application of organic manures and fertilizers over a period of 9 years, GLM plus 120:60:60 kg NPK ha^{-1} level was found to be the suitable combination for rice-rice sequence in Tamil Nadu.

Bhat *et al.* (1991) stated that the beneficial effects of continuous recycling of crop residues for seven years in rice-wheat on yield of both the crops. Dhillon and Dhillon (1991) also found that the application of crop residues and different levels of fertilizers increased the yield of groundnut and wheat crop over suboptimum level of chemical fertilizers alone. Grewal *et al.*(1991) studied the effect of phosphorus, potassium and farmyard manure for potato based crop rotations and revealed that the residual effect of PK fertilizers and FYM applied to potato were sufficient for the succeeding cereal crops like wheat, maize and paddy. Direct and residual effects of FYM were comparatively more than PK fertilizers. FYM increased the yield of maize and paddy.

Kumar *et al.* (1993) reported that in rice-wheat cropping system, rice grain yield in green manuring treatment was comparable with 150 kg N ha^{-1} through fertilizer. Incorporation of crop residue with green manuring showed no decreasing effect on rice yield, when compared with green manuring or urea treatment alone after five years of experimentation. Maskina (1993) observed that wheat residue application reduced maize grain yield in first year and second year as compared to control treatment. However, wheat yield increased due to residual incorporation on long term basis. Combination of inorganic fertilizers and crop residue gave additive effect over the inorganic fertilizers alone. Sidhu *et al.* (1993) reported that green manuring and FYM treatments showed positive effect on sustainable yield index over 12 years of experimentation in maize-wheat sequence. Kumar (1993) observed that application of 10 and 20 t FYM/ha increased fodder yield by 12.08 ad 23.36 per cent, respectively over control.

Bellakki and Badanur (1994) observed that incorporation of subabul alone @ 5 t ha^{-1} every year recorded sorghum production on par with recommended dose of fertilizer. Sorghum stubble with subabul loppings either every year or alternate year gave significantly higher grain yield than control and stubble alone. More (1994) also found that FYM and wheat straw increased the yield of both the crops significantly over control under rice-wheat sequence over years. The effect of organic and inorganic fertilizers alone and in combination on yield of sorghum-wheat cropping system grown on medium black soil was studied by Raghuvanshi and Umat (1994), they reported that FYM, crop residue and green manure in conjunction with inorganic fertilizers leading to increase average grain yield of both the crops and indicated that the possibility to save N at least 25-50 per cent by applying FYM or crop residues or green manuring to sorghum. Arokiaraj and Kannappan (1995) obtained the highest grain (15.82 q/ha) and fodder (123.60 q/ha) yields, and B:C ratio (1.18) with application of 5 t FYM/ha on moderately sodic clay loam soil at Tiruchirapalli (Tamil Nadu). Hegde (1996) opined that without any significant reduction in productivity in rice-rice system, about 25-50 per cent N need of crops could be substituted by organic manures like FYM and green manuring in coastal area. Tilak and Singh (1996) observed that incorporation of wheat residues before rice planting increased the yield of both the crops in rice-wheat sequence. Patil (1997) indicated that pearl millet-wheat cropping system with green manuring in summer gave high grain and biomass productivity/ha per rupee invested on fertilizer than other crop sequences and reduction in fertilizer dose to 50% of both the crops.

Application of 10 t FYM/ha increased grain yield of sorghum from 77.4 q/ha to 88.0 q/ha (Hunshal *et al.*, 1989) and from 21.6 to 26.1 q/ha (Kushwaha and Kushwaha, 1995).

Application of FYM at 10 t/ha increased grain and fodder yields of sorghum significantly (Dasalkar *et al.*, 1992; Sarangmath *et al.*, 1994 and Patil and Varade, 1998).

2.1.5.1 Harvest index

A significant improvement in harvest index of sorghum was observed with application of nitrogen upto 80 kg N/ha was recorded (Meghwanshi, 1992). Lomte *et al.* (1994) concluded that there was efficient utilization of N upto 80 kg/ha under dry sown condition. Hybrid CSH-9 and CSH-11 were superior to CSV-10 for the grain yield, but CSV-10 was superior to fodder yield. The application of 80 kg N/ha significantly increased the harvest index

(27.8%) over 40 kg N/ha (27.0 per cent) and control (25.8 per cent), respectively (Kumawat and Bansal, 1996). Poonia (1997) reported that harvest index was increased significantly upto 80 kg N/ha (32.4%) and decreased with further increase in the N rate upto 120 kg N/ha (26.05 per cent). Sharma (1997) also reported similar results. Sharma and Jain (1997) observed that nitrogen application at 90 kg/ha increased harvest index of sorghum (28.43%) over 30 kg N/ha (27.27%). However, the difference between 30-60 and 60-90 kg N/ha was not significant. Application of nitrogen upto 120 kg N/ha significantly increased harvest index of dual purpose sorghum during 1994, whereas, the influence of nitrogen application on harvest index was not significant during 1995 (Dashora, 1998).

Langewar and Khot (1978) observed superior harvest index of sorghum with phosphorus application. Meghwanshi (1992) observed that a successive increase in phosphorus application upto 40 kg P_2O_5 /ha significantly increased harvest index of sorghum.

Amrutsagar and Sonar (1999) reported that the highest grain and straw yield of sorghum (45 and 57 q/ha) were recorded by application of 120 kg K_2O ha^{-1}.

The harvest index of sorghum CSH-6 increased with full dose of fertilizer (75 kg N + 50 kg P_2O_5 /ha) as compared to half dose (Jadhav, 1994). However, Singh *et al.* (1996) noted that the harvest index did not differ significantly amongst fertility levels, as the grain yield did not increase proportionately to stover yield with increase in NP fertilization.

Chaudhari (1992) reported that hybrid CSH-5 and CSH-9 showed significant superiority over PJ8K, an old genotype through higher number of grains and harvest index. At Hanumangrah and Bichpuri both the pearl millet and wheat showed declining trend in yields over years even with NPK application. However, at Junagarh, there was an increasing trend in the yields of both crops over years with NPK application (Hegde and Katyal, 1999).

Application of organic manure and fertilizers in different combination significantly increased the grain yield over control. Considering the mean yield of N application increased the yield from 16.29 to 34.47 q ha^{-1}. The efficiency of N was tremendously increased when P was applied in combination raising the yield level to 45.05 q ha^{-1} (Deshmukh *et al.*, 1994). Rasal *et al.* (1996) observed that in sorghum phospho-compost not only replaced the single super phosphate but also saved 30 kg nitrogen requirement with an increase in biomass yield by 8% over the application of recommended dose of single super phosphate alone.

The application of 120 kg N/ha alongwith Azotobater and Azospirillum seed inoculation to sorghum (CSH-9) gave maximum grain yield (48.95 q/h) and fodder yield (127.47 q/ha) (Pawar *et al.*, 1996). Grain yield of sorghum (CSH-9) was increased with increase in fertilizers applied upto 80 q/ha of yield target beyond which the crop indicated adverse effect on grain and fodder yields. The fodder yields remained unaffected due to fertilizers applied upto 80 q/ha yield target. The harvest index remained almost stable beyond fertilizer application at 80 q/ha yield target (Tambe and Bhoi, 1999).

A long term field trial on integrated nutrient supply in pearl millet-wheat cropping system was concluded 11 years at 3 locations and results revealed that at Hisar, 50% recommended NPK + 50% N through FYM in *kharif* followed by 100% NPK in *rabi* gave system's yield of 6.16 t/ha while at

Hanumangarh, 50% recommended NPK + 50% N through green manuring in *kharif* followed by 100% recommended NPK in *rabi* gave systems productivity 5.86 t/ha and at S.K. Nagar, 75% recommended NPK + 25% N through crop residue applied in *kharif* followed by 75% recommended NPK in *rabi* gave maximum system productivity of 4.24 t/ha (Katyal *et al.*, 1999). Patil *et al.* (1999) revealed from pooled results that increasing fertility levels significantly increased the grain and fodder yields of sorghum over control where 50% NPK + 50% N through FYM applied to sorghum. Patidar (2000) revealed that application of 10 t FYM/ha, 75% RDF and Azospirillum and PSB inoculation gave maximum sorghum and fodder yield (52.15 and 117.08 q/ha).

2.1.5.2 Protein content

Application of nitrogen upto 100 kg/ha increased protein content in sorghum grain (Kohale *et al.*, 1986). Thakre *et al.* (1989) observed improvement in grain protein upto 150 kg N/ha. The crude protein content and protein yield also showed improvement upto application of 120 kg N/ha (Malik *et al.*, 1992). Sorghum fertilized with 150 kg N/ha recorded significantly higher protein yield by sorghum grain (Kushawaha and Chandel, 1997). Deshora (1998) observed that N fertilization did not significantly affected protein content in grain but it had a significant effect on protein content in stover of dual purpose cultivar CSV-15. Kehar Singh and Balyan (2000) reported that the protein content in sorghum (CSH-9) grains did not differ significantly due to different cropping systems. Each increase in nitrogen level upto 120 kg/ha significantly increased the protein content of sorghum grains.

The protein content of sorghum grain was increased with P application (Zadole and Padole, 1984). However, Patel *et al.* (1993) found that protein content was unaffected by P_2O_5 application.

Application of 100 per cent recommended level of fertilizer (60 kg N + 30 kg P_2O_5 /ha) yielded significantly higher protein content than 50 per cent recommended dose and control (Gangwar and Singh, 1992). Similarly, Jadhav (1994) also reported that protein content and protein production increased with full dose of fertilizers (75 kg N + 50 kg P_2O_5 /ha) as compared to half dose. Pal *et al.* (1996) found that protein content was higher by 57.6 per cent with application of 100 kg N + 50 kg P_2O_5 /ha as compared to 20 kg N + 10 kg P_2O_5 /ha.

2.2 Effect of integrated nutrient management on crop growth characters and yield attributes of wheat

Most of the investigations reported that the nitrogen, phosphorus and potassium favourably influenced the growth and growth contributing characters viz., plant height, tillering, number of functional leaves, leaf area and dry matter production in wheat. Similarly, the yield and yield contributing characters viz., productive tillers, length of panicle, number of spikelets per panicles, number of grains per panicle, grain weight per panicle, thousand grain weight and total biomass yield etc., are also found to be favourably influenced by judicious application of NPK.

2.2.1 Plant height

Studies on sowing dates, seed rates and fertilizer doses on growth and yield of late sown wheat by Auti (1980) indicated that variety Sonalika with the application of 100 kg N ha^{-1} produced 4 cm more plant height than that of 60 kg N ha^{-1}.

Dhuka *et al.* (1991) indicated that increase in N level also increased plant height significantly. However, the studies conducted by Awashti and Surajbhan (1993) to test the performance of wheat varieties with different levels of nitrogen in moisture scarce condition revealed that increased levels upto 60 kg N ha^{-1} increased the plant height significantly. Moreover, at Ludhiana field experiments conducted by Samra and Dhillion (1993) revealed that the application of N remarkably increased the plant height upto 180 kg ha^{-1}. Similarly, the results reported by Guriqbal Singh and Brar (1994) indicated that increasing levels upto 150 kg N ha^{-1} increased the plant height (79.50 cm). Significant increase in plant height was noticed at Junagarh, with the application of 120 kg N and 60 kg K_2O ha^{-1} (83.5 cm). Further, increase in N level was not beneficial as far as plant height was concerned (Patel *et al.*, 1995).

Hooda and Agrawal (1987) noticed that at harvest plant attained 6 cm more height with application of 120 kg N + 60 kg P_2O_5 ha^{-1}.

Nikam (1985) studied the effects of different sources and levels of fertilizer on growth, yield and quality of wheat cv. HD2189. It was observed that the plant height recorded with the application of 120 + 60 + 60 kg NPK ha^{-1} was the highest during entire growth and it was significantly more than rest of the reduced levels tried. Similar results have been reported by Barve (1987). Rajput *et al.* (1987) reported that the balanced dose of fertilizer increased the plant height. Wadile (1995) noticed that the plant height was highest during the entire growth and was significantly more with the application of 120 + 60 + 60 kg NPK ha^{-1} than the rest of the reduced levels tried except at the 60^{th} day at which the same was at par with that recorded with 90 + 45 + 45 kg N, P_2O_5 , K_2O ha^{-1}. Similar results were reported by Auti (1996).

Desai *et al.* (1999) observed maximum growth, dry matter and grain yield (35.77 q/ha) of wheat was obtained with an application of 120 kg N/ha half through vermi-compost and half through urea. Balyan (1992) reported that residual effect of legume incorporation into the soil increased the yield attributes: N concentration and N uptake by wheat plants. Grain yield, growth attributes, N concentration and uptake in wheat and available N in soil showed an increase with N level upto 80 kg/ha.

2.2.2 Leaf number and leaf area

Zope (1981) found that the leaf area was increased significantly with the increase in the nitrogen levels from 120 kg to 160 kg N ha^{-1}. Awasthi and Surajbhan (1993) showed that increasing level of N upto 60 kg ha^{-1} increased the leaf area index. Increasing N application upto 180 kg ha^{-1} resulted into significant increase in the leaf area and growth rate over control has been reported by Ashok Kumar *et al.* (1994).

Auti (1980) observed that the number of functional leaves and leaf area per plant with full dose of fertilizer i.e. 100 kg N + 50 kg P_2O_5 ha^{-1} was significantly more than the reduced dose of fertilizer i.e. 60 kg N + 60 kg P_2O_5 ha^{-1}.

While, Nikam (1985) reported the highest functional leaves and leaf area per plant due to application of 120 + 60 +60 kg NPK ha^{-1} throughout the growth. Similar results have been reported by Barve (1987).

Jadhav (1989) observed that an increase in leaf area per plant was due to increase in leaf number and its expansion with the increased levels of fertilizer.

2.2.3 Tillering (Total and productive)

Results of a field trial conducted at Rahuri (Borse and Mahajan, 1980) revealed that the productive tillers per plant were significantly more due to the application of 100 kg N ha^{-1} and 50 kg N ha^{-1} over control, however, differences amongst them were at par. Similarly, Rao and Bhardwaj (1981) noticed that there was significant increase in ear bearing shoots per meter length upto 120 kg N ha^{-1}. Malik (1981a) observed that effective tillers per square meter increased with increase in N level from 0 to 120 kg ha^{-1}. Adesh Bharti *et al.* (1987) found that effective tiller per meter row length significantly increased with increase in N level from 0 to 160 kg ha^{-1}. However, there were no significant differences between 120 and 160 kg N ha^{-1}. Similar findings have been reported by Barve (1987) and Pawar *et al.* (1988).

Soni *et al.* (1989) observed that effective tiller per plant increased with increase in N level from 0 to 125 kg ha^{-1}. Patel and Upadhyay (1993) reported that increasing the rate of N upto 120 kg N ha^{-1} significantly increased the total and effective tillers m^{-1}. While, Ashok Kumar *et al.* (1994) reported that the number of productive tillers increased significantly with increase in N dose from 0 to 180 kg ha^{-1}. The significant increase in effective tillers per plant with increasing level of N upto 90 kg N ha^{-1} was observed by Mishra *et al.* (1994).

Gautam *et al.* (1991) revealed that application of P either alone or in combination with N, produced significantly more number of effective tillers than their respective control. The study conducted by Singh *et al.* (1995)

revealed that nitrogen, phosphorus applications increased the effective tillers per meter square significantly upto 120 kg N + 60 kg P_2O_5 ha^{-1}.

Nikam (1985) reported that the number of total and productive tillers per plant due to the application of 120 + 60 + 60 kg N, P_2O_5 , K_2O ha^{-1} were the highest at all stages of growth and significantly more than those recorded with 60 + 30 + 30 kg N, P_2O_5, K_2O ha^{-1}. Girothia *et al.* (1987) studied the response of wheat cultivar to sowing time and fertility levels and observed that 120 + 60 + 60 kg N + P_2O_5 + K_2O ha^{-1} was the optimum dose for wheat which produced significantly more effective tillers. The number was 73.9 and 71.8 per meter row length during 1983-84 and 1984-85, respectively. Field experiment was conducted by Singh *et al.* (1993) on wheat to study the responses of planting method, seed rate and fertilizer. It was indicated that application of sub-optimum levels of fertilizers (60 kg N + 30 kg P_2O_5 + 25 kg K_2O ha^{-1}) significantly reduced the tiller per square meter and caused poor growth of crop and provided more space for weed to grow. Wadile (1995) opined that the mean number of tillers per plant produced with application of 120 + 60 + 60 kg N, P_2O_5 , K_2O ha^{-1} was the highest at all the stages of growth and was significantly more than that recorded at rest of the levels. Similar findings have been reported by Auti (1996).

2.2.4 Dry matter production

The results of the field experiment conducted to study the effect of different levels of nitrogen and phosphorus on growth, yield and quality of wheat by Jadhav (1976) indicated that dry matter per plant increased with increase in the levels of nitrogen at 80 days after sowing. Application of 180 kg N ha^{-1} increased the dry matter per plant significantly over 60 and 120 kg N ha^{-1}. Significant response to nitrogen fertilization in increasing dry matter per plant upto 100 kg N ha^{-1} over 50 kg N ha^{-1} has been reported by Borse and Mahajan (1980). While studying the response of wheat varieties to seed rates and nitrogen, Sharma and Dhillon (1987) reported that dry matter yield increased upto 140 kg N ha^{-1} and gave diminishing returns with higher rates. Awasthi and Surajbhan (1993) showed that increasing levels of N upto 60 kg N ha^{-1} increased the dry matter production.

Raundal *et al.* (1999) reported that application of 60 kg P_2O_5 /ha to previous crop produced significantly higher growth, dry matter, yield contributing characters and yield of wheat grown in *rabi* season.

Studies conducted by Auti (1980) revealed that the dry matter accumulation was influenced significantly by fertilizer levels, on all the days of observation. The fertilizer dose of 100 kg N and 50 kg P_2O_5 ha^{-1} produced significantly more dry matter than 60 kg nitrogen and 30 kg phosphate ha^{-1}.

Pandey *et al.* (1986) observed that the total dry matter yields increased with N application upto 120 kg N ha^{-1}. The differences between 120 and 180 kg N ha^{-1} were not significant. At the same time application of 120 kg N + 60 kg P_2O_5 increased the dry matter yield significantly over the half dose i.e. 60 kg N + 30 kg P_2O_5 ha^{-1} at all the stages of the crop. These results are in conformity of Barve (1987) and Jadhav (1989).

Nikam (1985) noticed that the total dry matter increased significantly with every successive increase in the level of fertilizers. The dry matter production with 120 + 60 + 60 kg NPK ha^{-1} was the highest and significantly more than that in the other lower levels of fertilizer. The study conducted by Singh *et al.* (1993) revealed that crop fertilized with 100 per cent recommended dose of fertilizer increased dry matter significantly than that of 50 per cent of the recommended dose of fertilizer and the control.

Auti (1996) observed that the mean dry mater increased significantly with every successive increase in the level of fertilizers and the highest dry matter was produced with 120 + 60 + 60 kg N, P_2O_5 , K_2O ha^{-1} at all the growth phases and was significantly more than those obtained in the rest of the levels of fertilizer tried. The values of total dry matter accumulated with 120 + 60 + 60 kg NPK ha^{-1} were 0.196, 3.523, 8.057 and 9.09 g per plant on the 30^{th}, 60^{th} and 90^{th} day of crop age and at harvest, respectively. Similar findings have been reported by Wadile (1995).

2.2.5 Length of panicle

Singh and Agrawal (1983) observed that the application of 120 kg N ha^{-1} produced the maximum spike length, while studying the effect of some wheat genotypes to *Azotobacter* and *Azospirillum* inoculation and effects of these inoculations under graded levels of nitrogen. Zambre (1983) observed that the ear length (cm) increased with each successive increase in the levels of nitrogen upto 90 kg N ha^{-1}. The values were 6.33, 7.29, 7.97, 8.55 and 8.52 cm, respectively. Moreover, 90 kg and 120 kg N ha^{-1} were at par with each other. Pandey *et al.* (1986) indicated that increase in the spike length was observed upto 120 kg N ha^{-1}. Dubey *et al.* (1989) reported that increasing level of N increased the ear length. The results of the experiment conducted by Sharma and Malik (1993) at Hissar indicated that length of ear (cm) increased only upto 120 kg N ha^{-1}. Ashok Kumar *et al.* (1994) observed that panicle length increased significantly with successive increase in the level of N from 0 to 180 kg ha^{-1}. Patel *et al.* (1995) reported that the length of spike increased only upto 120 kg N ha^{-1}. Further increase in N level was not found beneficial.

Auti (1980) reported that the earhead length was significantly more with 100 kg N + 50 kg P_2O_5 ha^{-1} than that with 60 kg N + 30 kg P_2O_5 per hectare. The experiment conducted by Patel and Upadhyay (1993) indicated that ear length was increased upto 120 kg N ha^{-1}. However, application of 60 kg and 75 kg P_2O_5 ha^{-1} gave no significant differences.

Nikam (1985) found that the panicle length recorded with 120 + 60 + 60 kg NPK ha^{-1} was the highest (8.19 cm) and was significantly more than those obtained with 60 +30 +30 kg NPK ha^{-1} (7.66 cm). Girothia *et al.* (1987) revealed that ear length significantly increased with increasing fertilizer dose upto 120 + 60 + 60 kg N + P_2O_5 + K_2O ha^{-1}. Further, increase in the level of fertilizers i.e. 180 kg N + 90 kg P_2O_5 + 90 kg K_2O ha^{-1} did not influence the additional length of earhead to the level of significance. This clearly indicated that 120 + 60 + 60 kg of N + P_2O_5 + K_2O ha^{-1} was optimum dose. Rajput *et al.* (1987) found that the fertilizer dose of 120 kg N + 60 kg P_2O_5 + 60 kg K_2O ha^{-1} increased the ear length. Pawar *et al.* (1988) revealed that the length of panicle was significantly more in recommended dose of fertilizer (9.1 cm) as compared to 50 per cent of the recommended level (8.2 cm).

Singh *et al.* (1993) revealed that wheat crop fertilized with 120 + 60 + 40 kg NPK ha^{-1} gave significantly more length of spike than that of 50 per cent of the recommended fertilizer and the control. Wadile (1995) observed that the panicle length recorded with 120 + 60 + 60 kg NPK ha^{-1} was the highest (8.30 cm) and was significantly superior to the rest of the fertilizer levels tried. Similar findings have been obtained by Auti (1996).

2.2.6 Number of spikelets per panicle

It was reported by Singh and Sharma (1976), the number of fertile spikelets per panicle increased significantly upto 120 kg N ha^{-1} and declined thereafter. Similar findings have been reported by Rao and Bhardwaj (1981). Gami *et al.* (1986) reported higher spikelet number per spike with 120 kg

N ha^{-1}. However, increase in the level of N from 120 kg to 160 kg ha^{-1} did not differ significantly as far as the number of spikelets per panicle are concerned. However, Dhuka *et al.* (1991) found that increase in the level of N increased the spikelets per spike. Sharma and Malik (1993) reported that fertilizer spikelets per ear increased only upto 120 kg N ha^{-1}. Further increase in N level upto 150 kg ha^{-1} decreased fertile spikelets.

Patel and Upadhyay (1993) revealed that the number of spikelets per panicle increased upto 120 kg N ha^{-1}. However, number of spikelets per panicle with 45 kg, 60 kg and 75 kg P_2O_5 ha^{-1} did not differ significantly.

Patel *et al.* (1995) reported that number of spikelets per spike increased with increase in N and K level upto 150 and 60 kg ha^{-1}, respectively.

Auti (1980) observed that the number of spikelets per earhead was significantly more with recommended level of fertilizers than those with reduced level of fertilizers. These results are in agreement of the findings of Nikam (1985). Barve (1987) observed the higher (16.66) spikelet number per panicle with recommended dose than the reduced levels of fertilizer. It was reported by Wadile (1995) that the spikelets number produced with 120 + 60 + 60 kg NPK ha^{-1} was the highest (20.86) and was significantly superior to the spikelet number due to reduced levels. Similar findings have been reported by Auti (1996).

2.2.7 Number of grains per panicle

Borse and Mahajan (1980) found that there was a significant response to nitrogen fertilization for number of grains per ear with application of 100 kg N ha^{-1} over 50 kg N ha^{-1} and the difference in the grain number per ear was not significant due to 100 and 160 kg N ha^{-1}.

Zope (1981) reported that with increasing nitrogen levels, the number of grains per ear was significantly increased from 120 to 160 kg N ha^{-1}. Zambre (1983) found that with increasing levels, the number of grains per ear increased significantly. The values were 28.32, 32.43, 33.53, 37.50 and 38.09 for 0, 30, 60, 90 and 120 kg nitrogen per hectare, respectively. The two levels viz., 90 kg N and 120 kg N ha^{-1} were at par with each other. The number of grains per ear increased significantly upto 150 kg N ha^{-1} was reported by Kumar and Prasad (1986).

Gami *et al.* (1986) revealed that number of grains per panicle due to 120 and 160 kg N ha^{-1} did not differ significantly but it was significantly higher as compared with lower level of N. Pandey *et al.* (1986) observed that with increasing levels of N upto 120 kg N ha^{-1} increased the grains per spike. However, the differences amongst 120 and 180 kg N ha^{-1} were not significant.

The study conducted by Auti (1980) revealed that the application of 100 kg N + 50 kg P_2O_5 per hectare produced significantly more number of grains per ear than 60 kg N + 30 kg P_2O_5 per hectare. Singh *et al.* (1995) found that grains per ear increased significantly with the application of N upto 180 kg ha^{-1}. Phosphorus application upto 60 kg ha^{-1} increased the grains per ear.

Patel and Upadhyay (1993) revealed that grain per spike increased significantly upto 150 kg N ha^{-1} and application of 60 and 75 kg P_2O_5 ha^{-1} gave no significant differences. Patel *et al.* (1995) reported that grains per spike increased upto 150 kg N ha^{-1} and 60 kg K_2O ha^{-1}

Nikam (1985) revealed that the number of grains per panicle was increased significantly with every successive increment in the level of fertilizer. However, the difference between 120+60+60 and 100+50+50 kg NPK ha^{-1} levels was not significant and the number of grains per panicle recorded in 120 + 60 + 60 kg NPK ha^{-1} was the highest (39.60 grains per panicle). Mahatim Singh *et al.* (1987) showed that application of 120 kg N + 40 kg P_2O_5 + 40 kg K_2O ha^{-1} increased the grains per spike which enhanced the grain and straw yield. Rajput *et al.* (1987) found that 120 + 60 + 60 kg NPK ha^{-1} had increased grains per ear significantly over control and lower doses of fertilizer. Similar findings are reported by Barve (1987) and Pawar *et al.* (1988). Patra (1990) reported that the highest number of grains per ear with 120 + 60 + 60 kg NPK ha^{-1} was obtained than that of reduced level of fertilizers.

Tomar *et al.* (1993) revealed that the increasing rate of fertility increased the grains per ear significantly. N, P and K @ 120, 60 and 40 kg ha^{-1} gave maximum grain per spike as compared to reduced level of fertility i.e. 60 + 30 + 20 kg NPK ha^{-1}. Wadile (1995) found that the number of grains per panicle recorded with 120 + 60 + 60 kg NPK ha^{-1} was the highest and more (42.15 grains per panicle) than those obtained in rest of the levels. Similar findings have been obtained by Auti (1996).

2.2.8 Grain weight per plant at harvest

While studying the response of late sown wheat varieties to nitrogen, Adesh Bharati *et al.* (1987) reported that grain weight per ear increased significantly with increase in the level of nitrogen upto 120 kg ha^{-1}. Sharma and Malik (1993) observed that weight of ear and grain weight per ear increased only upto 120 kg N ha^{-1}. Further increase in N level, did not increase the values of these characters favourably. Patel *et al.* (1995) reported that the grain weight per spike increased significantly upto 120 kg N ha^{-1}, and the differences between 120 kg and 150 kg N were not significant.

Upadhyaya and Dubey (1991) reported that the successive increment of fertility level upto 120 + 60 + 40 kg NPK ha^{-1} increased the weight of grains per plant. Wadile (1995) found that the application of 120 + 60 + 60 kg NPK ha^{-1} produced the highest grain weight per plant (2.23 g) which was significantly superior to that recorded due to the rest of the reduced levels tried. Similar findings have been reported by Auti (1996).

2.2.9 Thousand grain weight

The study conducted by Zambre (1983) revealed that the nitrogen levels significantly increased the thousand grain weight with each successive increased level from 0, 30, 60, 90 and 120 kg N ha^{-1} and the mean thousand grain weight values were 28.65, 34.36, 37.60, 41.09 and 43.38 g, respectively in case of cv. HD-2189. Gami *et al.* (1986) reported that the thousand grain weight increased with increase in the level upto 160 kg N ha^{-1}. However, there was no significant difference between 120 kg and 160 kg N ha^{-1}.

The thousand grain weight increased significantly due to successive increase in level of N from 50 to 150 kg ha^{-1} observed by Kumar and Prasad (1986). Sanira and Dhillon (1993) reported that the application of 0, 40, 80, 120 and 160 kg N ha^{-1} increased the thousand grain weight. Guriqbal Singh and Brar (1994) at Ludhiana indicated that thousand grain weight was decreased with each successive increment in the level of nitrogen and it was 42.4 (g) with 60 kg N ha^{-1} and 38.8 (g) with 150 kg N ha^{-1}. Patel (1999) reported that the grain and straw yield increased significantly upto 120 kg N/ha; this might be ascribed to the combined effect of significant improvement in growth and yield parameters i.e. plant height, number of productive tillers/plant, length of panicle, number of grains/panicle and 1000 grain weight with N application.

Gautam *et al.* (1991) found that application of P either alone or in combination with N produced significantly more thousand grain weight than their respective control.

While studying the response of wheat genotypes to nitrogen and phosphorus, Singh *et al.* (1995) reported that thousand grain weight increased with increase in the level of N from 0 (36.7 g) to 160 kg ha^{-1} (47.3 g) and P level from 0 (42.1 g) to 60 kg ha^{-1} (43.6 g).

The thousand grain weight recorded with 120 + 60 + 60 kg NPK ha^{-1} was significantly more (43.87 g) than those obtained in the rest of the reduced levels tried (Nikam, 1985). Barve (1987) opined that the thousand grain weight recorded with recommended dose of 120 + 60 + 60 kg NPK ha^{-1} was significantly more (42.11 g) than that with reduced level of 60 + 30 + 30 kg NPK ha^{-1}. Girothia *et al.* (1987) found that the thousand grain weight increased with increase in the level of fertilizer upto the highest level of 180 + 90 + 90 kg NPK ha^{-1}. Mahatim Singh *et al.* (1987) concluded that application of N, P and K had marked effect on yield attributes. Thousand grain weight did not show significant increase beyond 80 kg N ha^{-1} but the application of 120 + 40 + 40 kg NPK ha^{-1} increased the thousand grain weight. Pawar *et al.* (1988) revealed that the thousand grain weight was significantly more in recommended dose of fertilizer (42.1 g) as compared to 50 per cent of the recommended level (40.7 g).

2.2.10 Grain and straw yield

At Rahuri, Borse and Mahajan (1980) reported that the application of nitrogen at a rate of 100 and 150 kg N ha^{-1} significantly increased the grain and straw yields of wheat over 50 kg N ha^{-1}. While studying the response of wheat varieties to different levels of nitrogen under Sangaria (Raj.) condition, Malik

(1981) found that the grain yield increased with the increasing levels of nitrogen upto 120 kg N ha^{-1} (45.70 q ha^{-1}) and thereafter there was no significant increase in the grain yield (44.90 q ha^{-1}) at 160 kg N ha^{-1}. Chillar and Dargan (1982) at Karnal reported that the increasing levels of nitrogen increased the grain yield significantly. The grain yield increased nearly 5 times with 120 kg N ha^{-1} as compared to control.

The experiment conducted at Rahuri by Zambre (1983) indicated that the grain yield increased significantly with increase in each successive level of nitrogen. Maximum and significantly more grain yield (38.70 q ha^{-1}) was produced by 120 kg N ha^{-1} over 0, 30, 60 and 90 kg N ha^{-1}.

Regmi *et al.* (1984) reported that at IARI, nitrogen application to wheat increased both grain and straw yield significantly with each increasing N dose upto 120 kg ha^{-1}. This was in conformity with the results obtained by Singh and Singh (1984). The application of 150 kg N ha^{-1} produced higher grain yield (38.50 q ha^{-1}) over 120 kg N ha^{-1} (36.70 q ha^{-1}) was observed by Gurbachan Singh (1986).

The data of a trial conducted by Pandey *et al.* (1986) at Pantnagar with four levels of N i.e. 0, 60, 120 and 180 kg ha^{-1} revealed that the grain yield and total dry matter yield increased significantly upto 120 kg N ha^{-1}. The difference between 120 kg and 180 kg N ha^{-1} were not significant. Similar trend was noticed by Malik *et al.* (1986) at Hisar. Sharma and Dhillon (1987) found that the grain yield increased significantly upto 120 kg N ha^{-1} (40.80 q ha^{-1}) but further increase in the dose upto 160 kg N ha^{-1} had no effect. The straw yield also increased upto 120 kg N ha^{-1}. Khan and Tomar (1988) observed that higher grain yield was recorded under 120 kg N ha^{-1} as compared to 60 kg N ha^{-1}. Dhuka *et al.* (1991) found that the grain yield and straw yields at 80 and

120 kg N ha^{-1} were similar but significantly superior to those obtained with 40 kg N ha^{-1}. Lathwal *et al.* (1991) observed that application of 120 kg N ha^{-1} significantly increased the grain as well as straw yield. This might be due to more production of photosynthates and their translocation to the sink (yield attributes) under adequate irrigations and higher doses of N. Similar results were obtained by Rathore and Patel (1991).

The study conducted by Ashokkumar *et al* (1994) revealed that the grain yield of wheat increased by 68.2, 115.0 and 141.8 per cent with application of 60, 120 and 180 kg N ha^{-1} over control. Each successive increase in N from 0 to 180 kg N ha^{-1}, gave significantly higher yield. Patel (1999) reported that the grain and straw yields of wheat increased significantly upto 120 kg N/ha. Patel (1999) reported that application of N in split doses recorded better grain yield. Application of N in a ratio of 50:25:25 per cent at sowing 21 and 45 DAS, respectively recorded significantly higher grain yield (34.30 q/ha) compared to other methods of N application.

Reddy and Bhardwaj (1983) revealed that nitrogen application upto 120 kg ha^{-1} significantly increased the grain and straw yield of wheat. Similarly, phosphorus application also increased the grain and straw yield upto 50 kg ha^{-1} level. Patel and Upadhyay (1993) conducted the field experiment at Anand and found that the grain and straw yields increased significantly with increasing rate of N upto 120 kg N ha^{-1}. The application of 60 and 75 kg P_2O_5 gave higher straw yield over 45 kg P_2O_5 , the grain yield increased upto 75 kg P_2O_5 ha^{-1}.

The study conducted by Nikam (1985) under Rahuri conditions indicated that per hectare grain and straw yields obtained due to 120 + 60 + 60 kg NPK ha^{-1} were the highest (41.70 q ha^{-1}) and significantly more than the other reduced levels tried; except 100 + 50 + 50 kg NPK ha^{-1} which was on par (39.60 q ha^{-1}).

Singh *et al.* (1986) observed that the average response to N at 40, 80 and 120 kg N ha^{-1} was 7.74, 13.47 and 17.70 q ha^{-1}, respectively. The average response to P at 20, 40 and 60 kg P_2O_5 ha^{-1} was 4.37, 5.77 and 6.78 q ha^{-1}, respectively. The response to K at 20, 40 and 60 kg K_2O ha^{-1} was 1.72, 2.43, 4.56 q ha^{-1}, respectively. Response to zinc was not significant. The highest grain yield was obtained due to 120 + 60 + 60 kg NPK ha^{-1} (46.00 q ha^{-1}). The data of a trial conducted by Girothia *et al.* (1987) at Indore with four levels of N, P and K indicated that the grain yield (40.70 q ha^{-1}) increased with increase in the level of the fertilizer dose upto 120:60:60 kg NPK ha^{-1}. The results of the experiment conducted by Pawar *et al.* (1988) at MPKV, Rahuri for two years indicated that the yield of wheat (cv. HD-2189) was drastically reduced when fertilizer dose was reduced to 50 per cent of the recommended level (47.90 q ha^{-1}). The yield obtained with recommended level was 54.0 q ha^{-1}. On an average reduction of 3.6 q of grain and 5.6 q of straw ha^{-1} was observed when compared with 100 per cent recommended level.

Nakhtore and Kewat (1989) observed that grain and straw yields increased significantly with increase in fertility level from zero (13.20 q ha^{-1}) to 100 per cent recommended doe of 120 + 60 + 40 kg NPK ha^{-1} (37.20 q ha^{-1}). Similar results were reported by Patra (1990). Tomar *et al.* (1993) observed that grain and straw yields increased significantly due to 120:60:40 kg NPK ha^{-1} over 60:30:30 kg NPK ha^{-1}.

Hajra *et al.* (1982) noticed that application of wheat straw alone did not significantly affect the yield of wheat grain. However, N alone or wheat straw plus N increased the yield of wheat grain over control. Mishra *et al.* (1999)

reported the results on direct effect of lime, organic and inorganic nutrients on wheat productivity. Patil *et al.* (1999) revealed from pooled results that increasing fertility level significantly increased grain and straw yields of wheat where 50% NPK + 50% N through FYM applied to sorghum and 100% NPK to wheat was given.

2.2.11 Protein in wheat grain

Jadhav (1976) found that the protein percentage in grain increased with increase in the levels of nitrogen from 0 to 180 kg ha^{-1}. The maximum value of 13.8 per cent protein was observed at 180 kg nitrogen level and the lowest value of 12.5 per cent was recorded in control treatments. Singh and Awasti (1983) reported that the protein content in grain increased significantly with increase in the levels of nitrogen upto 150 kg ha^{-1}. The study conducted by Patel and Upadhyay (1993) indicated that protein content in grain increased due to 150 kg N ha^{-1}.

Similar trend was observed in case of phosphate also. The protein percentage increased with the increase in the levels of phosphate. The respective protein percentage values with 0, 60 and 120 kg phosphate levels were 12.9, 13.4 and 13.5, respectively. Similar, results have been reported by Attarde and Khuspe (1979), Auti (1980). Yadav and Verma (1983) found that grain protein content increased with increasing levels of phosphorus.

Singh and Singh (1994) reported that the quality character of wheat-grain was favourably influenced by the application of phosphorus. The protein and gluten yields increased significantly with the application of P. The pelshenke and sedimentation values were higher in P treated plant over the control. The P fertilization increased the water absorbing capacity of *chapati* dough, puffing, aroma, texture, sweeter taste and keeping quality of *chapati* improved with fertilization compared to untreated one.

Barve (1987) under Rahuri condition found that the protein (14.00 per cent), wet gluten (36.02 per cent) as well as dry gluten (12.34 per cent) contents in grain was the highest with recommended level i.e. 120 + 60 + 60 kg NPK ha^{-1}. Chougule *et al.* (1993) reported that the protein content was significantly increased with increase in the level of N, P and K fertilizers. Wadile (1995) reported that the protein content in wheat grain was the highest due to 120 + 60 + 60 kg NPK ha^{-1} (13.20 per cent) which was significantly superior to other levels of fertilizer. Similar findings have been reported by Auti (1996). Pandey *et al.* (1999) reported that protein content in grain was unaffected by wheat varieties and seed rates and it was increased with increasing fertilizer levels and recorded the maximum value at 150% more fertilizer than the recommended dose but significant difference was obtained only upto the recommended dose of fertilizers.

Application of 10 tonnes organic manure/ha recorded significantly higher protein content in wheat grains than without organic manure application. Higher protein content at higher levels of fertilizer and organic manure was due to higher N content and N-uptake by the crop (Thakur *et al.*, 1999).

2.3 Effect of integrated nutrient management on crop sequence

Hanuman Prasad *et al.* (1995) evaluated the effect of continuous pearl millet-wheat cropping sequence on soil fertility and yield stability. Application of 120 kg N/ha and 40 kg P_2O_5 /ha to each crop was found effective for cereal based cropping sequence under the condition of north western Rajsthan. The continuos fertilizer application built-up the fertility of the soil. Kumpawat and

Rathore and Patel (1991) evaluated the effect of continuous maize-wheat cropping system. The yield stability N @ 120 kg/ha and P_2O_5 @ 60 kg/ha to each crop was effective for cereal-cereal cropping sequence under semi-humid southern plains region of Rajasthan.

Naphade *et al.*(1995) revealed that it was must to apply balanced amount of NPK to sorghum and wheat crops. Lowering the doses to sub-optimal levels deceased the yields, whereas application of 150 per cent dose than optimum dose (100:50:40 for sorghum and 120:60:60 for wheat) produced maximum sorghum (43.43 q ha^{-1}) and wheat (22.89 q ha^{-1}) yields.

Harsharan Singh Grewal *et al.* (1992) reported that maize yield response to green manuring was 16 q/ha; whereas, response of succeeding wheat to the residual effect of green manuring was 5 q/ha. Green manuring increased the productivity of maize-wheat system by 21 q/ha. Sinsinwar (1994) reported that wheat grown after cowpea gave significantly higher grain yield (4.2 tonnes/ha), followed by wheat after field bean and economized fertilizer N to the extent of 40 kg N/ha. Wheat yield in grain sorghum-wheat sequence remained significantly lower (2.3 tonnes/ha) as both the crops are exhaustive in nature.

Roshan Lal *et al.* (1995) concluded that 25% nutrient requirement of pearl millet can be replaced through farm yard manure or green-manure at 25 or 50% level of obtaining the yield at par with treatment receiving 100% recommended dose through chemical fertilizers. Inclusion of wheat straw for substitution as N source is not comparable due to poor yields in pearl millet-wheat sequence.

Patel *et al.* (1995) clearly indicated that 50% N substitutions through farm yard manure or wheat straw had a significant residual effect and thereby the productivity of succeeding wheat crop was *maximum in pearl millet-wheat* crop sequence. As far as total productivity of the system (pearl millet-wheat) is concerned, the highest production was recorded (43.03 q/ha) with 75% NPK + 25% N through GM in *kharif* and 75% NPK during *rabi* to the system.

The combination of green manure with different rates of NPK recorded higher grain and straw yield of rice-wheat sequence over crop residue and NPK separately or in combinations (Rajput, 1995).

Patil *et al.* (1995) reported that application of 50% NPK through chemical fertilizers and 50% N through FYM to sorghum and 100% NPK through chemical fertilizer to wheat gave maximum sustainability yield index for grain (0.63) and biomass (0.66).

Verma (1997) worked out the most remunerative crop sequences for U.P and reported that the wheat planted after maize and pigeonpea gave higher yield and highest net profit on per rupee investment was recorded with pigeonpea-wheat crop sequence (Rs. 1.08).

The results of the experiment conducted from 85-86 to 92-93 indicated that pearlmillet-wheat cropping system with green manuring in summer gave high grain and biomass productivity/ha per rupee invested on fertilizer than other crop sequences and reduction in fertilizer dose to 50% of both the crops. Groundnut-wheat cropping system with 100% recommended fertilizers/ha was found highly remunerative with high net returns/ha and benefit cost ratio than other crop sequences (Patil, 1997).

Patil (1997) clearly indicated that highest total productivity was observed in 50% N through FYM plus 50% NPK fertilizers to sorghum and 100% RDF of NPK to wheat in sorghum-wheat sequence to sustain productivity over years as could be observed from SYI and total productivity on pooled mean basis. Ved Singh *et al.* (1998) reported that each crop sequences gave its maximum economic yield and net returns when treated with maximum optimum irrigation level.

A field experiment was conducted at Khandha, Gujrat to assess the production potential and economics of different cotton based cropping systems and results revealed that cotton-wheat cropping systems was the most remunerative and suitable for Narmada command (Maliwal *et al.*, 1999).

Singh *et al.* (1999) observed from the field experiment conducted at Hissar, integration of chemical fertilizers and organic manures in the form of FYM or green manure in the ratio of 50:50 or 75:25 applied in pearl millet and followed by 100% recommended dose of fertilizers in wheat crop gave the yield at par to that of 100% recommended dose of fertilizers applied to both the crops of the sequence. These treatments were significantly better than control and farmers practice.

Singh *et al.* (1999) reported that use of NPK + FYM gave as high yield of maize as the super-optimal dose of 150% and consistently higher yield of wheat grain. Use of S or Zn or hand weeding showed no yield advantage. The FYM treatment maintained high level of fodder yield of cowpea. Mishra *et al.* (1999) observed the direct effect of lime, organic and inorganic nutrients on wheat and its carry over effect on soybean. Lime, FYM and boron in combination with 60 kg N + 30 kg P_2O_5 + 20kg K_2O/ha resulted in the highest yield of wheat (29.3 q/ha).

Roundal *et al.* (1999) reported that the application of 60 kg P_2O_5 /ha through phospho-compost significantly increased the growth, dry matter and yield (18.33 q/ha) of green gram over application of 60 kg P_2O_5 /ha through phospho-manures. While testing the residual effect of phospho-manure on wheat it was found that the main plot treatment of application of 60 kg P_2O_5 /ha to previous crop produced significantly higher growth, dry matter, yield contributing characters and yield of wheat. Further, it was observed that application of 60 kg P_2O_5 /ha to wheat significantly produced more grain yield (60.03 q ha^{-1}) over application of 30 kg P_2O_5 /ha and control.

Patil *et al.* (1999) revealed from the pooled results that on nutrient management experiment, 75% RDF + 25% N through either FYM or GM to sorghum and 75% RDF of NPK to wheat is recommended for sustainable total productivity in sorghum-wheat sequence.

Patidar (2000) concluded that application of 10 t FYM/ha, 75% RDF and Azospirillum and PSB inoculation treatment combination optimized productivity of sorghum-wheat cropping sequence. Thus, system productivity indicated the possibility of economic fertilizer use to the extent of 25% of recommended level under irrigated nutrient management system.

2.4 Effect of integrated nutrient management on nutrient/microbial status, chemical and physical properties of soil

2.4.1 Nutrient uptake

The study conducted by Jadhav (1976) revealed that the grain, straw and total uptake of nitrogen were increased with increase in the levels of nitrogen. The results on the work done on direct and residual effect of fertilizers on the uptake of nutrients by crops indicated that direct application of N increased the uptake of all the nutrients by wheat and pearl millet crops, significantly (Gajbhyiae and Goswamy, 1981). More and Ghonsikar (1984) reported that N use efficiency in sorghum-wheat sequence was lower in all the N levels. However, percentage recovery of added N by wheat was comparable with green gram-wheat sequence and it was progressively decreased with increase in levels of fertilizer N applied. Malik *et al.* (1986) observed that the increasing levels of N significantly increased the N uptake in grain. Nitrogen uptake increased upto 120 kg N dose but further increase in N dose decreased the N uptake. This might be due to lodging which occurred when 180 kg N was applied. Similar results were reported by Barve (1987). Dhuka *et al.* (1992) found that N uptake in grain and straw was significantly more with 120 kg N ha^{-1} than 80 kg and 40 kg N ha^{-1}. Jain and Jain (1993) reported that application of N significantly increased the uptake of N, P and K over the control. The increase when compared with the control was 22.9, 40.1 and 58.2 per cent for N, 13.7, 34.9 and 48.8 per cent for P and 19.2, 36.1 and 52.2 per cent for K due to 40, 80 and 120 kg N ha^{-1}, respectively. Ashokkumar *et al.* (1995) conducted a trial and revealed that recovery of applied N was higher with 120 kg N ha^{-1} compared with 180 kg N ha^{-1}. N use efficiency increased with increasing N level upto 120 kg N ha^{-1} thereafter decreasing trend was observed.

Verma and Sharma (1994) reported that P uptake was significantly increased due to 90 kg P ha^{-1} over control.

Singh and Ghosh (1984) found that the higher doses of potassium (80 and 120 kg K_2O ha^{-1}) entailed higher uptake by wheat than lower ones.

Swarup and Ghosh (1978) observed that per cent recovery of N by pearl millet and wheat sequence ranged between 33.1 and 53.6 per cent and phosphorus recovery by pearl millet and wheat varied from 13.6 to 24.1 per cent, respectively. Auti (1980) indicated that the uptake of nitrogen and phosphorus in grain and straw was significantly more due to 100 + 50 + 50 kg NPK ha^{-1} than 60 + 30 + 0 kg NPK ha^{-1}.

Gupta *et al.* (1983) found that nutrient uptake of wheat decreased significantly with decreasing level of fertilizers in bajra-wheat rotations during both the years. The total uptake of N, P and K ranged from 54.2 to 104.2, 14.7 to 25.8 and 117.7 to 189.9 kg ha^{-1}, respectively. It is also apparent that N and P uptake by wheat was higher than pearl millet, whereas K uptake had a reverse trend. Dixit *et al.* (1984) observed that the uptake of N, P and K by wheat grain and N and K by wheat straw increased significantly with increase in levels of fertilizer application. It was also pointed out that application of N and P more than 100 per cent level of soil test recommendation could not be effectively utilized by wheat crop. Nikam (1985) reported that the total uptake of nitrogen, phosphorus and potassium in grain and straw were increased with the increase in the levels of fertilizer. The highest uptake was noticed due to 120 + 60 + 60 kg NPK ha^{-1} level and values of uptake were 95.27, 19.88 and 115.15 kg ha^{-1} in grain, straw and as total, respectively. Jadhav (1989) observed that the total N, available P and K balance after three years were deficit and the magnitude of decline was less with the increased level of fertilizer to wheat. This may be attributed to increase the nutrient status for vegetative growth, yield and uptake of these nutrients. Ram Nawaj and Yadav (1994) reported that the most productive system (maize-potato + Indian mustard-black gram) removed greater amount of N, P and K (345.94, 78.43 and 387.86 kg/ha/year respectively) from soil compared with the other systems. The balance for N and K was negative in all the systems but higher depletion of N and K (110.94 and 267.93 kg/ha/year, respectively) was recorded under maize-potato + Indian mustard-black gram systems. The balance for P was positive in all the systems and higher built up of P (101.56 kg/ha/year) in surface layer was found under same systems.

Sen Gupta (1961) indicated that N uptake by maize increased due to FYM application and decreased where continuous application of chemical fertilizers. Ballal *et al.* (1968) also reported the beneficial effect of green manuring on N uptake by wheat. Similar observations were also reported by Ramaswamy and Raj (1974). Nitrogen and phosphorus uptake by rice was increased due to application of N alone and green manuring.

In a field experiment continuing for six years on an acidic, red silty clay loam soil, balanced use of fertilizers proved highly effective in sustaining the level of productivity as well as nutrient composition and uptake of all the crops in rotation. In general, NPK fertilizers in combination with FYM and lime recorded the maximum removal of nutrients by wheat-soybean-potato cropping system (Sinha *et al.*, 1981). Prasad and Sinha (1981) also conducted a trial for eight years and reported that increasing levels of fertilizers combination with organic manures with lime gave the highest uptake of phosphorus and potassium from the soil and gave the positive gain of soil P and K in intensive cropping.

Narkhede and Ghugare (1987) found that addition of leucaena loppings caused increase in the N and P uptake significantly by sorghum 71.3 per cent and 77.5 per cent, respectively. Gaur (1992) revealed that integrated use of organic manures and fertilizers effectively checked the deterioration in the productivity of maize and wheat in acidic soil. Bhandari *et al.* (1992) reported that an application of fertilizers or their combined use with the organic manures increased the uptake of N, P and K significantly in a rice-wheat sequence. Kurlekar *et al.* (1993) reported that fertility status of the soil was also improved by adoption of legume-cereal (soybean-wheat) and cereal-legume (soybean-chickpea) than cereal-cereal (sorghum -wheat) crop sequences under different fertility levels. Raghuwanshi and Umat (1994) observed that under integrated nutrient management in sorghum-wheat cropping system, FYM, crop residue and green organic matters in combination with inorganic fertilizers proved to be better in enhancing the total nutrient uptake by the crop on medium black soil. Dudhat *et al.* (1997) reported that application of FYM alone or in combination with chemical fertilizers significantly increased the residual status of available N and P in soil. Application of either 5 tonnes castor cake + 120 kg N + 60 kg P_2O_5 or 5 tonnes castor cake + 60 kg N + 30 kg P_2O_5 /ha or 15 tonnes FYM + 120 kg N + 60 kg P_2O_5 /ha, being at par with each other, significantly improved growth, yield, quality and nutrient uptake by wheat.

Singh *et al.* (1999) results of a trial for more than one decade of experimentation at permanent site indicated that the nutrient status of soil under control and lower doses of fertilizer application declined to a much higher degree as compared to the application of either 100% recommended dose of chemical fertilizers or combination of organic and inorganic fertilizers.

Mishra *et al.* (1999) reported that the direct and carry-over effects of lime and organic manure along with inorganic nutrients application significantly increased the uptake of N, P and K by wheat-soybean cropping system.

2.4.2 Available nitrogen

Singh *et al.* (1980) reported that the concentration of available N increased and continuous build up in available N was observed in soil under multiple cropping at the end of each rotation as compared to its initial status. Continuous application of FYM and chemical fertilizers in long term experiments under pearl millet-wheat rotation revealed that available N increased significantly with application of phosphate and FYM (Chaudhary *et al.*, 1981). Similar results were also observed by Yaduwanshi and Tripathi (1983) in 8 years of fertilizer experiments and also found that inherently high status of available N did not show sustainable improvement over the initial value and small decrease in available N in a control was observed.

Chahal *et al.* (1984) obtained direct and residual effect of manuring with 50 tonnes ha^{-1} FYM to both the crops on available N status under pearl millet – wheat sequence at the end of 8 years of experimentation. Noticeable build up of available N was also observed by Mandal *et al.* (1984), Swarup and Ghosh (1984). Pandey *et al.* (1985) observed that the available N estimated after the harvest of wheat recorded the highest value in case of wheat straw application than other crop residues. Application of N, P and K at 100 and 150 per cent based on the initial soil test showed appreciable improvement in available N content and was maximum under FYM treatment in maize-wheat, rice-rice and rice-wheat cropping systems (Singh and Nambiar, 1986). In a long term field experiments under continuous cropping and application of fertilizers in combination with organic manures improved the available N status after about 14 years in an Alfisol (Acharya and Bishnoi, 1988).

Gupta *et al.* (1988) reported that the available N content of soil increased upto 20 days after FYM application and decreased thereafter in a coarse loamy soil. Udaysoorian (1990) reported that continuous application of organic manures and fertilizers over a period of 9 years significantly increased the available N content in rice-rice sequence. Bhat *et al.* (1991) concluded that the nitrogen supplying capacity of soil was higher, where crop residues were incorporated in the soil. The nitrogen status of soil was declined from 2 to 31 kg ha^{-1} when two cereals were included in crop sequence i.e. by 1.3 to 20.3 per cent (Bhakare *et al.*, 1991). Malewar and Hasnabade (1993) observed negative balance of available N in control and 50 per cent recommended level of fertilizers and positive available N balance observed in recommended dose of fertilizers and combination of inorganic and organic manures in sorghum-wheat sequence after two cycles. Similar results were also reported by Patil *et al.* (1993), Thind *et al.* (1993), More (1994) and Bhardwaj and Omanwar (1994). Malewar and Hasnabade (1995) reported that significant increase in available N was observed in organic + fertilizers treated plots particularly with FYM or subabul + NPK given to sorghum (CSH 9) and wheat (HD-2189) crop sequence. Malewar *et al.* (1999) reported that each oil seed based crop sequence showed differential effect on the availability of N, P and K in soil. Cotton-groundnut rotation proved superior in gaining soil available N, P and K. However, net loss of -35.43 kg N, -3.90 kg P_2O_5 and -23.05 kg K_2O was registered under cotton-sunflower rotation. Overall results indicated that the inclusion of legume in the system is beneficial for maintenance of soil fertility, its health and productivity, except in cotton-sunflower system.

Patidar (2000) reported that sorghum-wheat system productivity indicated the possibility of economise fertilizer use to the extent of 25% recommended level through use of organic manures under irrigated nutrient management system.

2.4.3 Available phosphorus

Arun Prasad *et al.* (1991) and Bhat *et al.* (1991) reported that available P also increased significantly with the addition of tree leaves and incorporation of crop residues. In respect of phosphorus there was increasing trend ranging from 3.1 to 8.9 kg ha^{-1} over initial status of soil in all the cropping sequences (Bhakare *et al.*, 1991).

Rao and Sharma (1978) reported that the greater increase in available P content of soil under fixed crop rotations with 3 fertilizer constraints after two years. Continuous application of FYM with NPK fertilizers under various long term experiments with fixed crop rotations showed that available P increased due to organic manures with mineral fertilizer application over a long period (Chaudhary *et al.*, 1981; Agrawal *et al.*, 1987; Bhriguvanshi, 1988; Udaysoorian, 1990 and Geneviri and Tano, 1991). Pandey *et al.* (1985) noticed that available P estimated after the harvest of wheat recorded the maximum value under maize stalk incorporation than sorghum, wheat and rice straw. Biswas *et al.* (1987) and Verma *et al.* (1987) found that initial soil status of available P was raised in fertilized plots which decreased in control under continuous rotational cropping in long term experiments. Continuous cropping without fertilization lead to the depletion of available P, while fertilization had beneficial effect on available P content as observed by Bharadwaj and Omanwar (1994).

Malewar and Hasnabade (1995) reported that the availability of phosphorus increased significantly over control due to fertilizer alone or in combination with organic manures which is largely attributed to minimization of P fixation and organic recycling. Raghuwanshi *et al.* (1991) reported that the available P showed deficit in all wheat based crop sequences and ranged from 91.2 to 97.3 kg P/ha.

2.4.4 Available potassium

Biswas *et al.* (1987) reported that after six cycles of crop rotations in multiple cropping system, the available K status of soil remained as such with all levels of NPK dose in a continued fertilizer experiment. Muthuswamy *et al.* (1990) observed that available K differed significantly and depletion of native soil K was observed over the initial soil K in treatments with balanced fertilizers after 16 years in multiple cropping system. Raghuwanshi *et al.* (1991) reported that the available K was improved ranging between 26.9 and

140.2 kg/ha in sorghum-wheat sequence. Other crop sequences showed deficit of soil K. Bharadwaj and Omanwar (1994) observed depletion of available K due to continuous cropping without fertilization and build up of available K in fertilized plots under continuous rotational cropping.

Sharma *et al.* (1984) found that available K status of the soil remained unaffected by K application but it was increased significantly with the application of FYM under fixed wheat-maize rotation for 10 years. Similar results were also reported by Bhriguvanshi (1988) and Bhat *et al.* (1991). Arun Prasad *et al.* (1991) noticed that available K content of soil markedly increased with subabul loppings. Malewar and Hasnabade (1993) noticed that available K content was more in the treatments involving inorganic fertilizers with organic manures except wheat straw. Chahal *et al.* (1984) noticed that available K status decreased with continuous cropping and K application did not show any significant effect after 8 years of experimentation on pearl millet-wheat sequence. More (1994) also noticed favourable effects of addition of inorganic fertilizers with FYM and wheat straw under rice-wheat system after three years on available K. The availability of potassium was found more in FYM and green manuring and subabul (organic sources) applied in combination with fertilizers: which may be attributed to acidulation as a result of decomposition of organic matter and release of mineral K_2O in soil solution (Malewar and Hasnabade, 1995). Tandon (1995) found that the effect of supplementary fertilizers with 5 t ha^{-1} dry leucaena leaves significantly increased available K content of soil because of its higher K contents. Hegde and Katyal (1999) reported that a build up of available soil K at Hanumangarh due to high silt load in the irrigation water.

2.4.5 Soil reaction

Rahate *et al.* (1979) reported that application of fertilizers used in combination with a small dose of five tonnes FYM ha^{-1} over a long period of 11 years under sorghum-wheat sequence resulted in little variation in soil pH due to various treatments. Continuous application of farm yard manure to a sierozem soil in the semi-arid region of Haryana resulted in lowering of pH to some extent (Verma *et al.*, 1980). Chaudhary *et al.* (1981) and Khiani and More (1984) also observed similar results due to long term application of FYM and mineral fertilizers. Lomte *et al.* (1993) reported that pH of soil was increased due to intercropping cow pea/pigeon pea with sorghum as also application of sieved FYM @ 1000 kg/ha compared to sole sorghum (without FYM). Kumar and Yadav (1993) and Bhardwaj and Omanwar (1994) also observed no marked effect of continuous rotational cropping and fertilization. Ram Nawaj and Yadav (1994) reported that the pH of the soil was decreased at the end of study under intensive cropping systems.

2.4.6 Electrical conductivity

Maurya and Ghosh (1972) observed no appreciable change in electrical conductivity under long term manuring and rotational cropping in the Pusa permanent manurial experiments over four decades. Chahal *et al.* (1984) found that electrical conductivity of soil was more or less unaffected with continuous application of manures and fertilizers in a long term experiment under pearl millet-wheat sequence. Similar results were also reported by Chaudhary *et al.* (1981), Bhriguvanshi (1988) and Badanur *et al.* (1990). Lomte *et al.* (1993) reported that the electrical conductivity (EC) was increased due to intercropping cow pea/pigeon pea with sorghum as also application of sieved FYM @ 1000 kg/ha compared to sole sorghum (without FYM).

2.4.7 Organic carbon

Sharma *et al.* (1984) found that organic carbon content of the soil increased significantly with the addition of FYM to a fixed maize-wheat rotation over 10 years in a calcic ustochrept. Fertilizer N and P with straw management practices in rice-wheat rotation were found to increase the organic carbon content (Dhillon and Dev, 1984). Similar results were also obtained by Verma *et al.* (1987) and Udaysoorian *et al.* (1988) under intensive rice-wheat rotation. Bhandari *et al.* (1989) observed that green manuring increased the organic carbon content of soil at harvest of crop. Incorporation of tree leaves in combination with fertilizer N significantly increased the organic carbon under incubation studies (Murthy *et al.*, 1990). Bhat *et al.* (1991) also reported increase in organic carbon in soil when crop residues were incorporated for seven years in rice-wheat system.

Harsharan Singh Grewal *et al.* (1992) reported that incorporation of green-manure crop at 1, 8 and 15 days before maize sowing equally efficient in increasing the productivity of maize-wheat system. Green manuring also improved the organic carbon content of the soils. Bhandari *et al.* (1992) reported that the combined use of organic manures with moderate levels of fertilizers, increased the organic carbon levels after completion of three cycles of rice-wheat cropping system. Thind *et al.* (1993) observed that organic carbon markedly increased in FYM treatment followed by green manuring in maize-wheat rotation. Lomte *et al.* (1993) reported that organic carbon content of the soil was increased due to intercropping cow pea/pigeon pea with sorghum as also application of sieved FYM @ 1000 kg/ha compared to sole sorghum (without FYM). Ram Nawaj and Yadav (1994) showed that the organic carbon, available nitrogen, phosphorus and potassium content of the soil was decreased from their initial content in the intensive cropping systems.

Bharadwaj and Omanwar (1994) reported that continuous cropping without fertilization leads to the depletion of organic carbon, whereas continuous fertilization had beneficial effect on organic carbon content. Varvel (1994) reported that organic carbon could be sequestered at 10 to 20 tonnes ha^{-1} $year^{-1}$ in some cropping systems with sufficient levels of N fertilizers during 8 years period in the Western Corn Bott. More (1994) also observed that farm waste and organic manures increased organic carbon under rice-wheat system on sodic vertisol. Meelu *et al.* (1994) concluded that green manuring and incorporation of crop residues alone or in combination with green manures significantly increased soil organic carbon.

Malewar and Hasnabade (1995) reported that organic carbon showed build up more than two times over initial value due to combined and long term use of organic manures and fertilizers indicating highest organic carbon in 50:50 inorganic (NPK) : organic (FYM) sources. Hegde and Katyal (1999) reported that there was a small build up in organic carbon but a general decline in other parameters of soil fertility even with NPK fertilization on all the soil types. Malewar *et al.*(1999) reported that cotton-groundnut sequence improved the porosity, water stable aggregates and organic carbon in soil as compared to other systems, whereas, they were adversely affected due to cotton-sunflower sequence.

2.4.8 Micronutrient status of soil

Randhawa and Arora (1970) revealed that multiple cropping system without use of bulky organic manures rendered the soils more deficient in micronutrients. Maurya and Ghosh (1972) reported that FYM application had increased the exchangeable Mn content and easily reducible Mn was fairly high in green manuring and NPK fertilizers treated plots in Pusa permanent manurial experiment after 40 years.

The available Zn content was declined with continuous cropping (Biswas *et al.*, 1977), wherein accumulation of Fe, Cu and Zn in soils treated with high analysis chemical fertilizers under intensive cropping was observed by Prasad *et al.* (1979). Use of FYM and NPK fertilizers over a period of 20 years has maintained and improved the Zn and Fe status of soil and was declined in control plots (Prasad and Singh, 1980).

Trehan and Grewal (1983) reported that green manuring in cropping sequence proved more effective than FYM in improving available Zn, Fe, Cu and Mn status of soil under intensive cropping and manuring for a period of eight years. Shuman (1988) also observed that organic matter increased the availability of Mn and Fe and possibly decreased the availability of Zn in incubation study with eight top soils treated with ground straw. Mandal *et al.* (1984) and Biswas and Benbi (1989) found noticeable build up of available Zn due to continuous cropping and manuring after 8 years jute-rice-wheat and maize-wheat rotations, respectively. The soils with higher organic matter content enhanced microbial activity and thereby increased the Fe, Cu and Zn content of soil after 28 years without supplementation of micronutrients through outside in rice-wheat rotation (Lal and Mathur, 1989).

Gupta and Mehta (1993) found lower extractable Fe after 6 years in control plots than that of higher fertility level, while Mn content was higher. Thind *et al.* (1993) studied the effect of organic manures on micronutrient availability after 13 years under maize-wheat rotation and reported that DTPA extractable Zn and Mn was the highest in FYM treated plots followed by green manuring and the lowest in control plots. Bharadwaj *et al.*(1984) observed more depletion of DTPA extractable Fe, Mn, Zn and Cu status in unfertilized plots than fertilized plots under continuous cropping and fertilization. Khapre *et al.* (1994) reported that a maximum grain yield (58.63 q/ha) was recorded when Zn was applied with Mn. There was significant increase in cob and grain weight/plant with application of Zn, Fe and Mn alongwith NPK fertilizers. Indulkar and Malewar (1994) pooled data showed that inorganic and organic sources of zinc improved the direct and residual effect of zinc on sorghum-wheat yield uptake and available zinc in soil. Comparing the effect of organic zinc sources, all inorganic zinc sources were superior when compared to direct effect of farm yard manure. Among the zinc sources, zinc coated suphala was found superior to other zinc sources. However, FYM in combination with inorganic source of zinc added to the residual value of zinc compared with inorganic source of zinc alone in the crop rotation. Malewar (1995) also reported that pearl millet-sorghum sequence had resulted into low content of Zn and Cu in vertisols. Malewar and Hasnabade (1995) reported that sorghum-wheat sequence has improved Zn build up nearly two times more over control in combined application of organic + inorganic fertilizers. Meelu (1996) and Takkar (1996) revealed that marked increase in available Zn due to FYM application and Fe and Mn in green manuring treatments obtained in long term experiments.

Patil (1997) reported that FYM application for 50% N substitution in combination with 50% NPK fertilizers showed higher content of Fe, Mn, Zn and Cu followed by WCS and GM application for 25 to 50% N substitution for sorghum-wheat sequence.

2.4.9 Physical properties of soil

Kanwar and Prihar (1962) observed marked increase in percentage of water stable aggregate with continued application of FYM in permanent manurial plots at Rothemsted. Darra *et al.* (1968) reported that green manuring has decreased bulk density with significantly increased water stable aggregates of large size and infiltration rate. Havangi and Mann (1970) also observed that application of FYM and fertilizer and green manures decreased bulk density of the soil and increased the water stable aggregates without appreciable effect on water retention and maximum water holding capacity of soil under intensive cropping.

While studying the cumulative effect of different levels of manures and fertilizers on physical properties of soil in the permanent manurial trial, Biswas *et al.* (1971) found that structural status, water retention and bulk density of the soil were significantly improved in the treatments with organic manures and there was very little change due to inorganic fertilizers alone. Similar results were also reported by Mathan *et al.* (1979) in respect of pore volume and water holding capacity of soil under long term soil cultivation and intensive cropping. Shanmugam and Ravikumar (1980) revealed that there was a marked improvement in aggregate stability due to incorporation of organic residues, FYM or pig manure @ 25 t ha^{-1} in the red soil to sorghum crop.

Sinha *et al.* (1980) and Bhatia and Shukla (1982) observed that use of chemical fertilizers alone increased the bulk density, while application of bulky organic manures improved structural status of soil. Burl meek *et al.* (1982) found that continuous manure application for 9-years increased water intake/infiltration rates in silty clay soils. Magar *et al.* (1983) also reported improvement in infiltration by about four folds and two folds due to incorporation of FYM and wheat straw in black soil. Pandey *et al.* (1985) observed that infiltration rate measured in wheat and rice straw treated plots increased significantly because of better soil aggregation. Rise in bulk density due to inorganic fertilizers and improvement in structural conditions due to continuous application of FYM after about six years under multiple cropping was observed by Prasad *et al.* (1983); Acharya and Bishnoi (1988) and Lal and Mathur (1989).

Badanur *et al.* (1990) found that organic manures and crop residues incorporation significantly increased the infiltration rate and water content at field capacity as compared to fertilizer treatments. Bangar (1991) reported that physical properties except bulk density were significantly and positively correlated with the grain yield. The bulk density was significant and negatively correlated with grain yield of sorghum. Bhat *et al.* (1991) found that the continuous recycling of crop residues for seven years in rice-wheat sequence significantly improved the aggregation of soil. Gaur (1992) noticed from the several studies on the impact of organic manures on soil structure, showed improvement in water holding capacity and infiltration rate by promoting greater water retention under long term experiments.

Kumar *et al.* (1993) observed that incorporation of organic materials promoted the formulation of soil aggregates, particularly more than 2 mm size and increased the mean weight. diameter, reduced bulk density and enhanced cumulative infiltration due to combined use of green manures and crop residues after five years in rice-whet sequence.

Lomte *et al.* (1993) revealed that the values of bulk density, water stable aggregates (>0.25 mm), infiltration rate, hydraulic conductivity of the soil were increased due to intercropping cow pea/pigeon pea with sorghum and also application of sieved FYM @ 1000 kg/ha compared to sole sorghum (without FYM).

Ram Nawaj and Yadav (1994) reported that the bulk density was reduced and infiltration rate of the soil was increased from their initial values to the end of experiment on intensive cropping systems.

Bellakki and Badanur (1994) also found that the water infiltration rate and water retention characteristics of vertisol increased and bulk density reduced with sorghum stubbles alone or in combination with leucaena loppings over that of fertilizer application. Leucaena loppings alone or in combination with sorghum stubbles increased the water stable aggregates significantly after 7 years of experimentation.

Bulk density of soil decreased significantly due to application of NPK fertilizers over initial value. It was further lowered down because of combined application of NPK fertilizers + organic manures indicating more favourable effect of 50% NPK + 50% N through green manuring and subabul leaves (Malewar and Hasnabade, 1995). Patil *et al.* (1995) reported that the fertility status of soil was improved by adoption of pigeon pea-wheat sequence, but reduced by cereal-cereal sequences. The recycling of organic waste was found beneficial in saving the applied as well as efficient in enriching the soil health. Amongst the recycled organic manures, farm yard manure was more efficient and followed by wheat straw. Patil (1997) reported that incorporation of FYM, WCS and GM for 25 to 50% N substitution in conjunction with balanced dose of NPK fertilizers in sorghum-wheat sequence increased the infiltration rate, water stable agreegates and organic matter content of soil and decreased the bulk density due to improvement in structural status of soil. Oilseed-based cropping sequences behaved differently in influencing physico-chemical properties of soil after two cycles over initial values. Overall results indicated that inclusion of legume in the system is beneficial for maintenance of soil fertility, its health and productivity, except cotton sunflower system (Malewar *et al.*, 1999).

2.4.10 Microbial population studies

Albuquerque and Patel (1955) observed while studying the effect of different manurial treatments on microbial population in 'B' type of soil at the farm during periodical microbial examination in the soil in the month of January, April and September. The fungi population was negligible and that of bacteria and actinomycetes predominated. Farm yard manure and safflower cake induced greater activities of the microorganisms as compared to other fertilizers and manures. The microbial population was found to be depressed by sulphate of ammonia and sodium nitrate; Super-phosphate showed a beneficial effect on the total population, but its effect was particularly seen on the non-symbiotic nitrogen fixing organisms. Sulphate of potash and muriate of potash did not show any specific differences in their effect.

Kamat (1978) reported that the different organic matter namely farm yard manure, paddy straw, dhaincha and karanj cake were added to the soil sample in order to study the development and influence of bacteria actinomycetes, fungi and azotobacter in the decomposition of the organic matter and it was found that the highest population of fungi was obtained in the soil mixed with paddy straw and karanj cake while it was seen that the soil treated with farm yard manure gave highest population of bacteria and azotobacter per gram of soil sample under aerobic condition. Quantitative study of microorganisms revealed that the microbial population was more or higher under aerobic condition where decomposition rate was faster while under water logged conditions, decomposition delayed and comparatively there was a decrease in the microbial population.

Application of farm yard manure on an alluvial sandy-loam (Kanpur) over the years (1954-71) gave the highest viable count of azotobacter, but their population in combination with inorganic N or NP, whereas the population of fungi and actinomycetes correspondingly had gone up. Application of castor cake depressed the population of bacteria, fungi and actinomycetes but there was no effect on the population of the nitrogen fixing azotobacter (Nambiar, 1994). Further he also reported in another experiment that the effect of long term manuring and intensive cropping on microbial population was evaluated on a red loam at Ranchi. The data clearly showed that the highest viable count was noted in the case of azotobacter, bacteria and actinomycetes with NPK + FYM treatment followed by lime + NPK treatment. However, the population of fungi reduced by more than one half in the case of lime treatment probably due to an increase in the soil pH. The fungi population appeared to be sensitive to alkaline pH. Thus, incorporation of farm yard manure in combination with NPK fertilizers, by and large, was found to provide a favourable environment for the growth and development of beneficial soil microorganisms.

2.5 Effect of integrated nutrient management on economical studies of the sequence

Dubey *et al.* (1997) reported that the grain yield and total profit of crops in both the crop sequences viz., rice-wheat and sorghum-wheat increased with every corresponding increase in recommended dose upto 100% level, but 75% of the recommended dose to both crops in these crop sequences appeared optimum dose to enhanced cost of fertilizers. The results indicated a saving of

25-50% quantity of costly N fertilizers and sustainability of grain production in the both cropping systems with the integrated use of fertilizer and organic manures.

Borgohain *et al.* (1991) reported that maximum net profit was obtained from jute-rice-rapeseed rotation followed by jute-rice-wheat or jute-rice-lentil sequence. Badiyala and Verma (1991) showed that the application of FYM @ 12 tonnes/ha alone or incombination of biofertilizer as well as biofertilizer alone significantly increased the grain yield of all crops viz., maize-soybean-wheat cropping sequence. Wheat equivalent yield, and gross and net returns/ ha/year with the combined use of farm yard manure and biofertilizer and alone were similar, but more than that from than other supplemental sources. Raghuwanshi *et al.* (1991) showed that out of four sequences soybean-wheat sequence was the most remunerative sequence. The urea super granules @ 120 kg/ha applied to preceeding rice proved superior (Rs. 8706.65; 1.94) to neem cake coated (Rs. 8217; 1.88) and prilled urea (6701.35; 1.56) in respect of net return/ha and benefit:cost ratio in rice-wheat sequence. Ahmed and Baroova (1992). The total net returns were in the order of cowpea-chinese cabbage-wheat > cowpea-cowpea-wheat > maize-chinese cabbage-wheat > sorghum-chinese cabbage-wheat > maize-maize-wheat and lowest after sorghum-sorghum-wheat cropping system (Kanwar Singh *et al.*,1992). Negi *et al.* (1992) recorded the response functions to P fertilization in wheat. Application of FYM and P to wheat gave significantly higher grain yield and gross returns. In maize, FYM resulted in a significantly higher grain yield and gross returns; however, the net returns were significantly lower compared with no FYM. Grain yield as well as the net returns from maize crop due to residual P applied to preceding wheat crop, were comparable with the direct application of P to maize, showing thereby that maize can thrive well on residual P.

Singh *et al.* (1992) observed a significant variation in yield equivalence (in terms of rice) and net returns due to different crop sequences. Maximum yield equivalence was recorded in rice-potato sequence with a net profit of Rs.15,534 and Rs.18,193/ha during first and second year, respectively.

The crop sequences with 300% cropping intensity gave higher net returns than the other sequences. The maximum (Rs. 15,807/- per ha) net returns was recorded from the complete forage crop sequence of deennath grass – maize + cowpea, rice-wheat-green gram and rice-berseem-green gram sequences, but it was on par with deennath grass - wheat – green gram and groundnut-oat-maize + cowpea sequences. Prasad and Kerketta (1992). Pawar *et al.* (1992) concluded that maximum monetary returns can be obtained from groundnut-*rabi* sorghum crop sequence.

Kurlekar *et al.* (1993) observed that out of ten different crop sequences tried, crop sequences viz. blackgram onion maize (f) chilli-summer groundnut, bajra-cabbage-groundnut/cotton-summer sunflower, sorghum-wheat-green gram/cotton summer groundnut, sorghum chickpea-cowpea (F)/chilli-Summer groundnut were found most productive and profitable. The net monetary returns recorded by these sequences were in the range of Rs. 35 to 40 thousand per hectare, while cost-benefit ratio ranged from 1:2.52 to 1:3.11. These crop sequences showed more land use efficiency and production efficiency over others.

An experiment to study the comparative performance of legume-cereal and cereal-legume with cereal-cereal crop sequences under different fertility levels was conducted and it was observed that, gross as well as net monetary returns of cereal-cereal green manuring (sorghum-wheat-sunhemp) and legume cereal (soybean-wheat) sequences with 100 per cent recommended fertilizer doses, were significantly more remunerative than other sequences tried (Kurlekar *et al.*, 1993).

Lomte *et al.* (1993) showed that sorghum + pigeon pea intercropping gave the maximum advantage followed by sorghum + cow pea intercropping with improving the soil physico-chemical properties.

Patel *et al.* (1994) observed that the net monetary returns from 25% basal N through castor cake + 75% basal N through urea to wheat was maximum (Rs. 3,917/ha). The highest net profit was obtained from 200 kg N/ha, followed by 160 kg/ha. Rajput *et al.* (1995) showed that application of farm yard manure @ 10 tonnes/ha + full N (20 kg N/ha) as foliar in equal 3 splits proved superior and half N as basal + half N as foliar in 3 splits, giving higher returns than other treatments. A dose of 5 kg $ZnSo_4$/ha as foliar application gave higher yields, net returns and N uptake than 10 kg $ZnSo_4$/ha as basal and no zinc.

Sinsinwar (1994) revealed that maximum net returns of Rs. 11,550/ha was obtained with cowpea-wheat sequence. Grain sorghum-wheat rotation resulted in the lowest returns of Rs. 3681.80/ha.

Kurlekar *et al.* (1994) showed that the highest per annum gross as well as net monetary returns were obtained from sorghum-sunflower-groundnut sequence closely followed by sunflower-chickpea-groundnut and cotton-groundnut sequences. The cost-benefit ratio and production efficiency was also more under these sequences.

Patil *et al.* (1995) reported that the gross as well as net monetary returns of pigeon pea-wheat sequence with recommended dose of fertilizer to both the crops were found remunerative and beneficial than other sequences tried. This crop sequences recorded more land use efficiency and production efficiency over the others.

The highest net return was found with rice-wheat cropping system. The higher net return in rice-wheat cropping system was due to higher total production of the system; while higher net return in rice-Indian mustard and rice-gram cropping systems was owing to high prices of Indian mustard and gram. Thus, rice-wheat followed by rice-Indian mustard appeared the most remunerative cropping system (Gangwar *et al.*, 1995).

Sawarkar *et al.* (1995) showed that wheat can successfully be grown after soybean, groundnut and sorghum. Groundnut-wheat, groundnut-chickpea and soybean-wheat gave significantly higher total yield of 6.41, 6.38 and 5.83 tonnes/ha respectively than sorghum-wheat (4.25 tonnes/ha), and higher significant net returns of Rs. 14,429, Rs. 13,345 and Rs. 13,125/ha. The best crop sequences were found groundnut-wheat and groundnut-chickpea, followed by soybean-wheat for economic return.

Tomar *et al.* (1996) conducted experiment to evaluate most productive and economic double cropping with pulses and oilseeds against wheat. The production potential in terms of wheat-grain equivalent was higher in soybean-chickpea and black gram-chickpea double cropping systems. Growing of chickpea in winter after soybean or black gram was highly profitable compared that of wheat-Indian mustard and linseed were found next to chickpea on the basis of monetary returns.

Patil (1997) reported that groundnut-wheat cropping system with 100% recommended fertilizer/ha was found highly remunerative with high net returns/ha and benefit:cost ratio than other crop sequences. However, reduction of 25% recommneded level of fertilizer to wheat in groundnut-wheat cropping system did not affect much productivity/ha, net return/ha, benefit:cost ratio per rupee invested on fertilizer compared to 100% recommended fertilizer to both the crops.

Gangwar and Sharma (1997), the results showed that productivity of sugarcane could be increased to the tune of 20% over farmer's practice (May planting) by planting sugarcane and wheat simultaneously in mid-December without tangible decrease in wheat productivity. Further higher net returns of Rs. 35,443/ha/annum can also be obtained under simultaneous planting compared with farmer's practice which recorded lowest net returns of Rs. 29,857/ha/annum.

Verma (1997) worked out the most remunerative crop sequences for the Central Plains Zone of Uttar Pradesh. Maize-Indian mustard-green gram gave highest net returns (Rs. 16,544/ha) folowed by rice-Indian mustard-green gram (Rs. 16,480/ha) and pigeon pea-wheat (Rs. 15,639/ha). Highest net profit on per rupee investment was recorded with pigeon pea-wheat crop sequence (Rs. 1.08). Ved Singh *et al.* (1998) reported that the net returns of Rs. 13,859/ha/year and Rs. 13,158/ha/year recorded respectively under cotton-wheat and pigeon pea-wheat were at par and significantly superior to those obtained under all other crop sequences.

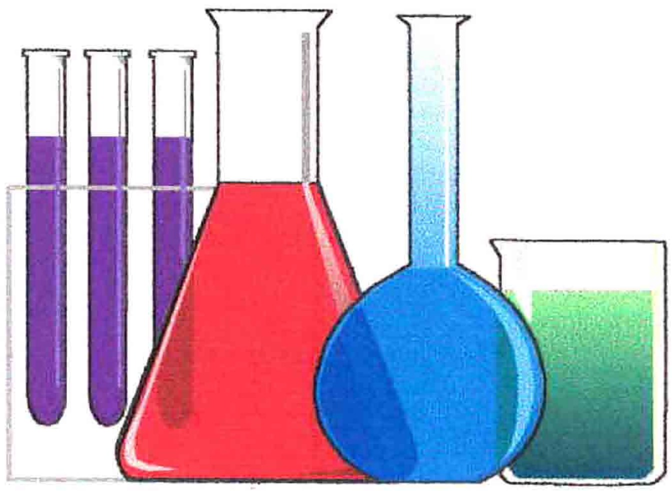
Tripathi *et al.* (1999) reported that among the crop sequences tried, the most remunerative crop sequence was the one where Pusa Basmati were grown during *kharif* and wheat during *rabi* season with and without green manuring in one year crop rotation followed by the sequences where a crop of berseem was included during *rabi* or soybean and Pusa Basmati were grown during *kharif* in two-year rotation. Maize-wheat rotation gave lowest average returns and the least profit.

Maliwal *et al.* (1999) results revealed that cotton-wheat cropping system was the most remunerative and suitable for Narmada command.

Patidar (2000) revealed that 10 t FYM and 100% RDF with Azospirillum + PSB inoculation maximized net returns of sorghum-wheat cropping sequence.

2.6 Effect of integrated nutrient management on energy use for crop production

The quantum and proportion of different forms of energy depends on the extent of use of inputs and intensity of farm operations. The highest energy consuming farm operations and inputs are responsible for the energy input-output relationship. Thus the pattern of energy use in the farm operations and different inputs provide a guideline to regulate the extent of input energy in crop production. Singh and Miglani (1976) showed that energy use per ha varied significantly between different types of soil crop-climate complexes, between level of technology and according to size of farm. Deshpande and Deshmukh (1982) from the field study at PKV, Akola found that *rabi* wheat production required 19568.73 MJ/ha. The highest energy required for land preparation was the extent of 37.60 per cent followed by fertilizer and it's application with 37.03 per cent and irrigation 12.48 per cent. Jadhav (1986) worked at Pune and recorded that the energy output was increased with sorghum-wheat cropping than groundnut-wheat cropping. Energy balance was positive in sorghum-wheat cropping, whereas, it was negative in groundnut-wheat cropping. Energy use efficiency was more with sorghum-whet cropping than groundnut-wheat cropping. Energy output, energy balance and energy use efficiency was more with full dose than half dose applied to *kharif* crops. He further reported that the energy output of both sorghum-wheat and groundnut-wheat cropping systems was increased with increased levels of fertilizers to wheat during all the three years. Energy balance of sorghum-wheat cropping was increased with increased levels of fertilizers during all the three years except during 1979-80 where it was increased upto 2/3 of the recommended levels of fertilizer application. Bhatnagar (1998) considering wheat-paddy rotation estimated the energy requirement as 42499 MJ per ha for an average productivity of 4 t/ha. Billore *et al.* (1994) reported from Sehore that legume-based cropping systems consumed less energy inputs than cereal based system. The soybean-gram sequence was found most energy efficient followed by soybean-sunflower. They stated that wheat cultivation either after soybean or sorghum showed the least energy use efficiency. Swaminathan *et al.*(1994) computed energy requirement for crop production in Tamil Nadu and expressed in mega joules, showed large variations. The highest energy required for sugarcane (planted) was 82267 MJ/ha followed by well irrigated paddy 68918 MJ/ha and cotton 25470 MJ/ha. Whereas, canal irrigated paddy needed only 1923 MJ/ha, which was less than for rainfed crops like jowar, 2850 MJ/ha; cotton 3140 MJ/ha and groundnut 8020 MJ/ha. Ram and Khandelwal (1994) using data from experimental field and farmer's field assessed the energy requirement for crop production in M.P. at existing technology. The total energy requirement was 22 GJ/ha for paddy-wheat rotation and 20 GJ/ha for soybean-wheat. The total energy requirements for major crops varied from 3.5 to 8 GJ/ha resulting in the total output-input ratio from 5.8 to 7.0. Bhatia (1995) reported from New Delhi that the total energy provided in terms of calories from a crop sequence, all the crop sequences were at par, soybean-wheat-green gram gave higher energy followed by soybean-barley-green gram. The energy balance and energy use efficiency of the sequence of intercropping of pigeon pea + soybean in 2:1 row proportion followed by wheat was conspicuously more than other cropping sequences tested. The wheat preceded by intercropping of pigeon pea + soybean in different row proportions was also efficient in energy use than when preceded by sole crop of either pigeon pea or soybean (Patil, 1997). Pawar (2000) concluded that among the different crops sugarcane was the highest energy consuming crop in both regions (i.e. rainfed and irrigated). It was followed by bajra, wheat, *rabi* jowar and *matki* in rainfed region and wheat, cotton, soybean and bajra in irrigated region. The yield per hectare in terms of energy for crops was higher in irrigated region than that in rainfed except few crops like *matki*, wheat and gram. The energy ratios were higher for rainfed crops than that for irrigated crops. The energy input used and output obtained, both on per farm and per hectare basis were higher in irrigated than that in rainfed region. However, the energy ratio were higher in the rainfed region.



MATERIAL AND METHODS

3. MATERIAL AND METHODS

The present investigation was carried out by laying out field experiment on "Integrated nutrient management system for productivity potential of sorghum-wheat sequence under irrigated conditions" during 1999-2000 and 2000-2001. Methods adopted for various growth observations and statistical analysis and material used in this investigation are discussed in this chapter.

3.1 Details of the experimental material

3.1.1 Location of the experimental site

The experiment was conducted in survey No. 133 of the Main Centre for Cropping Systems Research Project situated at Central Campus farm, Mahatma Phule Krishi Vidyapeeth, Rahuri-413722, Dist. Ahmednagar, Maharashtra State (India). The location of central campus is in between 19°47′ N to 19°57′ N latitude and between 74°19′ E to 74°32′ E longitude. The elevation above Mean Sea Level varied from 495 to 569 m.

3.1.2 Climate

Agro-climatically, the area falls in semi-arid zone (Region-VII) with an annual rainfall varying from 307 to 619 mm. The climate of semi arid ecosystem is characterized by hot and dry summer and winter ranges cool to mild. The annual average rainfall is 520 mm of which 80% received from South-West monsoon from June to September erratically distributed in 15 to 45 rainy days while rest of quantity received in the month of October and

November from North-East monsoon. Semi-arid zone is characterized by high climatic water demand and variable and erratic rainfall. Average annual maximum temperature is 37.9°C . Agroclimatically, this tract falls in a scarcity zone having low rainfall and dry climate. However, development of irrigation has made a sizeable part of semi arid ecosystem more productive and stable in production.

During the entire growth period of sorghum (June to October), the mean maximum temperature ranged from 27.9°C to 35.5°C and mean minimum temperature ranged from 13.4°C to 22.8°C during 1999, while the corresponding values for the year 2000 were 28.1°C to 33.4°C and 13.5°C to 22.8°C, respectively. The mean relative humidity during morning and evening ranged from 74 to 91 and 43 to 75 per cent during 1999 and corresponding values for 2000 were 78 to 93 and 28 to 78 per cent, resepctively (Fig 1. and Fig. 2).

The receipt of rainfall during *kharif* was 730.2 mm and 644.7 mm with 48 and 29 rainy days during 1999 and 2000, respectively. The distribution of rainfall during the growth period of *kharif* crop was satisfactory during 1999 and 2000 year of experimentation. This has helped in inducing optimum growth of sorghum crop.

During *rabi* season (November to March) the mean maximum temperature ranged from 26.5°C to 35.3°C in 1999 and 24.4°C to 35.0°C in 2000, respectively. The corresponding values of the mean minimum temperature were 6.6°C to 15.9°C and 7.7°C to 16.0°C during first and second year of experimentation, respectively. The mean relative humidity varied from 56 to 97 and 48 to 87 per cent during morning hours and it ranged from 15 to

44 and 17 to 44 per cent during evening hours in the year 1999 and 2000, respectively (Table 1 and 2). During *rabi* 1999 no rainfall was received, however, during 2000 very meagre quantity of rainfall (7.8 mm) was received in two rainy days i.e. at the tillering stage of crop, benefitted the growth of wheat, resulting in improving the productive tillering nature of wheat to some extent in the second year as compared to first year. By and large, during both the years, the season was congenial for growth and productivity of *kharif* and *rabi* crops.

3.1.3 Soil

The experimental soil was medium black with 60 to 90 cm depth. The dominant type of clay minerals is beidellite and montmorillonite. This soils are grouped under the order Vertisol and great group of Chromusterts. The soil belong to Otur soil series, which comprises members of fine montmorillonitic, isohyperthermic family of Typic Chromusterts. These soils have low intake rate and high swelling shrinkage properties.

In order to study the physical and chemical properties of the soil of the experimental field, the soil samples from 0 to 15 cm depth from ten different randomly selected locations were collected in the experimental area, before laying out the experiment. The composite sample was prepared and was analysed for the physical and chemical properties such as clay, silt, fine and, coarse sand and available nitrogen, phosphorus and potash, organic carbon and pH, respectively. The initial physical and chemical properties of the soil before start of experiment are presented in Table 3.

Table 1. Meteorological data for the year 1999-2000

Month	Mete-orol-ogical week	Dates	Temperature (%)		Humidity (%)		Rainfall (mm)	No. of rainy days
			Maxi-mum	Min-imum	Morning	Evening		
April. 1999	14	2-8	38.7	15.2	56	20	-	-
	15	9-15	39.4	15.1	61	19	-	-
	16	16-22	38.0	14.4	52	19	-	-
	17	23-29	38.8	16.2	58	30	-	-
May. 1999	18	30-6	39.6	16.4	49	17	-	-
	19	7-13	34.3	20.5	71	26	-	-
	20	14-20	36.2	20.6	80	39	32.4	2
	21	21-27	34.0	22.3	81	49	23.8	1
	22	28-3	34.8	21.6	82	45	56.2	3
June. 1999	23	4-10	35.5	20.9	81	61	-	-
	24	11-17	30.52	22.6	90	72	33.0	4
	25	18-24	29.2	22.8	88	72	27.6	5
	26	25-1	31.6	22.0	85	59	66.6	9
July. 1999	27	2-8	31.4	21.7	86	57	55.2	2
	28	9-15	30.9	22.4	87	69	8.2	1
	29	6-22	29.7	22.6	85	75	24.6	1
	30	23-29	29.1	22.7	81	63	4.0	-
	31	30-5	28.4	22.2	84	64	0.4	-
Aug. 99	32	6-12	27.9	22.2	86	69	11.8	2
	33	13-19	30.5	20.8	86	54	-	-
	34	20-26	30.7	20.5	74	51	4.8	1
	35	27-2	31.8	19.7	84	53	1.4	-
Sept. 99	36	3-9	30.3	21.3	84	56	19.0	2
	37	10-16	28.4	20.6	92	64	214.0	6
	38	17-23	29.9	19.4	87	61	19.8	1
	39	24-30	29.9	20.7	88	60	78.8	3

Table 1 (contd..)

Month	Mete-orolo-gical week	Dates	Temperature (%)		Humidity (%)		Rainfall (mm)	No. of rainy days
			Maxi-mum	Mini-mum	Morning	Evening		
Oct. 99	40	1-7	29.6	20.6	90	68	76.8	6
	41	8-14	30.3	21.2	91	60	83.6	5
	42	15-21	30.2	17.4	82	40	-	-
	43	22-28	30.1	16.1	81	43	0.6	-
Nov. 99	44	29-4	31.0	13.4	77	43	-	-
	45	5-11	31.8	15.9	77	31	-	-
	46	12-18	29.9	11.5	76	26	-	-
	47	19-25	28.3	10.5	76	31	-	-
Dec. 99	48	26-2	29.4	10.1	78	38	-	-
	49	3-9	28.6	9.4	78	39	-	-
	50	10-16	26.5	8.2	81	38	-	-
	51	17-23	27.4	6.6	82	27	-	-
	52	24-31	33.1	12.3	97	40	-	-
Jan., 2000	1	1-7	27.8	7.1	84	30	-	-
	2	8-14	28.4	8.1	82	33	-	-
	3	15-21	29.1	11.9	80	40	-	-
	4	22-28	29.5	9.9	79	44	-	-
	5	29-4	30.2	10.9	86	43	-	-
Feb. 2000	6	5-11	28.4	9.9	84	33	-	-
	7	12-18	28.9	9.2	72	35	-	-
	8	19-25	29.1	10.9	77	37	-	-
	9	26-4	31.4	12.2	73	36	-	-
March. 2000	10	5-11	32.6	10.9	70	28	-	-
	11	12-18	33.4	11.1	77	25	-	-
	12	19-26	34.4	12.7	56	15	-	-
	13	26-1	35.3	14.7	59	19	-	-
Total							730.2	48

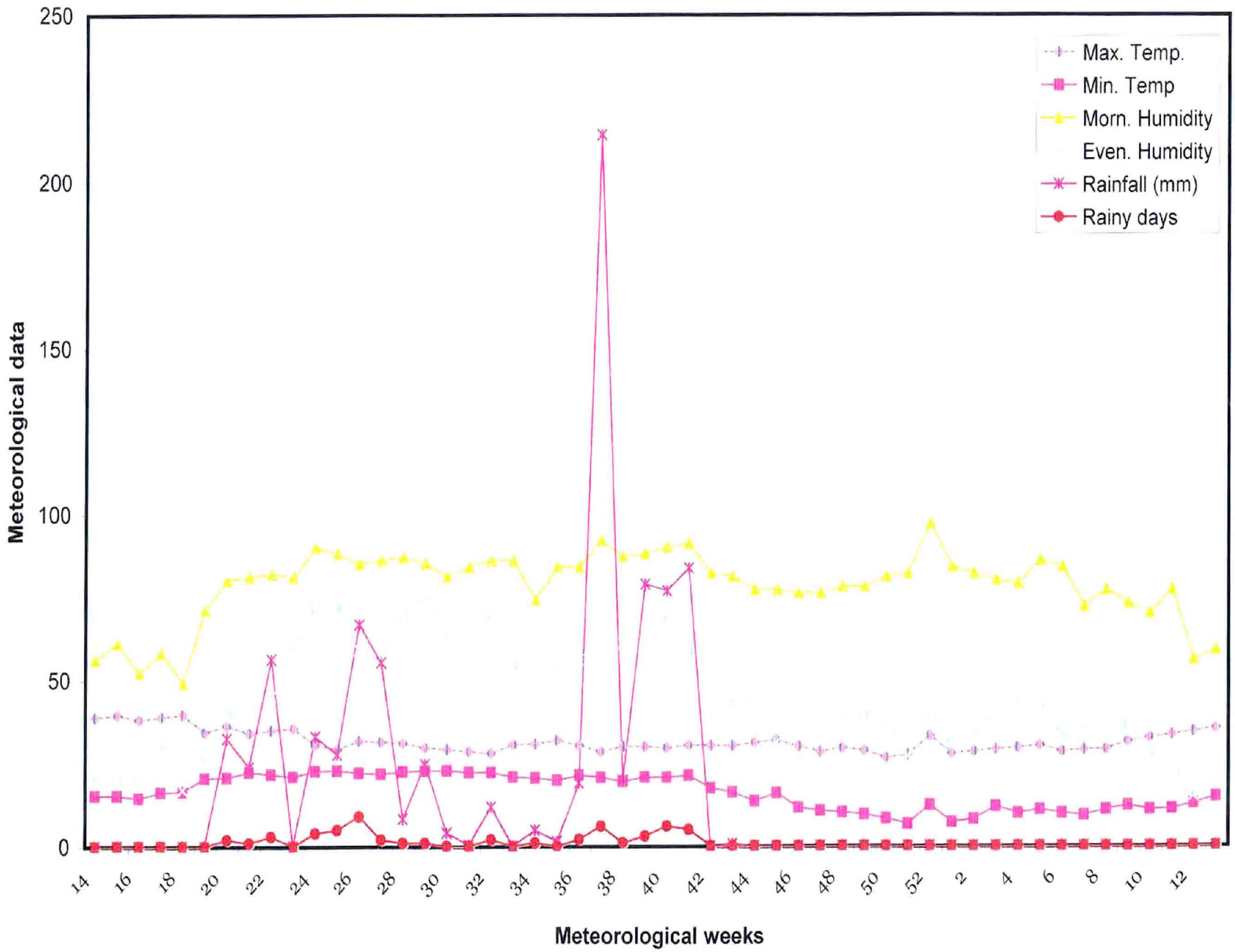


Fig. 1. Meteorological data for the year 1999-2000

Table 2. Meteorological data for the year 2000-2001

Month	Mete-orolo-gical week	Dates	Temperature (%)		Humidity (%)		Rainfall (mm)	No. of rainy days
			Maxi-mum	Mini-mum	Morning	Evening		
April, 2000	14	2-8	38.3	19.3	63	26	0.0	-
	15	9-15	38.8	20.0	65	32	0.0	-
	16	16-22	38.1	20.8	64	31	0.0	-
	17	23-29	38.1	18.9	60	26	0.0	-
May, 2000	18	30-6	39.9	20.1	61	27	0.0	-
	19	7-13	36.4	21.4	76	34	0.4	-
	20	14-20	34.2	22.1	74	44	1.2	-
	21	21-27	36.1	22.5	79	37	4.2	1
	22	28-3	34.9	23.1	82	53	34.4	3
June, 2000	23	4-10	31.7	21.9	93	61	190.2	5
	24	11-17	32.1	22.8	79	51	4.6	1
	25	18-24	31.8	21.7	78	57	0.0	-
	26	25-1	31.5	21.7	78	57	64.6	2
July, 2000	27	2-8	29.7	21.6	84	63	12.0	1
	28	9-15	28.6	21.9	85	73	45.4	3
	29	16-22	28.9	22.0	78	58	0.0	-
	30	23-29	31.4	20.2	82	46	0.0	-
	31	30-5	32.5	20.1	79	41	0.2	-
Aug. 2000	32	6-12	30.6	22.3	82	57	5.4	1
	33	13-19	31.2	21.6	82	53	0.0	-
	34	20-26	28.1	21.8	91	78	199.4	5
	35	27-2	29.1	21.9	88	66	16.8	2
Sept. 2000	36	3-9	29.4	20.2	86	53	1.7	-
	37	10-16	31.4	19.0	85	43	0.0	-
	38	17-23	32.5	20.2	87	44	9.8	2
	39	24-30	32.2	21.5	91	47	40.8	3
Oct. 2000	40	1-7	33.4	19.9	86	39	4.4	1
	41	8-14	30.9	20.4	93	56	41.8	2
	42	15-21	32.6	17.5	85	31	7.6	1
	43	22-28	33.3	16.5	87	28	0.0	-

Table 2 (contd..)

Month	Mete-orolo-gical week	Dates	Temperature (%)		Humidity (%)		Rainfall (mm)	No. of rainy days
			Maxi-mum	Mini-mum	Morning	Evening		
Nov. 2000	44	29-4	31.8	13.5	80	33	0.0	-
	45	5-11	31.4	14.2	78	29	0.8	-
	46	12-18	30.7	12.3	71	27	0.0	-
	47	19-25	31.2	11.5	74	26	0.0	-
Dec. 2000	48	26-2	29.8	11.9	66	35	0.0	-
	49	3-9	29.0	9.0	66	23	0.0	-
	50	10-16	29.3	7.9	74	19	0.0	-
	51	17-23	29.0	7.7	72	21	0.0	-
	52	24-31	28.7	8.8	84	37	3.0	1
Jan., 2001	1	1-7	24.4	11.1	87	44	4.8	1
	2	8-14	29.0	11.9	79	40	0.0	-
	3	15-21	30.3	15.1	79	35	0.0	-
	4	22-28	28.4	8.7	72	27	0.0	-
	5	29-4	31.0	12.5	67	25	0.0	-
Feb. 2001	6	5-11	32.3	9.5	61	17	0.0	-
	7	12-18	32.4	10.3	56	20	0.0	-
	8	19-25	33.7	11.8	59	19	0.0	-
	9	26-4	32.2	13.6	66	27	0.0	-
March, 2001	10	5-11	32.5	13.3	68	22	0.0	-
	11	12-18	32.9	15.5	69	23	0.0	-
	12	19-26	35.0	16.0	64	20	0.0	-
	13	26-1	34.5	15.1	48	20	0.0	-
Total							644.7	29

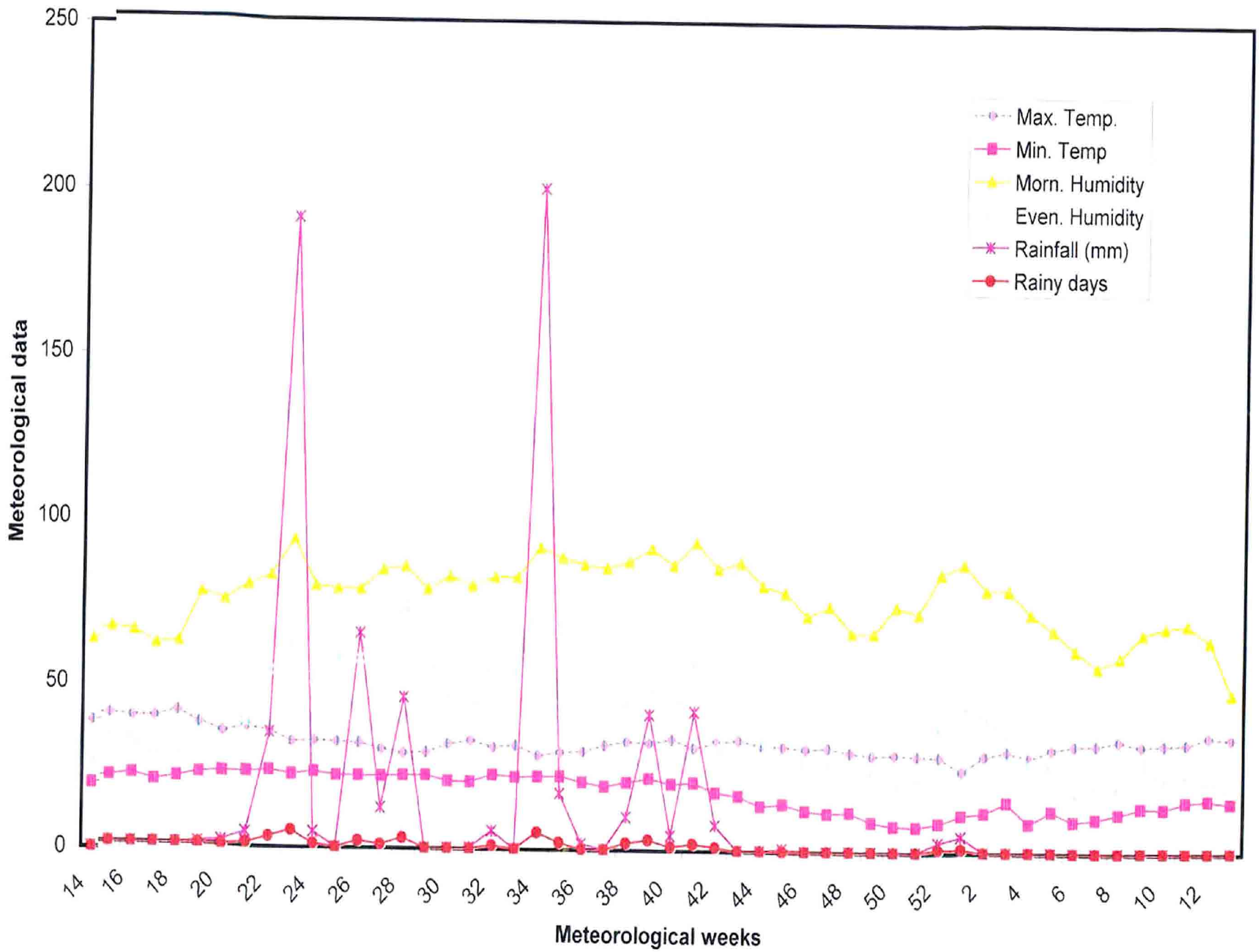


Fig. 2. Meteorological data for the year 2000-2001

Table 3. Physical and chemical properties of soil

	Particulars	Initial values
	Soil order	Vertisol
	Soil sub-order	Typic chromusterts
	Soil series	Otur
A	Physical properties	
	Coarse sand (%)	6.5
	Fine sand (%)	15.8
	Silt (%)	26.4
	Clay (%)	51.[illegible]
	Texture	Clay
	Bulk density (Mg m^{-3})	1.32
	Infiltration rate (cm h^{-1})	0.76
	Water stable aggregates (%) macro (>25 mm)	24.6
	micro (0.25-2.0 mm)	27.2
B	Chemical properties	
	pH (1:2.5)	8.2
	EC (dSm^{-1})	0.27
	Organic carbon (%)	0.64
	Available N (kg ha^{-1})	153
	Available P (kg ha^{-1})	14
	Available K (kg ha^{-1})	496
C	DTPA – extractable micronutrients (mg kg^{-1})	
	Fe	12.9
	Mn	22.1
	Zn	0.87
	Cu	3.27

3.1.4 Experimental details

Under nutrient management practices for sustaining the cropping systems, a permanent plot experiment on integrated nutrient supply system in a cereal based crop sequence (Sorghum-Wheat) on a fixed site is in progress since 1984-85 under the All India Co-ordinated Agronomic Research Project, through Main Centre for Cropping Systems Research Project, Mahatma Phule Krishi Vidyapeeth, Rahuri, Maharashtra. The framed field experiment consisted of twelve treatments out of which ten treatments are considered with four replications involving use of various levels of NPK fertilizers alone and in combination with organic sources viz., farm yard manure, wheat straw and gliricidia leaves in a randomized block design as depicted in Fig. 3. The details of the treatments adopted during *kharif* and *rabi* seasons are given in Table 4. Only ten treatments are considered for interpretation and remaining two treatments are treated as dummy (DT).

3.1.5 Plan of layout

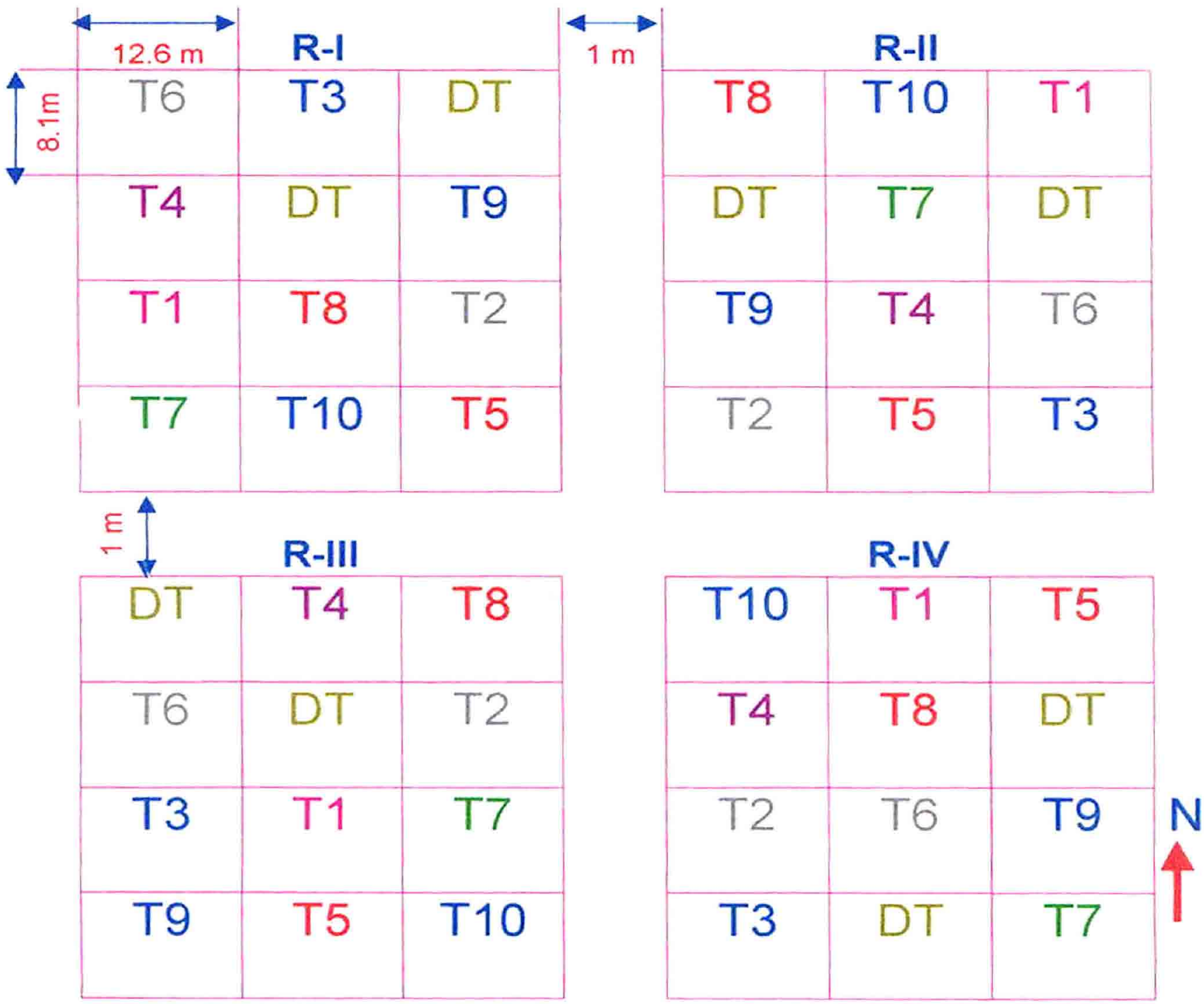
The plan of layout illustrating the relevant details is depicted in Fig.3. The other details of layout are furnished below.

1.	Number of treatments	:	10					
2.	Number replications	:	4					
3.	Statistical design	:	RBD					
4.	Gross plot size	:	12.6 x 8.1 m^2					
5.	Net plot size	:	12.0 x 7.2 m^2					
6.	Spacing	:	a.	Sorghum	:	45 x 12 cm		
			b.	Wheat	:	22.5 cm between lines		
						N	P_2O_5	K_2O /ha
7.	Recommended dose of fertilizer (Optimum level)	:	a.	Sorghum	:	120	: 60	: 60
			b.	Wheat	:	120	: 60	: 60

Table 4. Details of the treatments for field experiment

Treatment number	*Kharif* sorghum (CSH-9)	*Rabi* wheat (HD-2189)
1	No fertilizer, no organic matter (control)	No fertilizer, no organic matter (control)
2	50% recommended NPK dose through fertilizers	100% recommended NPK dose through fertilizers.
3	75% recommended NPK dose through fertilizers	75% recommended NPK dose through fertilizers.
4	100% recommended NPK dose through fertilizers	100% recommended NPK dose through fertilizers.
5	50% recommended NPK dose through fertilizers + 50% N through FYM	100% recommended NPK dose through fertilizers.
6	75% recommended NPK dose through fertilizers + 25% N through FYM	75% recommended NPK dose through fertilizers.
7	50% recommended NPK dose through fertilizers + 50% N through wheat cut straw (WCS)	100% recommended NPK dose through fertilizers.
8	75% recommended NPK dose through fertilizers + 25% N through wheat cut straw (WCS)	75% recommended NPK dose through fertilizers.
9	50% recommended NPK dose through fertilizers + 50% N through gliricidia leaves (GLM)	100% recommended NPK dose through fertilizers.
10	75% recommended NPK dose through fertilizers + 25% N through gliricidia leaves (GLM)	75% recommended NPK dose through fertilizers.

PLAN OF LAYOUT



DESIGN : **Randomized Block Design with Four Replications**

PLOT SIZE : **Gross : 12.6 m x 8.1 m; Net : 12.0 x 7.2 m**

FIG. 3

3.1.6 Cultural operations

The various field operations carried out in the experimental field during the *kharif* and *rabi* seasons of the years 1999-2000 and 2000-2001 are presented in Table 5.

3.1.7 Seeds and sowing

The seeds of sorghum hybrid CSH-9 and wheat variety HD-2189 were obtained from the Main Centre for Cropping Systems Research Project, Mahatma Phule Krishi Vidyapeeth, Rahuri. The treated sorghum seeds were line sown on 27.6.1999 and 23.6.2000 with recommended row spacing. While wheat seeds were line sown on 26.11.1999 and 14.11.2000.

3.1.8 Fertilizer application

The recommended doses of fertilizers for *kharif* sorghum (CSH-9) and wheat (HD-2189) were 120:60:60 kg ha^{-1} as $N:P_2O_5:K_2O$, respectively (optimum level). Organic manure viz., farm yard manures, wheat straw and gliricidia leaves were incorporated in soil one month before sowing of *kharif* sorghum on the basis of nitrogen content as per treatments. The nitrogen application was done in two splits, half of N, full dose of P_2O_5 and K_2O was applied as a basal and remaining half N, at 30 and 21 days after sowing of sorghum and wheat, respectively. The composition of organic manures and quantity of organic manures and chemical fertilizers added are presented in Table 6, 7 and 8.

3.1.9 Intercultivation and irrigation

First irrigation was given to each crop during each year immediately after sowing to ensure proper germination and subsequent irrigations were given as per the critical growth stages of the crops. Weeding and hoeing operations were carried out for both the crops as and when required during crop growth. The datewise details of operations are given in Table 5.

Table 5. Schedule of field operations carried out in the experimental plot during *kharif* and *rabi* season

Sr. No.	Name of operation	Date(s) of operation			
		Kharif		*Rabi*	
		1999-2000	2000-2001	1999-2000	2000-2001
A)	**Presowing operations**				
1.	Ploughing	23.5.1999	15.5.2000	11.11.1999	29.10.2000
2.	Harrowing	31.5.1999	18.6.2000	18.11.1999	8.11.2000
3.	Application of organic manures	13.5.1999	10.5.2000	-	-
4.	Layout of experiment	22.6.1999	20.6.2000	25.11.1999	11.11.2000
5.	Application of fertilizers	26.6.1999	22.6.2000	25.11.1999	13.11.2000
6.	Top dressing	23.7.1999	25.7.2000	15.12.1999	7.12.2000
B)	**Sowing**				
1.	Line sowing of sorghum	27.6.1999	23.6.2000	-	-
2.	Line sowing of wheat	-	-	26.11.1999	14.11.2000
C)	**Irrigations**				
1.	At the time of sowing	28.6.1999	24.6.2000	26.11.1999	14.11.2000
2.	First	18.7.1999	25.7.2000	15.12.1999	3.12.2000
3.	Second	7.8.1999	14.8.2000	6.1.2000	23.12.2000
4.	Third	31.8.1999	15.9.2000	26.1.2000	12.01.2001
5.	Fourth	-	-	18.2.2000	31.1.2001 18.2.2001
D)	**Post sowing operations**				
1.	Gap filling	12.7.1999	8.7.2000	6.12.1999	23.11.2000
2.	Thinning	17.6.1999	14.7.2000	-	-
3.	Weeding (i) First	10.7.1999	22.7.2000	23.12.1999	1.12.2000
	(ii) Second	21.7.1999	9.8.2000	1.1.2000	17.12.2000
4.	Hoeing	13.7.1999 3.8.1999	15.7.2000 31.7.2000	13.12.1999	5.12.2000
5.	Plant protection measures				
	(i) First	13.7.1999	12.7.2000	-	22.1.2001
	(ii) Second	6.8.1999	29.7.2000		
	(iii) Third	8.9.1999	17.8.2000 11.9.2000		
E)	**Harvesting**				
1.	Sorghum	27.10.1999	20.10.2000	-	-
2.	Wheat	-	-	29.3.2000	10.3.2001
F)	**Threshing**				
1.	Sorghum	21.11.1999	15.11.2000	-	-
2.	Wheat	-	-	10.4.2000	25.3.2001

Table 6. Chemical composition of organic manures

Organic manure	Moisture (%)	N (%)	P_2O_5 (%)	K_2O (%)	Org. C (%)	C:N ratio
1999						
Farm yard manure	22	0.62	0.63	0.76	15.70	25.32
Wheat straw	Air dry	0.43	0.14	1.30	34.32	79.81
Gliricidia leaves	70	2.90	0.26	4.52	36.27	12.50
2000						
Farm yard manure	21	0.67	0.66	0.80	16.60	24.70
Wheat straw	Air dry	0.47	0.16	1.32	35.37	75.10
Gliricidia leaves	76	2.72	0.28	4.60	36.30	13.4

Table 7. Quantity of organic manures added on N basis (t ha^{-1})

Year	Farm yard manure		Wheat straw		Gliricida leaves	
	25% N	50% N	25% N	50% N	25% N	50% N
1999	6.20	12.41	7.00	14.00	3.45	6.90
2000	5.67	11.34	6.38	12.77	4.60	9.19

Table 8. Quantity of organic and inorganic fertilizers applied (kg plot^{-1})

Treatment	Organic source	*Kharif* (Sorghum) Inorganic source			Top dressing of urea	*Rabi* (Wheat) Inorganic source			Top dressing of urea
		Urea	Single super phosphate	Muriate of potash		Urea	Single super phosphate	Muriate of potash	
1	-	-	-	-	-	-	-	-	-
2	-	0.666	1.914	0.528	0.666	1.331	3.827	1.055	1.331
3	-	0.998	2.870	0.792	0.998	0.998	2.870	0.792	0.998
4	-	1.331	3.827	1.055	1.331	1.331	3.827	1.055	1.331
5	I. 126.65 II. 115.74	0.666	1.914	0.528	0.666	1.331	3.827	1.055	1.331
6	I. 63.28 II. 57.87	0.998	2.870	0.792	0.998	0.998	2.870	0.792	0.998
7	I. 142.88 II. 130.33	0.666	1.914	0.528	0.666	1.331	3.827	1.055	1.331
8	I. 71.44 II. 65.16	0.998	2.870	0.792	0.998	0.998	2.870	0.792	0.998
9	I. 70.42 II. 93.79	0.666	1.914	0.528	0.666	1.331	3.827	1.055	1.331
10	I. 35.21 II. 46.95	0.998	2.870	0.792	0.998	0.998	2.870	0.792	0.998

Note : Plot size 12.6 x 8.1 m^2 I = First year, II = Second year

Table 8. Quantity of organic and inorganic fertilizers applied (kg plot^{-1})

Treatment	Organic source	*Kharif* (Sorghum) Inorganic source Urea	Single super phosphate	Muriate of potash	Top dressing of urea	*Rabi* (Wheat) Inorganic source Urea	Single super phosphate	Muriate of potash	Top dressing of urea
1	-	-	-	-	-	-	-	-	-
2	-	0.666	1.914	0.528	0.666	1.331	3.827	1.055	1.331
3	-	0.998	2.870	0.792	0.998	0.998	2.870	0.792	0.998
4	-	1.331	3.827	1.055	1.331	1.331	3.827	1.055	1.331
5	I. 126.65 II. 115.74	0.666	1.914	0.528	0.666	1.331	3.827	1.055	1.331
6	I. 63.28 II. 57.87	0.998	2.870	0.792	0.998	0.998	2.870	0.792	0.998
7	I. 142.88 II. 130.33	0.666	1.914	0.528	0.666	1.331	3.827	1.055	1.331
8	I. 71.44 II. 65.16	0.998	2.870	0.792	0.998	0.998	2.870	0.792	0.998
9	I. 70.42 II. 93.79	0.666	1.914	0.528	0.666	1.331	3.827	1.055	1.331
10	I. 35.21 II. 46.95	0.998	2.870	0.792	0.998	0.998	2.870	0.792	0.998

Note : Plot size 12.6 x 8.1 m^2 I – First year, II – Second year

3.1.10 Plant protection measures

A mild incidence of stem borer and army worm on sorghum crop and aphid infection on wheat crop were observed. Spraying of 35 EC Endosulphan @ of 2.5 ml per litre of water was done to sorghum and affected plants were rogued and destroyed for minimising the attack. As a preventive measure for midgefly and leaf eating caterpiller sparying of monocrotophos @ 4.5 ml/litre of water was carried out with the help of power sprayer.

3.2 Biometric observations (Sorghum)

3.2.1 Sampling technique

The various biometric observations were recorded on five randomly selected plants of sorghum from each net plot. Wooden pegs were fixed near the observational plants for their easy identification. The detail observations recorded on the growth and yield of sorghum during the course of investigation are given in Table 9.

3.2.2 Initial plant count

The plant number was recorded by counting all the plants from each net plot at 20 days growth.

3.2.3 Growth studies

The details regarding various growth observations are as follows.

3.2.3.1 Height of plant

Height of plant was recorded by measuring the length of shoot from its base near the ground level upto the fully opened top most leaf till the stage of earhead emergence. After the emergence of earhead, the height was measured upto the base of the earhead. The plant height was recorded at 30, 60 and 90 days of crop growth and at harvest.

Table 9. Details of biometric observations recorded for sorghum

Sr. No.	Details	Frequ-ency	After sowing	Sample size
A)	**Initial plant count**			
1.	No. of plants from net plot	1	20	Plants in each net plot
B)	**Growth studies**			
1.	Height of plant (cm)	4	30, 60 and 90 days and at harvest	5 plants
2.	No. of functional leaves per plant	4	-do-	5 plants
3.	Leaf area per plant (dm^2)	4	-do-	1 plant
4.	Leaf area index (LAI)	4	-do-	1 plant
5.	Days to 50 per cent flowering	1	70-90 days	From each net plot
6.	Dry matter per plant (g)	4	30, 60 and 90 days and at harvest	1 plant
C)	**Yield contributing characters**			
1.	Length of earhead (cm)	1	At harvest	5 plants
2.	Girth of earhead (cm)	1	At harvest	5 plants
3.	Weight of earhead (g)	1	At harvest	5 plants
4.	Grain weight per earhead (g)	1	At harvest	5 plants
5.	*Bhoosa* weight per earhead (g)	1	At harvest	5 plants
6.	No. of earheads per plot	1	At harvest	All plants from net plot
7.	No. of grains per earhead	1	At harvest	5 plants
8.	Hundred grain weight (g)	1	At harvest	5 plants
D)	**Yield**			
1.	Grain yield per plot (kg) and per hectare (q)	1	At harvest	All plants from net plot and per hectare
2.	Fodder yield per plot (kg) and per hectare (q)	1	At harvest	-do-
3.	Total biomass per net plot and per hectare	1	At harvest	Net plot and per ha.
4.	Fodder to grain ratio	1	At harvest	
5	Harvest index	1	At harvest	

Table 9 (Contd...)

Sr. No.	Details	Frequ-ency	Days after sowing	Sample size
E)	**Chemical analysis**			
1.	Physical and chemical properties of soil	1	Before sowing of the crop and at the end of experiment	½ kg of representative soil samples was collected from each plot
2.	Plant analysis for Nitrogen, Phosphorus and Potasisum	1	After harvest	5 plants
3.	Available Nitrogen, Phosphorus and Potassium in soil (kg ha^{-1})	1	After harvest	Representative soil sample from each net plot
4.	Nutrient balance studies (kg ha^{-1})	1	At the end of experiment	Per ha.
5.	Micronutrient status (µg/g)	1	-do-	-do-
F)	**Quality studies**			
1.	Protein percentage in grain	1	-do-	-do-
2.	Protein yield (q ha^{-1})	1	-do-	-do-
G)	**Microbial studies**	1	-do-	-do-
H)	**Economic studies**			
1.	Gross returns (Rs. ha^{-1})	1	-do-	-do-
2.	Net returns (Rs. ha^{-1})	1	-do-	-do-
3.	B:C ratio	1	-do-	-do-
I)	**Energy studies**			
1	Energy output (MJ ha^{-1})	1	-do-	-do-
2	Energy input (MJ ha^{-1})	1	-do-	-do-
3	Energy balance (MJ ha^{-1})	1	-do-	-do-
4	Energy balance/unit input (MJ ha^{-1})	1	-do-	-do-
5	Energy use efficiency	1	-do-	-do-

3.2.3.2 Number of functional leaves

Number of fully opened leaves were periodically recorded at 30, 60 and 90 days growth and at harvest. The leaf wherein more than half of the total leaf area was green, was considered as a functional leaf.

3.2.3.3 Leaf area per plant

For determination of the leaf area per plant, the total fully opened functional leaves were collected from the plant collected for dry matter studies at different stages viz., 30, 60 and 90 days of growth and at harvest and were separated into three groups viz., small, medium and big. Length and maximum breadth of one representative leaf from each of the group was recorded. The total number of leaves from each group was also recorded. Leaf area was calculated by using formula given by Stickler *et al.* (1961).

$$\text{Leaf area } (cm^2) = \text{Length } (cm) \times \text{Maximum breadth } (cm) \times 0.747$$

The total leaf area of each group was calculated by multiplying the leaf area of representative leaf with the number of leaves in that particular group. The total leaf area per plant was determined by adding the leaf area of the three groups. The leaf area per plant was thus recorded in cm^2 and converted into dm^2 at an interval of 30 days during the season.

3.2.3.4 Leaf area index (LAI)

The leaf area index was calculated from the data computed from leaf area per plant at the various growth stages of crop viz., 30, 60 and 90 days of growth and at harvest by using the formula (Watson, 1947).

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

3.2.3.5 Days to fifty per cent flowering

The number of days required for fifty per cent flowering by visual observations were recorded from the date of sowing.

3.2.3.6 Dry matter accumulation per plant

For dry matter studies, one plant each from the experimental plot was randomly uprooted. After removal of roots, the plant was kept for air drying and then in an oven at 60°C temperature till that attained a constant weight. Dry matter accumulation was recorded at the different growth stages viz., 30, 60 and 90 days of growth and at harvest.

3.2.4 Post harvest observations of sorghum

Post harvest observations were recorded for different plant parts of sorghum and enlisted below.

3.2.4.1 Earhead measurement

3.2.4.1.1 Length of earhead

The length of earheads (cm) of the five observational plants was measured from the tip of the earhead to the base of first spikelet on the panicle.

3.2.4.1.2 Girth of earhead

The maximum girth of the earhead was recorded from the same ears which were used for the ear length studies.

3.2.4.2 Earhead weight

3.2.4.2.1 Weight of earhead

The weight of earhead (g) was recorded from the five observational plants after harvesting the same and drying them in sun for about a week.

3.2.4.2.2 Weight of grains per earhead

The weight of gains per earhead (g) was recorded after separating them from the panicle.

3.2.4.2.3 Weight of *bhoosa* per earhead

Weight of *bhoosa* per ear was computed by deducting the mean weight of grains per earhead from the corresponding mean total weight of earhead.

3.2.4.3 Yield attributing characters

3.2.4.3.1 Number of plants per plot

Total number of plants from each plot was counted at the time of harvesting of sorghum.

3.2.4.3.2 Number of grains per earhead

The average number of grains per earhead from each treatment was worked out by the following formula.

$$\text{Avg. No. of grains per earhead} = \frac{\text{Mean weight of grains / earhead}}{\text{Mean thousand grain weight}} \times 1000$$

3.2.4.3.3 Hundred grain weight

A random sample of 100 grains was taken from the grain of the observational plants from each plot and its weight was recorded.

3.2.5 Yield of sorghum

The grain and fodder yields of sorghum were recorded as detailed below.

3.2.5.1 Grain yield

The dried ears from each net plot were threshed and grain weight was recorded. The grain yield per hectare was calculated on the basis of yield of grain per net plot.

3.2.5.2 Fodder yield

The fodder yield from each net plot was recorded after complete sun drying for 15 days. Per hectare yield of fodder was computed on the basis of the yield of fodder per plot.

3.2.5.3 Biological yield

The biological yield was recorded by summing the grain and fodder yield obtained from the net plot and converted into hectare basis by multiplying the hectare factor.

3.2.5.4 Fodder to grain ratio

The ratio was computed from the yield of grain (q/ha) and fodder (q/ha) in the corresponding treatments by dividing the yield for fodder by the yield of grain.

3.2.5.5 Harvest index

Harvest index was calculated by using the following formula.

$$\text{Harvest index} = \frac{\text{Grain yield}}{\text{Biological yield}} \times 100$$

3.3 Biometric observations (Wheat)

3.3.1 Sampling technique

For recording various growth observations five shoots were selected at random from each net plot. The wax coated label was fixed to each observational plant for easy identification. All the observations viz., plant height, number of leaves, number of tillers, panicle length, number of grains per panicle, number of spikelets per panicle were recorded. The schedule adopted for recording various growth observations is given in Table 10.

3.3.2 Growth studies

3.3.2.1 Plant count

The number of plant emerged were recorded on the 20^{th} day after sowing. In every net plots at two spots of one meter length were selected at random and the number of plants per meter length was recorded.

3.3.2.2 Height of the plant

Five randomly selected plants were used for measuring the height of the plant. It was measured on the main shoot from the ground level to the base of the last fully opened leaf till the stage of panicle emergence then thereafter height was measured from ground level to the base of panicle in cm.

3.3.2.3 Number of functional leaves per plant

The total number of fully opened green leaves per plant was recorded as functional leaves. The dried leaves were excluded while counting the number of functional leaves.

Table 10. Details of biometric observations recorded for wheat

Sr. No.	Details	Frequency	Days after sowing	Sample size
A)	**Initial plant count**			
1.	Count of emergence	1	20	At 1 meter length
B)	**Growth studies**			
1.	Height of plant (cm)	4	30, 60, 90 days and at harvest	5 plants
2.	No. of functional leaves per plant	3	30, 60 and 90 days	5 plants
3.	Leaf area (dm^2) per plant	3	30, 60 and 90 days	1 plant
4.	Total no. of tillers per plant	4	30, 60, 90 days and at harvest	At 1 meter length
5.	Dry matter per plant (g)	4	30, 60, 90 days and at harvest	1 plant
6.	Productive tillers per plant	1	At harvest	At 1 meter length
C)	**Yield contributing characters**			
1.	Length of panicle	1	At harvest	5 plants
2.	Number of spikelets per panicle	1	At harvest	5 plants
3.	Number of grains per panicle	1	At harvest	5 plants
4.	Weight of grains per plant (g)	1	At harvest	5 plants
5.	Hundred grain weight (g)	1	At harvest	Sample from each net plot
D)	**Yield**			
1.	Grain yield per net plot (kg) and per hectare (q)	1	At harvest	Net plot and per hectare
2.	Straw yield per net plot (kg) and per hectare (q)	1	At harvest	-do-
3.	Total biomass per net plot and per hectare	1	At harvest	-do-
4.	Straw to grain ratio	1	At harvest	-do-
5.	Harvest index	1	At harvest	-do-

Table 10 (Contd...)

Sr. No.	Details	Frequency	Days after sowing	Sample size
E)	**Chemical analysis**			
1.	Physical and chemical properties of soil	1	Before and at the end of experiment	Composite representative sample reduced to ½ kg from samples collected from different spots in the experimental field
2.	Plant analysis for Nitrogen, Phosphorus and Potassium	1	After harvest	5 plants
3.	Available Nitrogen, Phosphorus and Potassium of soil (kg ha^{-1})	1	Before sowing and at harvest	Representative sample from each net plot
4.	Nutrient balance studies (kg ha^{-1})	1	At the end of experiment	Per ha
5.	Micronutrient status (µg g^{-1})	1	-do-	-do-
F)	**Quality studies**			
1.	Protein percentage in grain	1	-do-	-do-
2.	Protein yield (q ha^{-1})	1	-do-	-do-
G)	**Microbial studies (1 x 10^{-4})**	1	-do-	-do-
H)	**Economic studies**			
1.	Gross returns (Rs. ha^{-1})	1	-do-	-do-
2.	Net returns (Rs. ha^{-1})	1	-do-	-do-
3.	B:C ratio	1	-do-	-do-
I)	**Energy studies**			
1	Energy output (MJ ha^{-1})	1	-do-	-do-
2	Energy input (MJ ha^{-1})	1	-do-	-do-
3	Energy balance (MJ ha^{-1})	1	-do-	-do-
4	Energy balance unit input (MJ ha^{-1})	1	-do-	-do-
5	Energy use efficiency	1	-do-	-do-

3.3.2.4 Leaf area per plant

The plants collected for dry matter study were used for measuring leaf area per plant. The leaf area was measured with the help of automatic leaf area meter in cm^2. The leaf area per plant was thus recorded and converted into dm^2 at an interval of 30 days during the season.

3.3.2.5 Number of tillers per plant

The total number of tillers from each of one meter length from two random locations from each net plot was counted. The average number of tillers per plant was computed by dividing the number of tillers excluding the main shoot by the number of main tillers, recorded on 30, 60, 90 days and at harvest.

3.3.2.6 Dry matter per plant

The dry matter per plant was recorded at an interval of 30 days after sowing. Single plant was cut at ground level, air dried and final dry weight was recorded after drying in oven at 60°C to 65°C until the constant weight was obtained.

3.3.3 Post harvest studies

3.3.3.1 Length of panicle

The length of panicle was measured from the basal spikelet to the tip of the panicle excluding awns from five randomly selected plants. The mean length of panicle was then worked out in cm.

3.3.3.2 Number of spikelets per panicle

The number of spikelets of the panicle was counted from the same panicles which were used for measuring the panicle length at harvest and the average number of spikelets per panicle was worked out.

3.3.3.3 Number of grains per panicle

The panicles which were used for the study of mean length, were used for this study. The grain number per panicle was counted and the mean was computed.

3.3.3.4 Weight of grains per plant

The grain weight per plant from five randomly selected plants was recorded and average was computed to obtain grain weight per plant.

3.3.3.5 Hundred grain weight

The random samples of grains from the total grain produce from each net plot was drawn. Then hundred grains were counted from random samples and weighed to obtain hundred grain weight for each treatment.

3.3.4 Yields

3.3.4.1 Yield of grain per plot

The panicles of the plants were threshed after drying and winnowed. The grain weight obtained was recorded as per treatments.

3.3.4.2 Yield of straw per plot

After threshing the panicles, the weight of straw arrived at by deducting the weight of grain from the weight of total produce per net plot was recorded.

3.3.4.3 Yield of total biomass per plot

The harvest produced from the net plot was dried in sun for six days and was weighed for recording the total produce per plot.

3.3.4.4 Straw to grain ratio

The ratio was estimated from the yield of grain and straw obtained from the net plot in the corresponding treatments by dividing the straw weight by that grain weight.

3.4 Chemical analysis

3.4.1 Soil sampling

The representative composite soil samples (0-30 cm) were collected from each plot treatmentwise before the sowing of *kharif* sorghum and *rabi* wheat and post harvest soil samples were also collected in polythene bags with the help of wooden peg for micronutrient analysis and with spade/*khurpi* for major nutrient analysis. The samples were then air dried in shade, ground with wooden morter and pastle and sieved through 2 mm sieve (Nylon netted) and analysed for physical and chemical properties as per the standard analytical methods (Table 11).

3.4.2 Plant sampling

After recording the yield of grain and fodder/straw from individual plot samples of grain and fodder/straw were taken separately. The plant samples were air dried initially and then dried in an electrical hot air oven at 60°C till constant weight. The samples were powdered in a grinding mill and stored and analysed as per the standard analytical method (Table 11).

Table 11. Analytical methods used for soil and plant analysis

Sr. No.	Parameter	Method applied	Reference
A)	**Physical**		
1.	Mechanical analysis	International pipette	Piper (1966)
2.	Bulk density	Core sampler	Blake and Hortge (1986)
3.	Infiltration rate	Double ring infiltrometer	Klute (1986)
4.	Water stable aggregates	Modified Yoder's wet sieving technique	Biswas *et al.* (1961)
B)	**Chemical**		
5.	Soil pH	Potentiometric	Jackson (1973)
6.	Electrical conductivity	Conductometric	Jackson (1973)
7.	Organic carbon	Wet oxidation	Jackson (1973)
8.	Available N	Alkaline permanganate	Subbiah and Asija (1956)
9.	Available P	0.5 N $NaHCO_3$ at pH 8.5	Olsen *et al.* (1954)
10.	Available K	Neutral N ammonium acetate	Hanway and Heidal (1952)
C)	**Plant analysis**		
11.	Total N	Micro-Kjeldahl	Parkinson and Allen (1975)
12.	Total P	Vanadomolybdate yellow colour	Jackson (1973)
13.	Total K	Flame photometric	Chapman and Pratt (1961)
D)	**Micronutrient (soil)**		
14.	DTPA- exctractable Fe, Mn, Zn and Cu	Atomic Absorption Spectrophotometer	Lindsay and Norvell (1978)

3.4.3 Quality of grain

3.4.3.1 Protein percentage in grain

The protein percentage in grain was determined by multiplying the percentage of nitrogen in the grain by the factor 6.25 and 5.70 for sorghum and wheat, respectively.

3.4.3.2 Protein yield

The protein yield per hectare was calculated by multiplying the protein content by per hectare grain yield of respective treatments of sorghum and wheat. The following formula used for estimating the protein production.

$$\text{Protein production } (\text{kg ha}^{-1}) = \frac{\text{Grain protein content } (\%)}{100} \times \text{Grain weight } (\text{kg ha}^{-1})$$

3.4.4 Microbial studies

The microorganism counts in the soil were recorded after completing the crop sequence; particularly actinomycetes, azotobacter population treatmentwise after harvest of the crop by using the media.

3.5 Economic studies of the sequence

3.5.1 Gross returns of sequence

Per hectare gross monetary returns were worked out by considering the grain and fodder yields of sorghum and wheat from different treatments and prevailing market prices of the commodities.

3.5.2 Input cost of cultivation

The input cost was worked out by considering the amount required for the purchase of inputs like seeds, fertilizers, pesticides, irrigation charges and amount spent on the labour charges and bullock charges required for all the operations including watch and ward.

3.5.3 Net returns of sequence

The net returns were worked out by substracting the total input cost of cultivation from the gross returns of the corresponding treatments.

3.5.4 Benefit cost ratio

The benefit cost ratio was worked out by considering per hectare values of gross returns divided by cost of cultivation. The details of prices used for calculation of economic of sequences is given in Appendix-I.

3.6 Energy studies

Energy input, output in crop production, energy balance, energy use efficiency and energy balance per unit inputs of the sequences were worked out. The energy output and energy input were worked out by using the itemwise energy values mentioned in the Appendix-II.

3.6.1 Energy output

The treatmentwise energy output from grain and fodder/straw of sorghum and wheat were worked out by multiplying treatmentwise grain and fodder/straw yields of sorghum and wheat by the energy values of grain and fodder/straw of the sorghum and wheat. By adding energy values of grain and fodder/straw, total energy output (MJ ha^{-1}) of sorghum and wheat were worked out.

3.6.2 Energy input

The treatmentwise energy input were worked out by using the itemwise energy values mentioned in Appendix-II.

3.6.3 Energy balance

The treatmentwise energy balance (MJ ha^{-1}) was worked out by substracting the treatmentwise energy input from the treatmentwise energy output.

3.6.4 Energy balance per unit input

The treatmentwise energy balance per unit input was calculated by using following formula.

$$\text{Energy balance per unit input (MJ ha}^{-1}\text{)} = \frac{\text{Energy balance}}{\text{Energy input}}$$

3.6.5 Energy use efficiency

The treatmentwise energy use efficiency was calculated by using following formula.

$$\text{Energy use efficiency} = \frac{\text{Energy output}}{\text{Energy input}}$$

3.7 Statistical analysis

Statistical analysis for the yield data, uptake of nutrients by plants, chemical properties of soil was carried out by using the procedure described by Panse and Sukhatme (1967) for standard statistical method "Analysis of variance". When the treatment differences were significant, appropriate standard error (S.E.) and critical differences (C.D.) were calculated at 5 per cent level of significance and when the treatment differences were not significant, only S.E. was calculated. The data were also appropriately presented in tables and depicted through suitable graphical illustrations.

Sustainability yield index (SYI) :

The sustainability yield index was calculated by using following formula.

$$SYI = \frac{Y - \sigma}{Y \max.}$$

Where,

Y = Estimated average yield of a treatment over years.

σ = Estimated standard deviation (S.D.)

Y max = Observed maximum yield of experiment over years.

EXPERTIMENTAL RESULTS

4. EXPERIMENTAL RESULTS

The results obtained from experiment conducted on "Integrated nutrient management system for productivity potential of sorghum-wheat sequence under irrigated conditions" during the year 1999-2000 and 2000-2001 are presented in this chapter.

4.1 Effect of integrated nutrient management on *kharif* sorghum

4.1.1 Plant stand

The plant population of sorghum as influenced by integrated nutrient management for sorghum-wheat cropping sequence at 20 days after sowing (DAS) and at harvest per hectare are presented in Table 12. The data clearly revealed that the plant population of sorghum was not significantly influenced by the various treatments during both the years of experimentation at 20 DAS and at harvest. The initial mean plant population was 184428 and 184634 in 1999 and 2000, respectively which was in the range of 183813 to184989 per ha. and 184009 to185224 per hectare, during first and second years, respectively. However, at harvest it was ranged in between 183152-184009 and 183250-184303 per hectare, respectively which was 99.40 and 99.67 per cent of the initial plant population. The plant stand reduced as the crop age advanced and reached the maturity during both the years. The reduction was nearly to 1% which may be attributed to self thinning process and competition effects between healthy and weaker.

Table 12. Effect of integrated nutrient management on plant population per hectare of sorghum

Sr. No.	Treatments	Plant population						% to the initial mean
		20 DAS			At harvest			
		1999	2000	Mean	1999	2000	Mean	
1.	Control (No fertilizers)	184989	184793	184891	183813	183960	183887	99.46
2.	50% RDF	184695	184891	184793	183911	183667	183789	99.40
3.	75% RDF	184303	184107	184205	183666	183298	183482	99.60
4.	100% RDF	183813	185087	184450	183152	184303	183728	99.61
5.	50% RDF + 50% N (FYM)	184989	185224	185107	184009	184205	184107	99.46
6.	75% RDF + 25% N (FYM)	184303	184303	184303	183519	183519	183519	99.57
7.	50% RDF + 50% N (WCS)	183911	184499	184205	183470	183740	183605	99.67
8.	75% RDF + 25% N (WCS)	184793	184827	184810	183690	184107	183899	99.50
9.	50% RDF + 50% N (GLM)	184377	184597	184487	183715	183764	183739	99.60
10.	75% RDF + 25% N (GLM)	184107	184009	184058	183372	183250	183311	99.59
	S.E. ±	238	430	-	180	403	-	-
	C.D. at 5%	N.S.	N.S.	-	N.S.	N.S.	-	-
	General mean	184428	184634	184531	183632	183781	183707	99.55

4.1.2 Growth studies

4.1.2.1 Plant height

The response of sorghum to integrated nutrient management for their mean plant height at 30 days interval was recorded in Table 13 and depicted in Fig. 4. The integrated nutrient management for sorghum crop resultantly enhanced the height at 30, 60, 90 DAS and at harvest significantly in both the years of experimentation. The magnitude of increasing in height was more during second year of experimentation than that of first year of experimentation at 30 DAS and trend was reverse during succeeding intervals. The plant height at 30, 60, 90 DAS and at harvest was 27.81, 113.91, 160.44 and 166.86 cm, respectively.

The sorghum plant attended the maximum height (27.55 cm) with an application of 50 per cent RDF + 50 per cent substitution of nitrogen through gliricidia which was at par with all the treatments except control, and 50 per cent RDF + 50 per cent substitution of nitrogen through wheat cut straw at 30 DAS. The reduced height may be attributed to the fact that the added quantity of wheat cut straw requires more energy for their decomposition by means of soil organism as well as moisture. The energy might have obtained from the readily available source of N from soil. This fact makes the shortage of moisture and N to crop plant at their critical growth stage which affect the height of plant during first year of experimentation. However, during second year of experimentation, the sorghum plant attended the maximum height (35.30 cm) with the application of 75 per cent RDF + 25 per cent N through gliricidia which was at par with all the treatments except control and treatment in which substitution of 25 and 50 per cent nitrogen through wheat cut straw.

Table 13. Effect of integrated nutrient management on plant height (cm) of sorghum.

Sr. No.	Treatments	Plant height (cm)											
		30 DAS			60 DAS			90 DAS			At harvest		
		1999	2000	Mean	1999	2000	Mean	1999	2000	Mean	1999	2000	Pooled mean
1.	Control (No fertilizers)	8.65	14.95	11.80	32.90	34.20	33.55	126.40	97.60	112.00	141.90	123.60	132.75
2.	50% RDF	25.15	30.00	27.58	127.20	92.05	109.63	176.75	141.00	158.88	188.70	145.10	166.90
3.	75% RDF	26.00	33.70	29.85	136.45	108.95	122.70	182.25	141.25	161.75	192.85	142.20	167.48
4.	100% RDF	26.55	35.25	30.90	141.00	111.45	126.23	196.20	142.95	169.58	199.15	145.30	172.23
5.	50% RDF + 50% N (FYM)	27.20	35.15	31.18	152.75	118.65	135.70	198.70	146.95	172.83	200.25	155.65	177.95
6.	75% RDF + 25% N (FYM)	26.85	35.05	30.95	141.55	113.80	127.68	189.85	142.00	165.93	203.25	142.80	173.03
7.	50% RDF + 50% N (WCS)	22.85	30.20	26.53	120.30	103.10	111.70	190.40	143.40	166.90	182.85	143.55	163.20
8.	75% RDF + 25% N (WCS)	24.80	30.85	27.83	132.15	107.20	119.68	179.25	141.85	160.55	194.05	142.20	168.13
9.	50% RDF + 50% N (GLM)	27.55	34.00	30.78	141.90	108.35	125.13	199.65	140.95	170.20	197.30	150.45	173.88
10.	75% RDF + 25% N (GLM)	26.15	35.30	30.73	142.00	112.25	127.13	191.75	139.50	165.63	204.70	141.20	172.95
	S.E. ±	1.02	1.27	-	3.60	4.15	-	5.70	4.35	-	3.36	4.90	6.83
	C.D. at 5%	2.96	3.69	-	10.44	12.05	-	16.55	12.61	-	9.74	13.03	21.83
	General mean	24.18	31.45	27.81	126.82	101.00	113.91	183.12	137.75	160.44	190.50	143.21	166.86

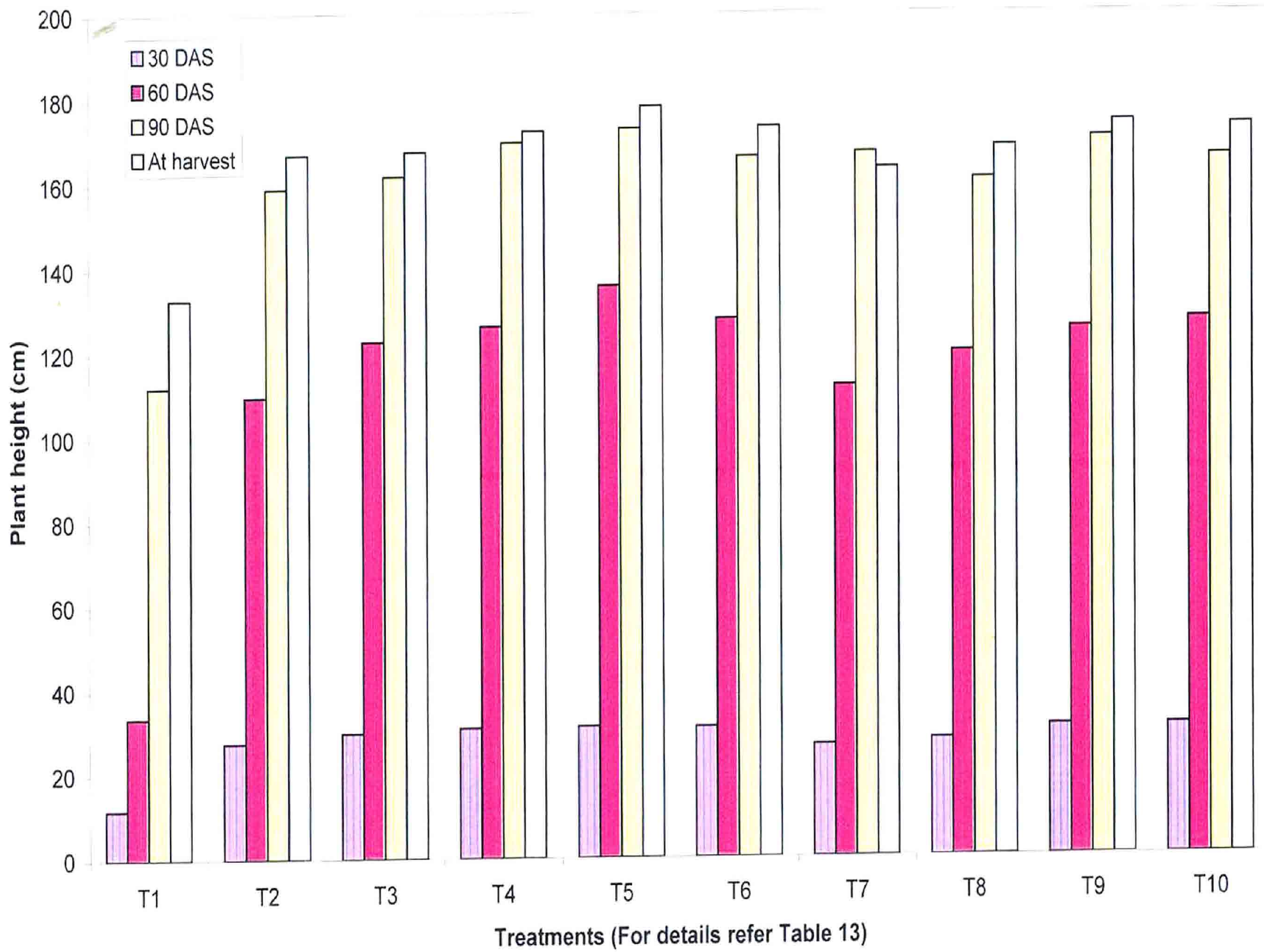


Fig. 4. Mean plant height (cm) of sorghum as influenced periodically by different treatments

The similar trend was also found at 60, 90 DAS and at harvest during both the year of experimentation.

In general, the application of inorganic fertilizer in conjunction with organic manure like 25 and 50 per cent substitution of nitrogen through FYM and gliricidia was beneficial for enhancing the growth in terms of height of sorghum whereas, the substitution of nitrogen through wheat cut straw had an adverse effect on height of sorghum plant during their growth period.

4.1.2.2 Number of functional leaves per plant

The data in respect of mean number of functional leaves per plant of sorghum as influenced by different treatments at various growth stages of sorghum are presented in Table 14.

The mean number of leaves per plant at 30, 60, 90 DAS and at harvest was 6.79, 10.07, 7.16 and 4.36 in 1999 and 6.17, 12.02, 7.17 and 4.37 in 2000, respectively. The differences in mean number of leaves per plant due to different treatments were significant at 30, 60 and 90 DAS and non-significant at harvest, during both the years of experimentation. The organic sources used for 50 per cent substitution of nitrogen through FYM, wheat cut straw and gliricidia were found to be responsible for an increase in mean number of leaves per plant of sorghum at 30 DAS during both the years compared to inorganic source of fertilizers i.e., 50, 75 and 100% RDF and control. During further growth period of crop no fixed trend was noticed in increasing and decreasing the mean number of leaves per plant of sorghum at 60, 90 DAS and at harvest during both the years of experimentation due to use of different sources of nutrients. The maximum leaf number per plant averaged over two seasons was observed at 60 DAS which was in the range of 10.98 to 11.88

Table 14. Effect of integrated nutrient management on number of leaves of sorghum

Sr. No.	Treatments	Number of leaves/plant											
		30 DAS			60 DAS			90 DAS			At harvest		
		1999	2000	Mean	1999	2000	Mean	1999	2000	Mean	1999	2000	Pooled mean
1.	Control (No fertilizers)	4.65	4.90	4.78	6.00	6.85	6.43	6.10	6.65	6.38	3.65	5.00	4.33
2.	50% RDF	6.95	6.30	6.63	10.35	12.70	11.53	7.15	6.90	7.03	4.15	4.30	4.23
3.	75% RDF	6.95	6.05	6.50	10.60	12.85	11.73	7.35	7.45	7.40	4.45	4.45	4.45
4.	100% RDF	7.30	6.20	6.75	10.60	12.95	11.78	8.05	7.55	7.80	4.45	4.70	4.58
5.	50% RDF + 50% N (FYM)	7.20	6.85	7.03	11.15	12.60	11.88	7.50	6.60	7.05	4.40	4.15	4.28
6.	75% RDF + 25% N (FYM)	6.85	6.35	6.60	10.20	12.35	11.28	7.00	6.60	6.80	4.45	4.65	4.55
7.	50% RDF + 50% N (WCS)	7.00	6.30	6.65	9.65	12.30	10.98	6.40	6.95	6.68	4.53	4.50	4.52
8.	75% RDF + 25% N (WCS)	6.90	5.80	6.35	10.50	12.65	11.58	6.90	7.55	7.23	4.00	3.30	3.95
9.	50% RDF + 50% N (GLM)	7.15	6.20	6.68	11.30	12.25	11.78	7.65	7.45	7.55	5.05	4.50	4.78
10.	75% RDF + 25% N (GLM)	6.90	6.75	6.83	10.30	12.65	11.48	7.45	7.95	7.70	4.48	3.55	4.02
	S.E. ±	0.15	0.23	-	0.29	0.27	-	0.33	0.47	-	0.25	0.32	0.30
	C.D. at 5%	0.45	0.67	-	0.85	0.77	-	0.97	N.S.	-	N.S.	N.S.	0.96
	General mean	6.79	6.17	6.48	10.07	12.02	11.05	7.16	7.17	7.17	4.36	4.37	4.37

except control, thereafter the leaf number reduced substantially due to senescence of leaves at maturity.

4.1.2.3 Leaf area per plant

The data pertaining to mean leaf area (dm^2) per plant of sorghum as influenced periodically by different treatments tried are presented in Table 15.

It could be revealed from the data in Table 15 that the mean leaf area was found to be increased progressively with an advancement in the crop age and reached maximum upto 60 DAS of sorghum and further declined till harvest of the crop. The mean values of leaf area ranged from 7.62 to 37.35 dm^2 during crop growth period.

At 60 DAS, maximum leaf area of 52.28 dm^2 was registered due to application of 100% RDF which was almost identical with that of 75% RDF during 1999. The values of leaf area due to above treatments were significantly more than control but at par with rest of the treatments. In the second year, it was maximum (44.31 dm^2) due to 100 per cent recommended dose of fertilizer to sorghum at 60 DAS which was significantly higher than the treatments 75 per cent RDF + 25 per cent N through wheat cut straw, 50 and 75 per cent RDF and control. Among the organic sources used for substitution of nitrogen, the sources viz., FYM and gliricidia performed better than the wheat cut straw at 30 and 60 DAS during both the years of experimentation. Similar trend was noticed during the later growth period of the crop with decline in leaf area per plant in all treatments. In control treatment where no organic and inorganic fertilizers used were registered less leaf area through out the crop growth period during both the years.

Table 15. Effect of integrated nutrient management on leaf area (dm^2) of sorghum

Sr. No.	Treatments	Leaf area (dm^2) per plant											
		30 DAS			60 DAS			90 DAS			At harvest		
		1999	2000	Mean	1999	2000	Mean	1999	2000	Mean	1999	2000	Mean
1.	Control (No fertilizers)	1.83	1.39	1.61	9.93	12.75	11.34	8.86	16.50	12.68	5.07	7.31	6.19
2.	50% RDF	10.20	3.34	6.77	40.26	30.32	35.29	8.20	20.48	14.34	7.02	12.30	9.66
3.	75% RDF	11.18	4.69	7.93	49.20	33.50	41.35	13.78	27.02	20.40	7.71	14.88	11.30
4.	100% RDF	13.29	5.32	9.31	52.28	44.31	48.29	21.44	30.01	25.73	11.27	20.62	15.94
5.	50% RDF + 50% N (FYM)	12.51	6.58	9.55	44.05	41.28	42.66	13.33	29.96	21.64	11.40	19.79	15.60
6.	75% RDF + 25% N (FYM)	11.84	5.72	8.78	45.12	36.65	40.88	15.51	26.99	21.25	7.03	13.92	10.47
7.	50% RDF + 50% N (WCS)	8.16	5.32	6.74	39.22	36.32	37.77	15.70	21.76	18.73	8.47	13.27	13.60
8.	75% RDF + 25% N (WCS)	11.09	4.62	7.86	41.03	28.83	34.93	9.85	24.77	17.31	5.81	13.61	9.71
9.	50% RDF + 50% N (GLM)	13.03	5.22	9.13	44.58	37.07	40.83	14.73	25.41	20.07	11.21	10.51	10.86
10.	75% RDF + 25% N (GLM)	10.48	6.53	8.50	42.36	36.02	39.19	14.12	15.65	14.88	9.08	11.99	10.53
	S.E. ±	0.95	0.58	-	3.76	2.96	-	2.91	3.26	-	1.55	3.42	-
	C.D. at 5%	2.25	1.70	-	10.92	8.58	-	N.S.	9.46	-	N.S.	N.S.	-
	General mean	10.36	4.87	7.62	40.80	33.70	37.25	13.55	23.85	18.70	8.41	13.82	11.39

4.1.2.4 Leaf area index (LAI)

The data pertaining to leaf area index (LAI) per plant as influenced periodically by the use of organic and inorganic sources of nutrients are presented in Table 16. It could be observed that the LAI was found to be higher (9.68 and 8.21) at 60 DAS in treatment where 100 per cent RDF applied to sorghum during 1999 and 2000, respectively which was significantly higher than the treatments comprising of 50 per cent RDF + 50 Per cent N through wheat cut straw, 75 per cent RDF + 25 per cent N through wheat cut straw, 50 per cent RDF + 50% N through gliricidia, control and 50 per cent RDF in 1999 and 75 per cent RDF + 25 per cent N through wheat cut straw, control, 50 per cent RDF and 75 per cent RDF in 2000. Among the organic sources used viz., FYM and gliricidia leaves registered higher LAI than the wheat cut straw at 60 DAS during both the years. The LAI values were narrowed during later growth stages of crop, but the trend was found to be similar. In control treatment where no organic and inorganic sources of nutrients was used lower LAI were registered through out the crop growth period during both the years of experimentation.

4.1.2.5 Days to 50% flowering

The data in respect of mean number of days required for 50% flowering of sorghum crop during both the years were recorded and presented in Table 17.

The data clearly indicated that early flowering started in the treatment where 50 per cent RDF + 50 per cent substitution of nitrogen through FYM during both the seasons which was significantly early in respect of 50% flowering in sorghum (i.e. 74.75 and 73 days). This was closely followed by

Table 16. Effect of integrated nutrient management system on leaf area index (LAI) of sorghum

Sr. No.	Treatments	LAI 30 DAS			LAI 60 DAS			LAI 90 DAS			LAI at harvest		
		1999	2000	Mean	1999	2000	Mean	1999	2000	Mean	1999	2000	Mean
1.	Control (No fertilizers)	0.34	0.26	0.30	1.84	2.36	2.10	1.64	3.06	2.35	0.94	1.36	1.15
2.	50% RDF	1.89	0.62	1.26	7.46	5.61	6.54	1.52	3.79	2.66	1.30	2.28	1.79
3.	75% RDF	2.07	0.87	1.47	9.11	6.20	7.66	2.55	5.01	3.78	1.43	2.76	2.10
4.	100% RDF	2.46	0.99	1.73	9.68	8.21	8.95	3.97	5.56	4.77	2.09	3.82	2.96
5.	50% RDF + 50% N (FYM)	2.33	1.22	1.78	8.16	7.64	7.90	2.47	5.55	4.01	2.11	3.67	2.89
6.	75% RDF + 25% N (FYM)	2.19	1.06	1.63	8.36	6.79	7.58	2.87	5.00	3.94	1.30	2.58	1.94
7.	50% RDF + 50% N (WCS)	1.51	0.99	1.25	7.26	6.73	7.00	2.91	4.03	3.47	1.57	2.46	2.02
8.	75% RDF + 25% N (WCS)	2.05	0.86	1.46	7.60	5.34	6.47	1.82	4.59	3.21	1.08	2.52	1.80
9.	50% RDF + 50% N (GLM)	2.41	0.97	1.69	8.26	6.87	7.57	2.73	4.71	3.72	2.08	1.95	2.02
10.	75% RDF + 25% N (GLM)	1.94	1.21	1.58	7.85	6.67	7.26	2.62	2.90	2.76	1.68	2.22	1.95
	S.E. ±	0.175	0.109	-	0.696	0.548	-	0.54	0.604	-	0.287	0.633	-
	C.D. at 5%	0.507	0.315	-	2.021	1.591	-	N.S.	1.752	-	N.S.	N.S.	-
	General mean	1.92	0.90	1.41	7.56	6.24	6.90	2.51	4.42	3.47	1.56	2.56	2.06

Table 17. Effect of integrated nutrient management system on day to 50% flowering of sorghum

Sr. No.	Treatments	Days to 50% flowering		
		1999	2000	Mean
1.	Control (No fertilizers)	90.00	90.25	90.13
2.	50% RDF	79.25	84.50	81.88
3.	75% RDF	77.25	81.75	79.50
4.	100% RDF	75.50	76.75	76.13
5.	50% RDF + 50% N (FYM)	74.75	73.00	73.88
6.	75% RDF + 25% N (FYM)	75.50	77.50	76.50
7.	50% RDF + 50% N (WCS)	79.75	81.50	80.63
8.	75% RDF + 25% N (WCS)	76.00	83.50	79.75
9.	50% RDF + 50% N (GLM)	75.75	80.50	78.13
10.	75% RDF + 25% N (GLM)	75.00	77.50	76.25
	S.E. ±	0.68	0.79	-
	C.D. at 5%	1.96	2.28	-
	General mean	77.88	80.68	79.28

treatment comprising of 75 per cent RDF + 25% N through gliricidia during both the years. Wheat cut straw application in conjunction with RDF and 75 per cent RDF during both the year prolonged the 50 per cent flowering by about 5 to10 days while in case of 100, 75 and 50 per cent of RDF applied through inorganic fertilizers delayed the 50 per cent flowering by about 2 to 3 days during both the years.

In control treatment with devoid of added nutrients, the crop delayed the 50 per cent flowering by about 15 to 17 days than the earliest treatment. It took 90 days for 50 per cent flowering after sowing of the crop. It could be pointed out that the use of applied fertilizer of any kind hastened the flowering. This was beneficial for early maturity and harvesting so that the field can be cleared up early for succeeding crop in the sequence.

4.1.2.6 Dry matter accumulation per plant

The data pertaining to mean total dry matter accumulation per plant of sorghum as influenced periodically by different treatments are presented in Table 18 and graphically depicted in Fig. 5.

It could be revealed from the data averaged over the years (Table 18) that mean dry matter per plant produced were 4.35, 50.94, 142.63 and 166.92 g/plant at 30, 60, 90 DAS and at harvest, respectively. As expected the dry matter accumulation increased with an advancement of the crop age. At 30 DAS, the total dry matter accumulation was maximum (5.71 g/plant) due to 50 per cent RDF + 50 per cent N through FYM which was followed by 75 per cent RDF + 25 per cent N through FYM. At 60 DAS, application of 100 per cent RDF recorded maximum (74.21 g/plant) dry matter accumulation which was followed by 50 per cent RDF + 50 per cent N through FYM. Almost

Table 18. Effect of integrated nutrient management on dry matter accumulation (g per plant) of sorghum

Sr. No.	Treatments	Dry matter accumulation											
		30 DAS			60 DAS			90 DAS			At harvest		
		1999	2000	Mean	1999	2000	Mean	1999	2000	Mean	1999	2000	Pooled mean
1.	Control (No fertilizers)	1.33	1.03	1.18	13.78	10.03	11.91	37.20	56.05	46.63	61.15	28.90	45.03
2.	50% RDF	5.75	2.83	4.29	73.14	27.93	50.54	88.13	116.40	102.27	167.23	160.40	163.82
3.	75% RDF	6.88	2.35	4.62	80.13	36.55	58.34	148.85	141.90	145.38	244.53	175.00	209.77
4.	100% RDF	5.65	3.38	4.52	97.26	51.15	74.21	179.10	267.58	223.34	208.20	252.63	230.42
5.	50% RDF + 50% N (FYM)	6.69	4.73	5.71	76.46	47.18	61.82	121.83	261.60	191.72	222.03	201.93	211.98
6.	75% RDF + 25% N (FYM)	6.46	4.00	5.23	74.90	33.40	54.15	155.75	211.30	183.25	163.15	166.90	165.03
7.	50% RDF + 50% N (WCS)	4.35	3.48	3.92	74.91	33.35	54.13	130.40	158.93	144.67	183.85	190.80	187.33
8.	75% RDF + 25% N (WCS)	5.30	2.78	4.04	67.58	29.98	48.78	95.78	151.15	123.47	114.28	153.25	133.77
9.	50% RDF + 50% N (GLM)	6.74	3.58	5.16	68.36	31.25	49.81	120.40	181.23	150.82	229.25	172.98	201.12
10.	75% RDF + 25% N (GLM)	5.84	3.88	4.86	57.63	33.90	45.77	124.95	104.05	114.50	185.58	116.35	150.97
	S.E. ±	0.66	0.43	-	10.30	5.23	-	26.30	19.69	-	30.13	17.37	15.05
	C.D. at 5%	1.91	1.24	-	29.83	15.17	-	76.32	57.13	-	87.43	50.40	30.25
	General mean	5.50	3.20	4.35	68.41	33.47	50.94	120.24	165.02	142.63	177.92	161.91	166.92

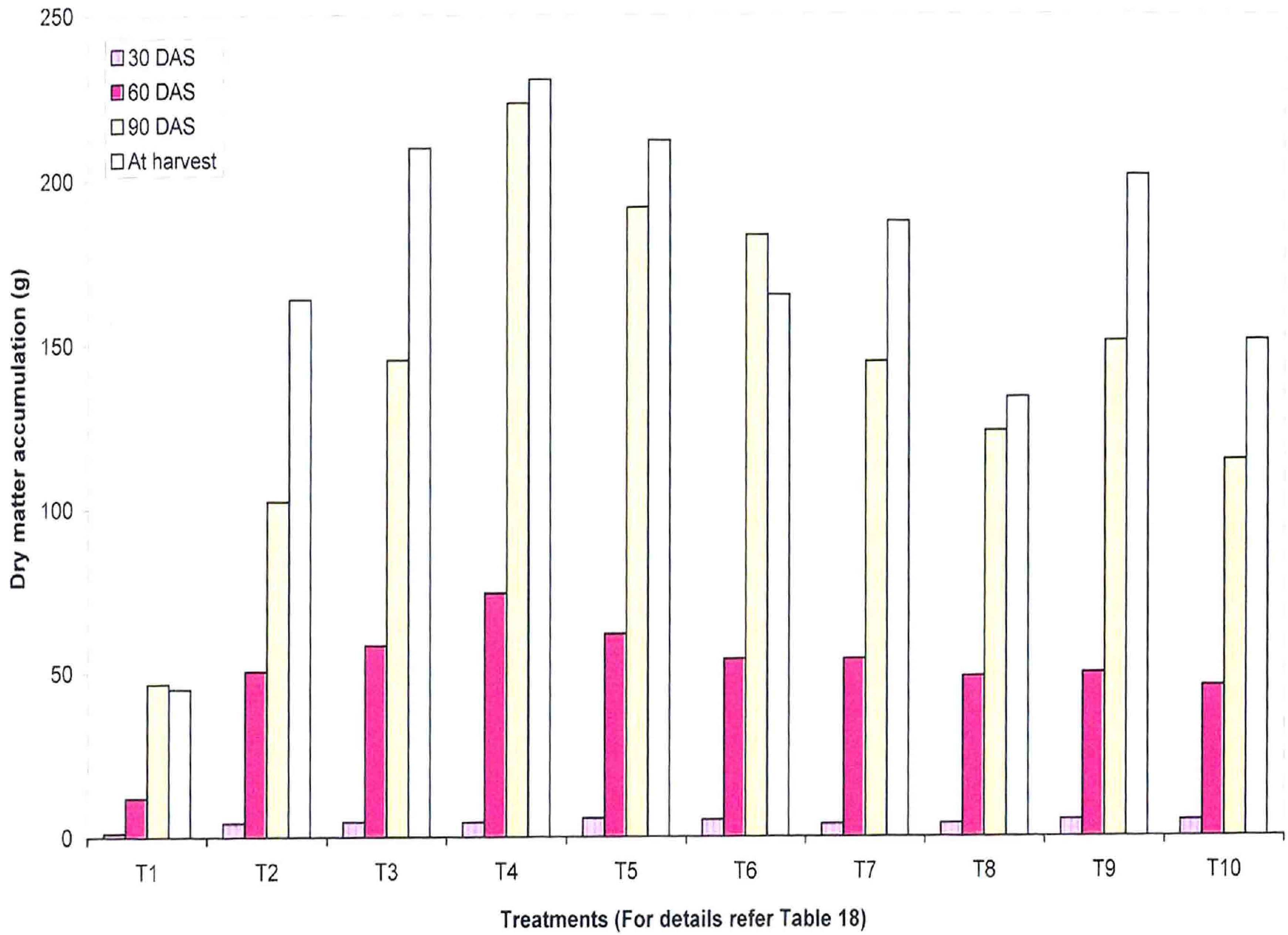


Fig. 5. Mean dry matter accumulation (g) per plant of sorghum as influenced periodically by different treatments

similar trend was noticed in dry matter accumulation at 90 DAS and at harvest. The maximum (230.42 g/plant) dry matter accumulation was observed at harvest due to application of 100 per cent RDF. In general, amongst the organic sources viz., FYM, wheat cut straw and gliricidia used for N substitution alongwith the inorganic fertilizers, the higher dry matter accumulation per plant of sorghum was observed by the source of farm yard manure during all the intervals of the growth of crop. However, when compared with different levels (50, 75 and 100 per cent RDF) of inorganic fertilizers applied to the crop, resultantly showed the higher dry matter accumulation with the treatment of 100 per cent RDF at 60, 90 DAS and at harvest except at 30 DAS, while 75 per cent RDF showed better performance.

4.1.2.7 Length and girth of earhead

The data in respect of mean length and girth of earhead at 90 DAS and at harvest as influenced by different treatments are presented in Table 19. The data presented in Table 19 clearly indicated that the mean length of earhead at 90 DAS of sorghum was maximum (30.45 and 28.60 cm) in the treatment where 50 per cent RDF + 50 per cent substitution of nitrogen through FYM was supplied during both the seasons. This was at par with all the rest of the treatments except control and 50 per cent RDF in 1999 and only control in 2000 indicating its superiority. Among the chemical fertilizers, the earhead length at 90 DAS and at harvest increased with increase in the dose of fertilizers in both the years. While in N substitution through organic sources, FYM showed its superiority over wheat cut straw and gliricidia when the data was averaged over two years.

The mean girth of earhead of sorghum crop was found to be significantly higher in the treatment where 50 per cent RDF + 50 per cent N

Table 19. Effect of integrated nutrient management system on length and girth of earhead of sorghum

Sr. No.	Treatments	Earhead length (cm)						Earhead girth (cm)					
		90 DAS			At harvest			90 DAS			At harvest		
		1999	2000	Mean	1999	2000	Pooled mean	1999	2000	Mean	1999	2000	Mean
1.	Control (No fertilizers)	20.65	13.20	16.93	20.75	19.85	20.30	13.10	5.75	9.43	9.20	10.65	9.93
2.	50% RDF	26.50	26.45	26.48	26.55	28.35	27.45	19.70	19.00	19.35	14.65	17.80	16.23
3.	75% RDF	29.25	27.10	28.18	26.65	27.10	26.88	20.65	20.35	20.50	14.90	18.30	16.60
4.	100% RDF	30.20	27.45	28.83	28.00	28.50	28.25	21.10	21.15	21.13	15.10	18.15	16.63
5.	50% RDF 50% N (FYM)	30.45	28.60	29.53	29.30	30.00	29.65	21.45	19.40	20.43	15.90	17.55	16.73
6.	75% RDF 25% N (FYM)	29.00	27.35	28.18	27.70	29.80	28.75	19.05	19.35	19.20	14.45	18.85	16.65
7.	50% RDF 50% N (WCS)	27.50	27.80	27.65	25.90	28.85	27.38	19.40	18.60	19.00	14.10	17.65	15.88
8.	75% RDF 25% N (WCS)	27.40	27.30	27.35	24.85	27.20	26.03	18.65	21.40	20.03	14.10	16.85	15.48
9.	50% RDF 50% N (GLM)	29.70	26.90	28.30	27.40	29.40	28.40	19.40	19.45	19.43	15.30	18.10	16.70
10.	75% RDF 25% N (GLM)	29.25	28.10	28.68	26.10	27.60	26.85	18.90	20.25	19.58	14.80	18.30	16.55
	S.E. ±	1.23	1.20	-	1.18	1.23	0.85	0.88	1.10	-	0.50	0.59	-
	C.D. at 5%	3.56	3.49	-	3.43	3.57	2.39	2.55	3.18	-	1.44	1.70	-
	General mean	27.99	26.03	27.01	26.32	27.67	27.00	19.14	18.47	18.81	14.25	17.22	15.74

through FYM (21.45 cm) in 1999 and 75 per cent RDF + 25 per cent N thsough wheat cut straw (21.40 cm) at 90 DAS in 2000 which were at par with all the treatments except 75 per cent RDF + 25 per cent N through wheat cut straw and control during first year and control treatment during second year. The girth of earhead of sorghum lowered down at harvest which was maximum (15.90 cm) in the treatment where 50 per cent RDF + 50 per cent N through FYM applied to sorghum during first year and 75 per cent RDF + 25 per cent N through FYM applied (18.85 cm) during second year. These treatments were significantly superior over control, 50 per cent RDF, 75 per cent RDF + 25 per cent N through FYM, 50 per cent RDF + 50 per cent N through wheat cut straw and 75 per cent RDF + 25 per cent N through wheat cut straw in 1999 and control in 2000.

4.1.3 Yield contributing characters

The data pertaining to yield contributing characters viz., earhead length, weight of earhead, grain weight of earhead, number of grains per earhead and 100 grain weight as influenced by different treatments considered under integrated nutrient management system are presented in ensuing Table 20.

4.1.3.1 Earhead length

The data presented in Table 20 indicated that the mean length of earhead per plant of sorghum crop at harvest was 26.32and 27.67 cm in 1999 and 2000, respectively. During both the seasons, the treatment comprising of 50 per cent RDF + 50 per cent N through FYM recorded maximum (29.30 cm in 1999 and 30.00 cm in 2000) earhead length which was significantly superior and at par with those obtained from other treatments under study except

Table 20. Effect of integrated nutrient management on earhead length, weight, grain weight, no. of grains and 100 grain weight of sorghum

Sr. No.	Treatments	Earhead length (cm)			Weight earhead (g)			Grain wt. earhead (g)			Grains earhead			100 grain weight (g)		
		1999	2000	Pooled mean	1999	2000	Mean	1999	2000	Pooled mean	1999	2000	Mean	1999	2000	Pooled mean
1.	Control (No fertilizers)	20.75	19.85	20.30	11.77	19.30	15.54	7.34	10.70	9.02	520	553	536	1.476	1.921	1.699
2.	50% RDF	26.55	28.35	27.45	84.71	113.10	98.91	64.78	88.60	76.69	2810	3164	2987	2.208	2.583	2.396
3.	75% RDF	26.65	27.10	26.88	90.46	111.50	100.98	70.94	85.80	78.37	3005	3449	3227	2.413	2.760	2.586
4.	100% RDF	28.00	28.50	28.25	92.84	112.85	102.85	73.15	96.40	84.78	3142	3487	3315	2.529	2.689	2.609
5.	50% RDF 50% N (FYM)	29.30	30.00	29.65	101.51	104.50	103.01	80.15	84.50	82.33	3451	3280	3366	2.356	2.659	2.508
6.	75% RDF 25% N (FYM)	27.70	29.80	28.75	79.07	119.80	99.41	59.76	95.60	77.68	2999	3533	3266	2.183	2.693	2.438
7.	50% RDF 50% N (WCS)	25.90	28.85	27.38	70.74	107.80	89.27	54.58	81.80	69.69	2215	3553	2881	2.463	2.596	2.53
8.	75% RDF 25% N (WCS)	24.85	27.20	26.03	75.97	94.80	85.39	55.26	72.70	63.98	2264	2710	2487	2.442	2.698	2.570
9.	50% RDF 50% N (GLM)	27.40	29.40	28.40	94.00	112.40	103.20	72.26	91.00	81.63	3106	3365	3235	2.391	2.702	2.547
10.	75% RDF 25% N (GLM)	26.10	27.60	26.85	88.10	107.70	97.90	68.29	85.90	77.10	2983	3004	2994	2.288	2.757	2.573
	S.E. ±	1.18	1.23	0.85	8.98	8.58	-	6.26	7.35	4.88	102.9	273.9	-	0.16	0.10	0.08
	C.D. at 5%	3.43	3.57	2.39	26.05	24.88	-	18.17	21.33	13.81	1169.2	794.8	-	0.45	0.30	0.17
	General mean	26.32	27.67	27.00	78.92	100.38	89.65	60.65	79.60	70.13	2649.7	3010.0	2829.8	2.275	2.594	2.435

control. Among the levels of fertilizers, 100 per cent RDF proved its superiority over 75 per cent and 50 per cent RDF even though the differences were not significant in both the seasons.

4.1.3.2 Weight of earhead

The data pertaining to mean weight of earhead/plant of sorghum presented in Table 20 clearly indicated that the mean weight for earhead was 89.65 g when averaged over two years. In 1999, the maximum (101.51 g) weight/earhead was recorded due to application of 50 per cent RDF + 50 per cent N through FYM which was at par with those obtained from rest of the treatments except 50 per cent RDF + 50 per cent N through wheat cut straw and control showed significant differences. While in 2000 season, maximum (119.80 g) and significantly more weight/earhead was observed due to application of 75 per cent RDF + 25 per cent N substitution through FYM than that of 75 per cent RDF + 25 per cent N substitution through wheat cut straw and control and at par with rest of the treatments.

4.1.3.3 Weight of grains per earhead

The perusal of the data regarding mean weight of grains per earhead of sorghum in Table 20 indicated that the maximum average grain weight per earhead of sorghum was 84.78 g due to the treatment of 100 per cent RDF. While in individual yearwise data, it could be seen from the first season of the study, the maximum grain weight per earhead (80.15 g) was obtained due to application of 50 per cent RDF + 50 per cent N substitution through FYM which was significantly more than those obtained from application of 75 per cent RDF + 25 per cent N through FYM, 50 per cent RDF + 50 per cent N through wheat cut straw, 75 per cent RDF + 25 per cent N through wheat cut straw and control, and on par with rest of the treatments. While in season, application of inorganic fertilizers alone @ 100 per cent RDF registered significantly more grain weight per earhead (96.40 g) than that of 75 per cent RDF + 25 per cent N substitution through wheat cut straw and control and almost identical with rest of the treatments in respect of producing grain weight/earhead.

4.1.3.4 Number of grains per earhead

The data in respect of number of grains per earhead of sorghum (Table 20) indicated that maximum and significantly higher number of grains (3451) per earhead was obtained in the treatment 50 per cent RDF + 50 per cent N through FYM applied during first year which was at par with all the treatments except treatments of 50 and 75 per cent RDF and 50 and 25 per cent N through wheat cut straw and control. While during second year of experimentation it was maximum and significantly higher (3487) due to application of 100 per cent RDF than that of control. Rest of the treatments were at par with each other in respect of number of grains/earhead. The average maximum number of grains per earhead was 3366 observed in treatment 50 per cent RDF + 50 per cent N substituted through FYM. Whereas minimum number of grains per earhead (537) was recorded by the control treatment where no fertilizer and manure applied.

4.1.3.5 Hundred grain weight

The data regarding mean hundred grain weight of sorghum (Table 20) revealed that the average maximum hundred grain weight (2.61 g) was recorded in the treatment 100 per cent RDF. From yearwise data, it could be noticed that the maximum (2.53 g) and significantly higher hundred grain weight of sorghum grains was registered by the treatment 100 per cent RDF and 75 per cent RDF (2.76 g) during first and second years of experimentation, respectively. Both the treatments were significantly superior over control only and at par with rest of the treatments during both the years. The minimum average hundred grain weight of sorghum (1.70 g) was recorded in the control treatment where no fertilizers and manures were applied.

4.1.4 Yield studies

The data in respect of the mean grain, fodder and pooled means, biological yield (q ha^{-1}), harvest index and fodder to grain ratio as influenced by different treatments through use of organic and inorganic sources of nutrients for the year 1999 and 2000 are presented in Table 21 and also graphically depicted in Fig. 6. The integrated nutrient management for sorghum crop in sorghum-wheat cropping system responded significantly for grain, fodder and biological yield of sorghum during both the year of experiments. The values of grain, fodder and biological yields were 41.39, 76.90 and 118.00 in 1999 and 40.07, 64.12 and 104.16 q/ha in 2000, respectively.

4.1.4.1 Grain yield

The application of 50 per cent RDF + 50 per cent substitution of nitrogen through FYM during 1999 and 2000 produced significantly more grain yield to the tune of 54.25 and 49.03 q ha^{-1}, respectively with pooled mean of 51.64 q/ha. During first year of experimentation, this treatment was at par with 100 per cent RDF and significantly superior over rest of the treatments. While in second year, same treatment was at par with 100 per cent RDF, 75 per cent RDF + 25 per cent N through FYM and 50 and 75 per cent RDF with 50 and 25 per cent N substitution through gliricidia and significantly more than

Table 21. Effect of integrated nutrient management on grain, fodder, biological yield, harvest index and fodder to grain ratio of sorghum

Sr. No.	Treatments	Grain yield (q ha^{-1})			Fodder yield (q ha^{-1})			Biological yield (q ha^{-1})			Harvest index			Fodder to grain ratio		
		1999	2000	Pooled mean	1999	2000	Pooled mean	1999	2000	Pooled mean	1999	2000	Mean	1999	2000	Mean
1.	Control (No fertilizers)	1.53	2.84	2.19	11.30	22.21	16.76	12.83	25.05	18.94	12.11	11.48	11.80	7.39	7.82	7.61
2.	50% RDF	34.83	43.74	39.29	70.86	64.39	67.63	105.69	108.13	106.91	32.97	40.66	38.82	2.03	1.47	1.75
3.	75% RDF	43.71	39.26	41.49	83.25	63.37	73.31	126.96	102.24	114.61	34.39	38.37	36.38	1.91	1.62	1.77
4.	100% RDF	51.14	48.97	50.06	93.64	74.96	84.30	144.77	123.93	134.35	35.31	39.83	37.57	1.84	1.53	1.69
5.	50% RDF + 50% N (FYM)	54.25	49.03	51.64	102.32	74.71	88.52	156.57	123.73	140.15	34.64	39.56	37.10	1.89	1.54	1.72
6.	75% RDF + 25% N (FYM)	46.96	46.11	46.54	81.91	75.11	78.51	128.88	121.22	125.05	36.42	38.31	37.38	1.75	1.64	1.70
7.	50% RDF + 50% N (WCS)	39.09	36.62	37.86	72.17	65.25	68.71	111.26	101.87	106.57	35.05	36.07	35.56	1.88	1.79	1.84
8.	75% RDF + 25% N (WCS)	45.43	41.45	43.44	80.06	71.15	75.61	123.53	112.59	118.06	36.82	37.00	36.91	1.77	1.72	1.75
9.	50% RDF + 50% N (GLM)	48.76	46.33	47.55	90.10	64.59	77.35	138.86	110.92	124.89	35.18	42.18	38.68	1.85	1.39	1.62
10.	75% RDF + 25% N (GLM)	48.23	46.38	47.31	83.39	65.50	74.45	131.62	111.87	121.75	36.70	41.72	39.21	1.73	1.44	1.59
	S.E. ±	1.22	1.69	2.03	2.33	5.11	5.72	2.73	5.76	6.81	0.90	1.78	-	0.26	0.32	-
	C.D. at 5%	3.54	4.91	6.47	6.76	14.84	18.29	7.92	16.72	21.78	2.61	5.18	-	0.75	0.93	-
	General mean	41.39	40.07	40.73	76.90	64.12	70.51	118.10	104.16	111.13	32.96	36.52	34.74	2.41	2.21	2.31

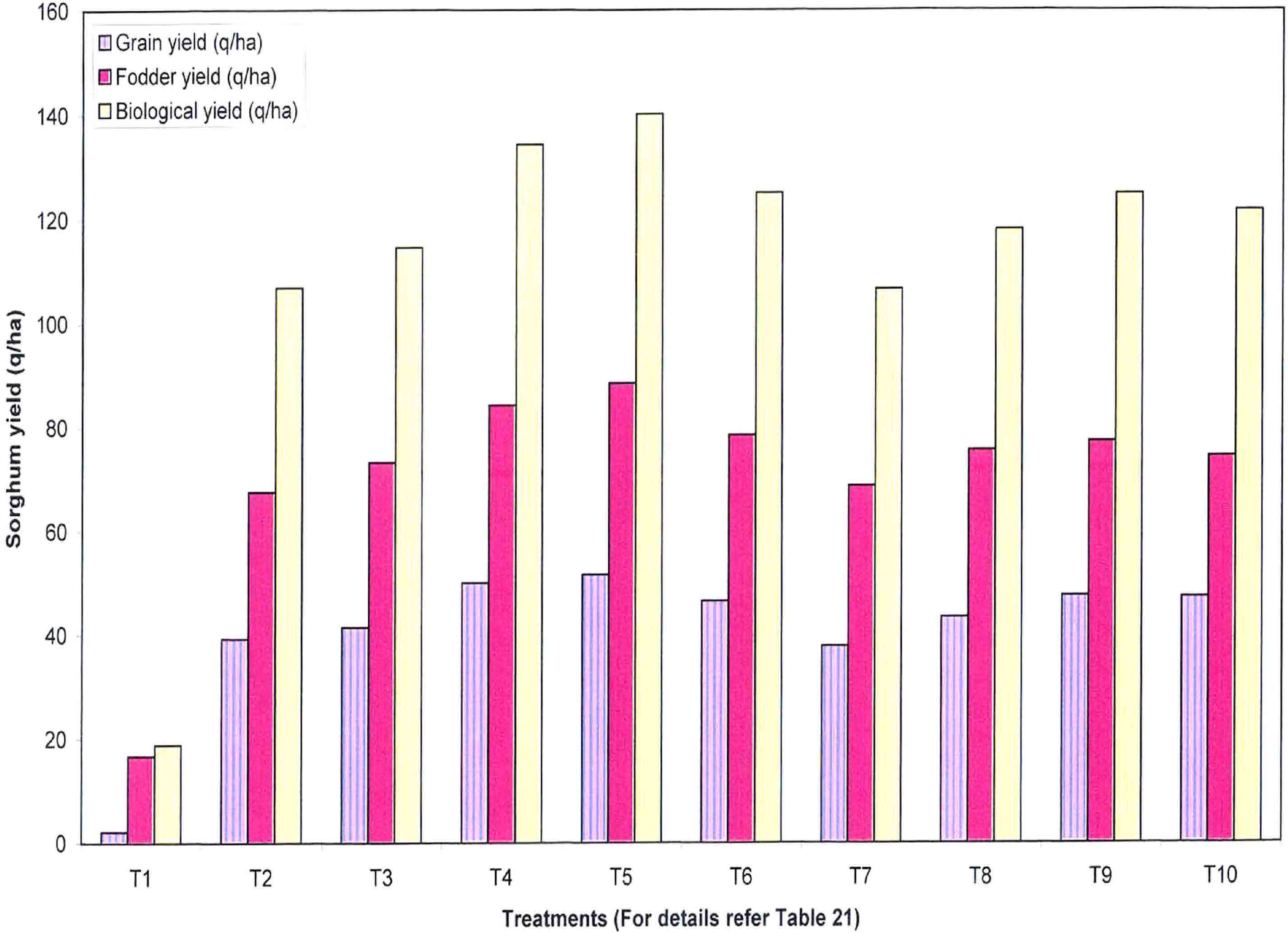


Fig. 6. Mean grain, fodder and biological yield (q/ha) of sorghum as influenced by different treatments

PLATE 1. Use of sub-optimum and optimum level of inorganic fertilizer


Kharif-Sorghum
2000
Kh. R
50% RDF-100% RDF
+50% FYM


Kharif-Sorghum
2000
Kh. R
50% RDF-100% RDF
+50% WCS.


Kharif-Sorghum
2000
50% RDF+50% GM

the rest of the treatments. When the data were pooled over seasons, it could be seen that maximum grain yield (51.64 q/ha) was observed due to 50 per cent RDF + 50 per cent N substitution through FYM which was at par with that of 100 per cent RDF, 75 per cent RDF + 25 per cent N substitution through FYM, 50 per cent RDF + 50 per cent N through gliricidia and 75 per cent RDF + 25 per cent N through gliricida and significantly more than the control, 50 per cent RDF, 75 per cent RDF, 50 per cent RDF + 50 per cent N through wheat cut straw and 75 per cent RDF + 25 per cent N through wheat cut straw. Reduced level of fertilizer and wheat cut straw application reflected in the reduction in grain yield of sorghum during both the years.

4.1.4.2 Fodder yield

The scrutiny of data presented in Table 21 regarding mean fodder yield per hectare revealed that the fodder yield of sorghum was significantly higher in 50 per cent RDF + 50 per cent substitution of N through FYM (102.32 q ha^{-1}) than those of other treatments . However, this was followed by 100 per cent RDF (93.64 q ha^{-1}) and 50 per cent RDF + 50 per cent substitution of nitrogen through gliricidia (90.10 q ha^{-1}) during first year. While, in subsequent year, the treatment 75 per cent RDF + 25 per cent N substituted through FYM recorded significantly higher (75.11 q ha^{-1}) fodder yield which was at par with all the treatments except control. The pooled fodder yield data revealed that the maximum fodder yield to the tune of 84.31 q/ha was obtained due to application of 100 per cent RDF which was significantly superior over control and at par with rest of the treatments.

4.1.4.3 Biological yield

The perusal of the data presented in Table 21 regarding mean biological yield of sorghum per hectare revealed that the average (pooled over) maximum biological yield was 140.15 q ha^{-1}. However, in 1999, it was 156.57 q/ha from 50 per cent RDF + 50 per cent N substitution through FYM being maximum and significantly more than those obtained from rest of the treatments. While in 2000, application of 100 per cent RDF to sorghum produced significantly more (123.93 q/ha) biological yield than those obtained from control, 75 per cent RDF and 50 per cent RDF + 50 per cent N substituted through wheat cut straw and was at par with rest of the treatments.

4.1.4.4 Fodder to grain ratio

The data of mean fodder to grain ratio of sorghum presented in Table 21 clearly indicated that the fodder to grain ratio obtained from organic sources viz., FYM, wheat cut straw and gliricidia leaves applied to sorghum crop along with 50 per cent RDF were in the range from 1.85 to 1.89 during first year and 1.39 to 1.79 during second year. However, where certain levels of fertilizers viz., 50, 75 and 100 per cent applied to sorghum during first year, the values of fodder to grain ratio were 2.04, 1.91, 1.84 and in the second year 1.47, 1.62 and 1.53, respectively. This might be due to decreased grains and fodder yields by different levels of inorganic fertilizers used. In control treatment, the fooder to grain ratio obtained was 7.43 and 8.02 during first and second year, respectively, however, it was higher because of less yield of grains obtained in control plot.

4.1.4.5 Harvest index

The data of mean harvest index of sorghum (Table 21) revealed that the treatment comprising the application of organic sources viz., FYM, wheat cut straw and gliricidia for N substitution alongwith 75 per cent RDF recorded higher harvest indices of 36.42, 36.82 and 36.70, respectively and it was lowered down to 35.31 to 32.97 where inorganic fertilizer levels were tried during first year of experimentation. However, during the second year of experimentation the inorganic fertilizers levels tried showed increasing trend in harvest indices rather than use of organic sources of fertilizer for N substitution except gliricidia application. The gliricidia application with 50 or 75 per cent RDF registered the significantly higher harvest index during second year.

4.2 Effect of integrated nutrient management on *rabi* wheat

4.2.1 Plant population

The data pertaining to mean plant count at initial stage (20 DAS) of wheat as influenced by different treatments are presented in Table 22.

It would be seen from the data in Table 22 that neither the fertilizer levels nor the different sources of fertilizers used in previous seasons had any significant effect on plant population indicating that the initial plant population was uniform in all the treatments during both the years of experimentation. The mean number of plants per meter length was observed to be 86.58 and 79.28 in 1999 and 2000 seasons, respectively. Even though the differences were not significant, the maximum initial plant population was observed where 75 per cent RDF to wheat with 75% RDF + 25 per cent N substitution through FYM to sorghum was applied. Almost similar trend was noticed during second season, however, it was 18.5 per cent less than the first season.

4.2.2 Growth attributes of wheat

Studies on growth includes observations on various growth characters viz., plant height, number and area of functional leaves per plant, dry matter accumulation by whole plant and total number of tillers per plant at successive phases of crop growth.

Table 22. Effect of integrated nutrient management on plant population per mt length of wheat crop.

Sr. No.	Treatments		Mean number of plants/m length at 20 DAS		
	Kharif sorghum	*Rabi* wheat	1999	2000	Mean
1.	Control (No fertilizers)	Control (No fertilizers)	76.25	74.25	75.25
2.	50% RDF	100% RDF	83.25	73.00	78.13
3.	75% RDF	75% RDF	75.75	83.00	79.38
4.	100% RDF	100% RDF	83.25	85.75	84.50
5.	50% RDF + 50% N (FYM)	100% RDF	75.00	82.00	78.50
6.	75% RDF + 25% N (FYM)	75% RDF	102.50	83.50	93.00
7.	50% RDF + 50% N (WCS)	100% RDF	100.00	74.50	87.25
8.	75% RDF + 25% N (WCS)	75% RDF	83.75	81.75	82.75
9.	50% RDF + 50% N (GLM)	100% RDF	89.50	79.25	84.38
10.	75% RDF + 25% N (GLM)	75% RDF	96.50	75.75	86.13
	S.E. ±		9.91	4.49	-
	C.D. at 5%		N.S.	N.S.	-
	General mean		86.58	79.28	82.93

4.2.2.1 Plant height

The plant height generally indicates the vigour and growth of the plant. The data regarding the mean plant height of wheat as influenced periodically by various treatments under study are presented in Table 23 and shown graphically in Fig. 7. The values of mean plant height at 30, 60, 90 DAS and at harvest were 25.47, 49.90, 72.90 and 77.87 cm in 1999 and 22.40, 50.11, 77.12 and 78.27 cm in 2000, respectively. The mean plant height increased at faster rate upto 90 days and thereafter till harvest it was slowed down. The mean maximum plant height of wheat was 29.40 cm at initial stage of 30 days and reached to its maximum as crop age advanced upto harvest and it was 84.95 cm per plant due to the treatment of 75 and 100 per cent RDF to wheat with application of 50 per cent RDF + 50 per cent N through wheat cut straw and 100 per cent RDF to sorghum, respectively during first year and was 25.65 and 84.43 cm per plant at 30 days after sowing and at harvest, respectively in 100 per cent RDF each to wheat and 50 per cent RDF + 50 per cent N through FYM and 50 per cent RDF to preceding crop of sorghum, respectively during second year of experimentation. The differences in the mean plant height recorded at various phases of crop growth were significant due to levels of fertilizers. The mean plant height was maximum during entire growth of wheat crop due to application of 120+60+60 kg N, P_2O_5, K_2O ha^{-1} (RDF) irrespective of inorganic and organic fertilizers applied to sorghum than the rest of reduced levels tried during both the years of experimentation.

4.2.2.2 Functional leaf number per plant

Data regarding the mean number of functional leaves per plant as affected periodically by different levels of fertilizers are presented in Table 24.

Table 23. Effect of integrated nutrient management on plant height (cm) of wheat

Sr. No.	Treatments		Plant height (cm)											
	Kharif sorghum	*Rabi* wheat	30 DAS			60 DAS			90 DAS			At harvest		
			1999	2000	Mean	1999	2000	Mean	1999	2000	Mean	1999	2000	Pooled mean
1.	Control (No fertilizers)	Control (No fertilizers)	8.60	11.50	10.05	22.25	26.95	24.60	38.20	45.60	41.90	41.10	47.34	44.22
2.	50% RDF	100% RDF	27.10	22.00	27.55	53.05	52.65	52.85	77.55	81.40	79.48	83.80	84.43	84.12
3.	75% RDF	75% RDF	26.45	23.20	24.83	47.85	52.00	49.93	72.30	79.85	76.08	79.05	81.88	80.47
4.	100% RDF	100% RDF	28.65	24.00	26.33	56.20	54.05	55.13	80.20	80.55	80.38	84.95	79.32	82.14
5.	50% RDF + 50% N (FYM)	100% RDF	27.80	25.65	26.48	53.20	53.55	53.38	72.90	83.65	78.28	82.80	83.18	82.99
6.	75% RDF + 25% N (FYM)	75% RDF	29.40	24.90	27.15	53.10	51.95	52.53	74.70	81.10	77.90	80.05	79.52	79.79
7.	50% RDF + 50% N (WCS)	100% RDF	28.35	23.40	25.88	53.70	56.60	55.15	77.40	80.80	79.10	83.30	83.78	83.54
8.	75% RDF + 25% N (WCS)	75% RDF	26.45	23.15	24.80	52.80	49.90	51.35	74.90	78.00	76.45	79.50	79.87	79.69
9.	50% RDF + 50% N (GLM)	100% RDF	27.40	23.65	25.53	53.70	54.10	53.90	81.65	79.45	80.55	84.00	81.68	82.84
10.	75% RDF + 25% N (GLM)	75% RDF	24.50	22.50	23.50	53.15	49.30	51.23	79.20	80.80	80.00	80.10	81.75	80.93
	S.E. ±		1.21	1.01	-	1.37	1.31	-	2.03	1.34	-	1.57	1.79	2.22
	C.D. at 5%		3.50	2.93	-	3.97	3.81	-	5.89	3.88	-	4.55	5.19	7.09
	General mean		25.47	22.40	23.94	49.90	50.11	50.00	72.90	77.12	75.01	77.87	78.27	78.07

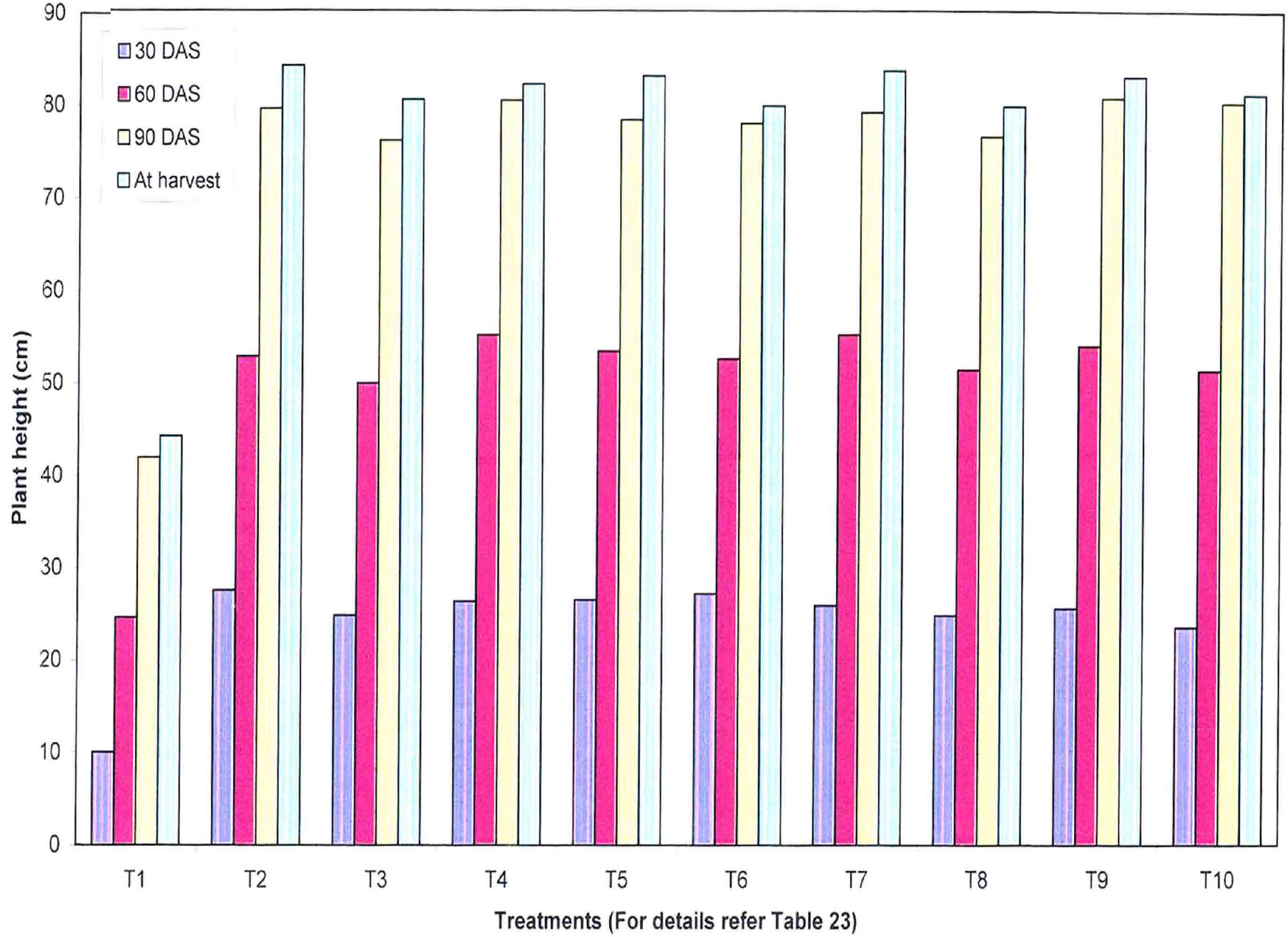


Fig. 7. Mean plant height (cm) of wheat as influenced periodically by different treatments

Data from Table 24 revealed that the mean number of functional leaves per plant increased with an advancement in the age of the plant upto 60 DAS and thereafter till harvest leaf number per plant reduced substantially during both the seasons. Since, the lower leaves started drying, the number of functional leaves decreased at faster rate as the crop age advanced. The mean values of leaf number per plant were 5.82, 6.31 and 2.88 in 1999 and 7.19, 7.86 and 2.68 in 2000 at 30, 60 and 90 DAS, respectively. In first year of the experimentation at 30 DAS the maximum (6.15) leaf number per plant was observed where 50 per cent RDF + 50 per cent N substitution through FYM to sorghum and 100 per cent RDF to wheat were applied which was at par with rest of the treatments and significantly more than those of control and 50 per cent RDF + 50 per cent N through wheat cut straw to sorghum and 100 per cent RDF to wheat. Almost similar trend was noticed during second year. However, at 60 DAS, same treatment showed maximum leaf number per plant but was significantly superior to control, 75 per cent RDF + 25 per cent N through FYM to sorghum and 75 per cent RDF to wheat and 50 per cent RDF + 50 per cent N through gliricidia applied to sorghum and 100 per cent RDF applied to wheat and at par with the remaining treatments. While in second year, it was significantly more than that of control and 75 per cent RDF applied to wheat preceded by 75 per cent RDF + 25 per cent N through wheat cut straw to sorghum. At 90 DAS, even though the differences were not significant during first year, the same treatment showed its superiority for producing more number of leaves per plant during both the years. The number of functional leaves increased due to application of organic sources viz. FYM and gliricidia to preceding crop in 50 per cent proportion while reducing trend was noticed due to application of wheat cut straw for 50 per cent N substitution to previous crop irrespective of levels of RDF to wheat. This trend was observed

Table 24. Effect of integrated nutrient management on number of leaves of wheat

Sr. No.	Treatments: *Kharif* sorghum	Treatments: *Rabi* wheat	Number of leaves 30 DAS 1999	30 DAS 2000	30 DAS Mean	60 DAS 1999	60 DAS 2000	60 DAS Mean	90 DAS 1999	90 DAS 2000	90 DAS Mean
1.	Control (No fertilizers)	Control (No fertilizers)	4.10	5.20	4.65	5.50	5.75	5.63	1.35	1.25	1.30
2.	50% RDF	100% RDF	6.00	7.75	6.88	6.35	8.72	7.54	3.45	2.75	3.10
3.	75% RDF	75% RDF	5.85	6.53	6.19	6.27	7.80	7.04	3.20	2.70	2.95
4.	100% RDF	100% RDF	6.15	8.48	7.32	6.45	8.63	7.54	3.10	3.20	3.15
5.	50% RDF + 50% N (FYM)	100% RDF	6.15	8.65	7.40	6.70	8.93	7.82	3.65	3.35	3.36
6.	75% RDF + 25% N (FYM)	75% RDF	6.05	8.33	7.19	6.20	7.49	6.85	2.95	2.75	2.85
7.	50% RDF + 50% N (WCS)	100% RDF	5.70	7.25	6.48	6.50	8.55	7.53	3.25	2.90	3.08
8.	75% RDF + 25% N (WCS)	75% RDF	6.05	5.90	5.98	6.45	7.20	6.83	2.60	2.50	2.55
9.	50% RDF + 50% N (GLM)	100% RDF	6.10	7.78	6.94	6.20	7.98	7.09	3.15	2.85	3.00
10.	75% RDF + 25% N (GLM)	75% RDF	6.05	6.08	6.07	6.50	7.55	7.03	2.05	2.55	2.30
	S.E. ±		0.14	0.76	-	0.15	0.52	-	0.50	0.16	-
	C.D. at 5%		0.41	2.21	-	0.44	1.50	-	N.S.	0.45	-
	General mean		5.82	7.19	6.51	6.31	7.86	7.09	2.88	2.68	2.78

throughout the growth phases of the wheat during both the years. Amongst inorganic fertilizers, applied @ 50, 75 or 100 per cent of RDF to preceding crop with 75 and 100 per cent levels of RDF applied to wheat, reflected in reducing the number of functional leaves per plant as compared to organic sources applied to previous crop of sorghum. This has showed the residual significant effect of organic sources on number of functional leaves per plant of wheat during both the year of experimentation.

4.2.2.3 Leaf area (LA) per plant

The data regarding leaf area per plant (dm^2) as influenced by different treatments are presented in Table 25.

It could be observed that the mean leaf area per plant average over two season was increased rapidly upto 60 days after sowing (2.65 dm^2) and then decreased subsequently being 0.63 dm^2 at 90 DAS. The leaf area increased in greater from 1.01 to 2.01 dm^2 and 0.77 to 1.01 dm^2 30 DAS by the treatment 100 per cent RDF applied to wheat during first and second years, respectively. The differences in leaf area due to various levels of fertilizers applied to wheat preceded by inorganic and organic fertilizers applied to sorghum were not significant at all the days of observation during both the years of experimentation except 30 and 90 DAS during 1999. By and large, it was observed that maximum leaf area per plant 3.43 dm^2 and 0.81 dm^2 due to 100 per cent RDF to wheat preceded by 50 per cent RDF + 50 per cent N substituted through FYM to sorghum at 60 and 90 DAS. However, there was no specific trend in leaf area due to various treatments under study. The mean values of leaf area obtained maximum at 60 DAS indicated that use of various organic sources coupled with inorganic fertilizers applied to preceding crop of

Table 25. Effect of integrated nutrient management on leaf area (dm^2) per plant of wheat

Sr. No.	Treatments		Leaf area (dm^2)								
	Kharif sorghum	*Rabi* wheat	30 DAS			60 DAS			90 DAS		
			1999	2000	Mean	1999	2000	Mean	1999	2000	Mean
1.	Control (No fertilizers)	Control (No fertilizers)	0.23	0.29	0.26	0.98	0.74	0.86	0.06	0.24	0.15
2.	50% RDF	100% RDF	1.01	1.01	1.01	3.56	2.50	3.03	057	1.00	0.78
3.	75% RDF	75% RDF	1.48	0.86	1.17	2.88	2.27	2.57	0.75	0.81	0.78
4.	100% RDF	100% RDF	1.71	0.96	1.34	3.47	2.34	2.90	0.27	1.18	0.73
5.	50% RDF + 50% N (FYM)	100% RDF	1.32	0.77	1.05	4.35	2.34	3.34	0.63	1.00	0.81
6.	75% RDF + 25% N (FYM)	75% RDF	1.29	0.97	1.13	2.80	1.95	2.38	0.39	0.67	0.53
7.	50% RDF + 50% N (WCS)	100% RDF	1.36	0.83	1.09	2.74	2.89	2.82	0.52	0.72	0.62
8.	75% RDF + 25% N (WCS)	75% RDF	1.29	0.76	1.02	3.52	2.57	3.04	0.34	0.98	0.66
9.	50% RDF + 50% N (GLM)	100% RDF	2.01	0.94	1.48	3.63	2.46	3.05	0.46	1.08	0.77
10.	75% RDF + 25% N (GLM)	75% RDF	1.52	1.03	1.27	2.88	2.09	2.49	0.24	0.60	0.42
	S.E. ±		0.27	0.17	-	0.57	0.55	-	0.12	0.19	-
	C.D. at 5%		0.78	N.S.	-	N.S.	N.S.	-	0.35	N.S.	-
	General mean		1.32	0.84	1.08	3.08	2.22	2.65	0.42	0.83	0.63

sorghum and 100 per cent and 75 per cent RDF to wheat registered more leaf area per plant of wheat compared to reduced levels of inorganic fertilizers and control.

4.2.2.4 Number of tillers per plant

Relevant data on mean number of tillers per plant as influenced periodically by different treatments are presented in Table 26.

The average mean number of tillers per plant at 30, 60, 90 DAS and harvest for both the years was 1.94, 2.38, 1.64 and 0.75, respectively. Reduction in the number of tillers with an advancement of the crop age from 90 DAS to harvest was due to exposure of wheat to adverse atmospheric temperature in the month of February and March. The differences in the mean number of tillers per plant, due to fertilizer levels was significant through out the growth phases under study. The optimum level of fertilizers (100 per cent RDF) produced higher number of tillers compared to those produced by its lower level (75 per cent RDF) of fertilizer irrespective of inorganic and organic sources of fertilizers applied to preceding crop of sorghum. However, significantly, lowest number of tillers were recorded in control during both the years of experimentation. Among the organic sources, applied to previous crop of sorghum, with 100 and 75 per cent RDF to wheat did not influence the number of tillers significantly at all the growth phases. The tillers per plant increased upto 60 DAS. The mortality of tillers started thereafter being lowest number of tillers per plant at harvest. This might be due to the higher suppressing effect of high population of main plants right from beginning to harvest and due to the shy tillering habit of the cultivar under study. During both the seasons, the maximum number of tillers per plant were recorded due

Table 26. Effect of integrated nutrient management on number of tillers per plant of wheat

Sr. No.	Treatments		Number of tillers/plant											
	Kharif sorghum	*Rabi* wheat	30 DAS			60 DAS			90 DAS			At harvest		
			1999	2000	Mean	1999	2000	Mean	1999	2000	Mean	1999	2000	Mean
1.	Control (No fertilizers)	Control (No fertilizers)	0.20	0.15	0.18	0.22	0.25	0.24	0.12	0.10	0.11	0.00	0.00	0.00
2.	50% RDF	100% RDF	2.16	2.90	2.53	2.85	2.90	2.88	1.88	1.95	1.92	0.85	0.88	0.87
3.	75% RDF	75% RDF	1.85	2.10	1.98	2.10	2.30	2.20	1.28	1.30	1.29	0.60	0.65	0.63
4.	100% RDF	100% RDF	2.20	2.65	2.43	2.98	3.00	2.99	2.01	2.14	2.09	0.85	0.93	0.89
5.	50% RDF + 50% N (FYM)	100% RDF	2.18	2.40	2.29	3.05	3.02	3.04	2.14	2.20	2.17	1.08	0.98	1.03
6.	75% RDF + 25% N (FYM)	75% RDF	1.90	2.15	2.03	2.35	2.28	2.32	1.60	1.55	1.58	0.78	0.78	0.78
7.	50% RDF + 50% N (WCS)	100% RDF	2.11	2.20	2.16	2.78	2.85	2.82	1.96	1.98	1.97	0.95	0.89	0.92
8.	75% RDF + 25% N (WCS)	75% RDF	1.78	1.80	1.79	2.18	2.20	2.19	1.55	1.40	1.48	0.82	0.80	0.81
9.	50% RDF + 50% N (GLM)	100% RDF	2.07	2.35	2.21	2.88	2.80	2.84	2.00	2.08	2.04	0.85	0.75	0.80
10.	75% RDF + 25% N (GLM)	75% RDF	1.70	1.95	1.83	2.25	2.35	2.30	1.68	1.78	1.73	0.77	0.70	0.74
	S.E. ±		0.13	0.15	-	0.04	0.05	-	0.04	0.03	-	0.04	0.03	-
	C.D. at 5%		0.37	0.43	-	0.12	0.13	-	0.13	0.09	-	0.11	0.08	-
	General mean		1.82	2.07	1.94	2.36	2.40	2.38	1.63	1.65	1.64	0.76	0.74	0.75

to 100 per cent RDF to wheat with 50 per cent RDF plus 50 per cent N substitution through FYM. The respective values were 3.05 and 3.02 in 1999 and 2000, respectively. This was significantly superior over rest of the treatments except 100 per cent RDF to wheat and sorghum in 1999 and 100 per cent RDF to wheat and sorghum and 100 per cent RDF to wheat preceded by 50 per cent RDF to sorghum in 2000. At 90 DAS and at harvest same treatment showed its superiority over rest of the treatments during both the years of experimentation.

4.2.2.5 Dry matter accumulation

Data pertaining to the mean total dry matter accumulation per plant at 30, 60, 90 DAS and harvest are presented in Table 27 and graphically depicted in Fig. 8.

The total dry matter accumulation per plant was increased with increment in age of the crop till harvest during both the seasons. The mean values of dry matter accumulation per plant averaged over two seasons were 0.69, 3.01, 3.67 and 4.37 g/plant at 30, 60, 90 DAS and harvest, respectively. The highest dry matter weight per plant of wheat recorded at 30 DAS by the treatment 100 per cent RDF to wheat during first (0.88 g) and second years (0.83 g) with 50 per cent RDF + 50 per cent N through FYM to sorghum and 100 per cent RDF to wheat and 50 per cent RDF to sorghum and 100 per cent RDF to wheat crop, respectively even though the differences in dry matter accumulation were not significant in both the years. While at 60 DAS during first year, the dry matter weight of 5.28 g/plant was registered by the treatment of 100 per cent RDF to wheat and 50 per cent RDF + 50 per cent N through FYM to previous crop i.e. sorghum which was significantly superior to

Table 27. Effect of integrated nutrient management on dry matter accumulation (g) of wheat

Sr. No.	Treatments: *Kharif* sorghum	Treatments: *Rabi* wheat	Dry matter accumulation: 30 DAS 1999	30 DAS 2000	30 DAS Mean	60 DAS 1999	60 DAS 2000	60 DAS Mean	90 DAS 1999	90 DAS 2000	90 DAS Mean	At harvest 1999	At harvest 2000	At harvest Pooled mean
1.	Control (No fertilizers)	Control (No fertilizers)	0.25	0.53	0.39	1.18	0.88	1.03	1.15	1.33	1.24	1.58	1.58	1.58
2.	50% RDF	100% RDF	0.73	0.83	0.78	3.85	2.78	3.31	3.75	3.97	3.86	4.73	4.73	4.73
3.	75% RDF	75% RDF	0.60	0.68	0.64	3.45	2.35	2.90	3.68	3.58	3.63	4.68	4.68	4.68
4.	100% RDF	100% RDF	0.70	0.80	0.75	4.35	2.75	3.55	3.95	4.50	3.98	4.75	4.30	4.53
5.	50% RDF + 50% N (FYM)	100% RDF	0.88	0.70	0.79	5.28	2.70	3.99	4.60	4.14	4.37	5.30	5.50	5.40
6.	75% RDF + 25% N (FYM)	75% RDF	0.68	0.80	0.74	3.65	2.10	2.88	3.60	3.90	3.75	4.15	3.95	4.05
7.	50% RDF + 50% N (WCS)	100% RDF	0.63	0.78	0.70	4.08	2.13	3.10	4.55	3.73	4.14	4.95	4.20	4.58
8.	75% RDF + 25% N (WCS)	75% RDF	0.73	0.68	0.70	3.33	2.58	2.95	3.73	3.78	3.75	4.30	5.05	4.68
9.	50% RDF + 50% N (GLM)	100% RDF	0.70	0.75	0.73	4.63	2.40	3.51	3.55	3.74	3.65	5.08	5.08	5.08
10.	75% RDF + 25% N (GLM)	75% RDF	0.73	0.73	0.73	2.58	3.25	2.34	4.73	4.05	4.39	4.80	4.05	4.43
	S.E. ±		0.12	0.06	-	0.54	0.47	-	0.52	0.21	-	0.62	0.78	0.47
	C.D. at 5%		N.S.	N.S.	-	1.56	N.S.	-	1.50	0.62	-	1.79	2.10	1.32
	General mean		0.65	0.73	0.69	3.64	2.39	3.01	3.73	3.62	3.67	4.43	4.31	4.37

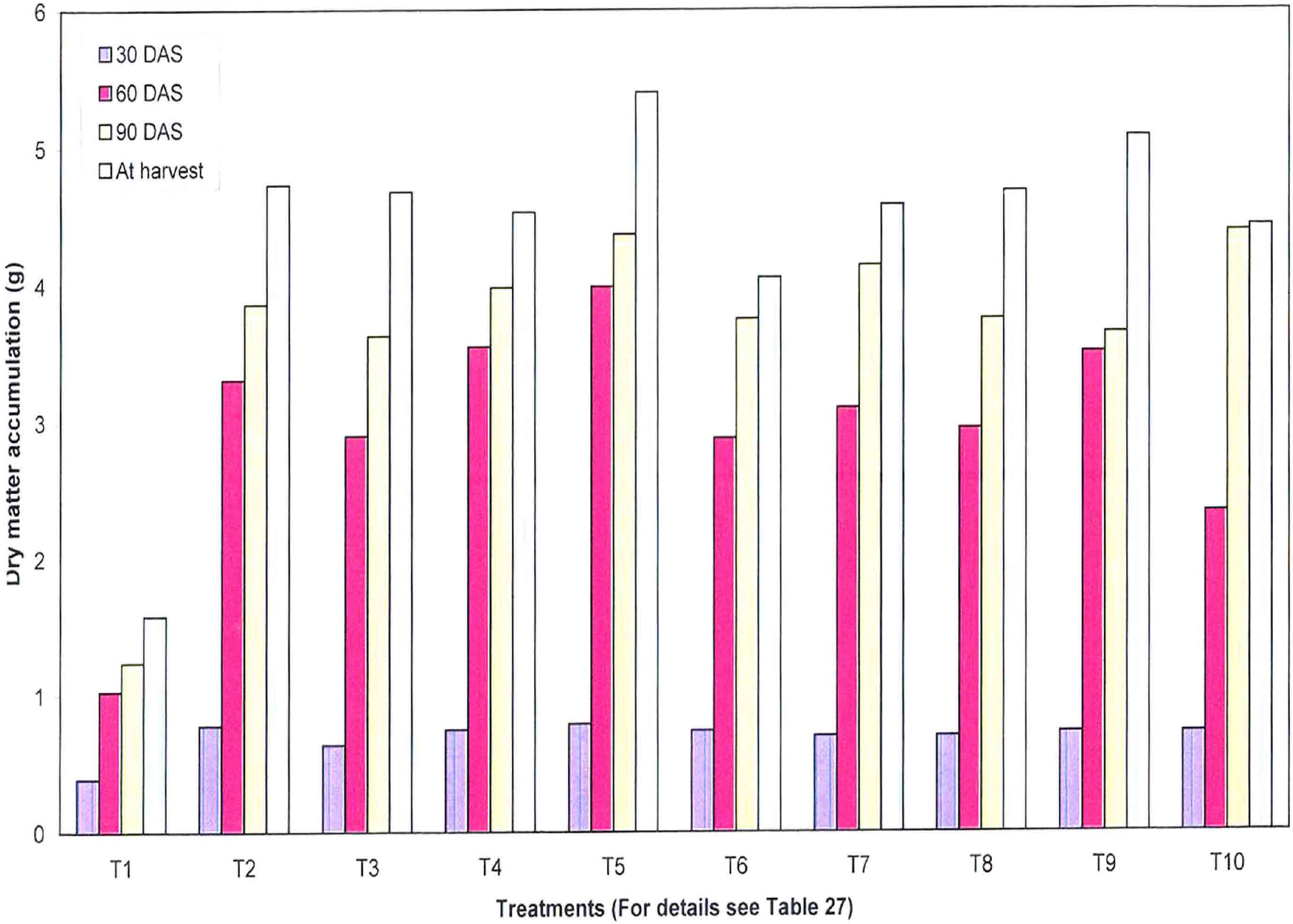


Fig. 8. Mean dry matter accumulation (g) per plant of wheat as influenced periodically by different treatments

all the treatments except optimum dose i.e. 100 per cent RDF applied to wheat with 100 and 50 per cent RDF alone and 50 per cent RDF + 50 per cent N through wheat cut straw and gliricidia, respectively applied to preceding crop of sorghum. During second year at 60 DAS, the dry matter accumulation per plant of wheat was affected non-significantly by different treatments.

At 3rd phase i.e. 90 DAS of crop growth the dry matter accumulation per plant of wheat was affected significantly during both the years of experimentation. The treatment which comprised with 75 per cent RDF to *rabi* and 75 per cent RDF + 25 per cent N through gliricidia to *kharif* crop recorded the highest (4.73 g/plant) dry matter accumulation which was significantly more than control and was on par with rest of the treatments. Similar trend was also noticed during second year.

The maximum dry matter accumulation in wheat per plant at harvest stage was 5.30 and 5.50 g due to 100 per cent RDF to wheat preceded by 50 per cent RDF plus 50 per cent N through FYM applied to sorghum crop during first and second year of experimentation, respectively. These values were significantly higher than the control whereas all other treatments were at par with each other during both the years. Almost similar trend was noticed when data were pooled for two seasons. In general, optimum and sub-optimum levels of fertilizer applied to *rabi* crop i.e. wheat grown after sorghum with sub-optimum levels of RDF coupled with organic sources viz., gliricidia, wheat cut straw and FYM were responsible for increment in the dry matter accumulation per plant of wheat.

4.2.3 Yield contributing characters

Data regarding mean number of productive tillers per plant, length of panicle, number of spikelets per panicle, number of grains per panicle, grain weight per plant at harvest and hundred grain weight are recorded and presented in Table 28.

4.2.3.1 Number of productive tillers per plant

It could be evident from the data in Table 28 that the mean number of productive tillers per plant over years was 0.74. The differences in the mean number of productive tillers per plant, due to levels of fertilizers tried, were significant. The number of productive tillers obtained with application of 120 + 60 + 60 kg N, P_2O_5 , K_2O ha^{-1} (100 per cent RDF to wheat) was the highest (0.97 per plant) and was significantly superior to treatments to which sub-optimum level of fertilizer (75 per cent RDF) was applied during first year. During the second year of experimentation, similar trend was noticed in respect of number of productive tillers per plant at harvest. The treatments which had the organic sources for substitution of N along with the 50 per cent RDF to *kharif* sorghum and 100 per cent RDF to *rabi* wheat increased the productive tillers per plant at harvest during both the years. This could be attributed to the beneficial residual effect of the organic and inorganic sources of nutrients applied to previous crop plus optimum level of fertilizer applied to succeeding crop.

4.2.3.2 Length of panicle

The data in Table 28 revealed that the average mean length of panicle was 8.09 cm, where the maximum and significantly more (8.65 and 9.88 cm in 1999 and 2000, respectively) length of panicle was registered in the treatment of 100 per cent RDF to wheat with 50 per cent RDF plus 50 per cent N through FYM to previous crop of sorghum than those of control, 75 per cent RDF to wheat and 75 per cent RDF to sorghum, 75 per cent RDF to wheat preceded by

Table 28. Effect of integrated nutrient management on number of productive tillers/plant, length of panicle (cm), number of spikelets/panicle, number of grains/panicle, grain weight (g)/panicle and 100 grain weight (g) of wheat

Sr. No.	Treatments		No. of productive tillers/plant			Length of panicle (g)			No. of spikelets/panicle		
	Kharif sorghum	*Rabi* wheat	1999	2000	Mean	1999	2000	Pooled mean	1999	2000	Pooled mean
1.	Control (No fertilizers)	Control (No fertilizers)	0.00	0.00	0.00	2.78	4.58	3.68	4.70	6.80	5.75
2.	50% RDF	100% RDF	0.89	0.89	0.89	8.00	9.60	8.80	13.90	17.40	15.65
3.	75% RDF	75% RDF	0.65	0.65	0.65	6.90	9.40	8.15	14.00	17.40	15.70
4.	100% RDF	100% RDF	0.92	0.95	0.93	7.60	9.68	8.64	15.60	16.60	16.10
5.	50% RDF + 50% N (FYM)	100% RDF	0.97	0.98	0.98	8.65	9.88	9.27	16.00	18.10	17.05
6.	75% RDF + 25% N (FYM)	75% RDF	0.67	0.67	0.67	7.20	9.65	8.43	14.90	17.70	16.30
7.	50% RDF + 50% N (WCS)	100% RDF	0.94	0.93	0.93	7.10	9.50	8.30	14.70	18.00	16.35
8.	75% RDF + 25% N (WCS)	75% RDF	0.67	0.67	0.67	7.20	9.50	8.35	13.70	17.40	15.55
9.	50% RDF + 50% N (GLM)	100% RDF	0.96	0.96	0.96	7.75	9.50	8.63	15.30	17.30	16.30
10.	75% RDF + 25% N (GLM)	75% RDF	0.67	0.67	0.67	7.75	9.60	8.68	15.20	17.50	16.35
	S.E. ±		0.02	0.04	-	0.38	0.35	0.26	0.57	0.64	0.42
	C.D. at 5%		0.06	0.11	-	1.09	1.00	0.74	1.66	1.87	1.20
	General mean		0.73	0.74	0.74	7.09	9.09	8.09	13.80	16.40	15.10

Table 28 (Contd…)

Sr. No.	Treatments		No. of grains panicle			Grain weight plant (g)			100 grain weight (g)		
	Kharif sorghum	*Rabi* wheat	1999	2000	Mean	1999	2000	Mean	1999	2000	Pooled mean
1.	Control (No fertilizers)	Control (No fertilizers)	8.90	13.73	11.32	0.48	0.46	0.47	3.15	3.39	3.27
2.	50% RDF	100% RDF	39.30	40.55	39.93	1.60	1.58	1.59	4.26	4.08	4.17
3.	75% RDF	75% RDF	30.90	44.65	37.78	1.56	1.51	1.53	4.18	4.08	4.13
4.	100% RDF	100% RDF	36.90	45.48	41.19	1.87	1.78	1.82	4.45	4.09	4.27
5.	50% RDF 50% N (FYM)	100% RDF	41.75	46.70	44.23	1.96	1.79	1.87	4.35	4.10	4.23
6.	75% RDF + 25% N (FYM)	75% RDF	35.10	44.70	39.90	1.64	1.66	1.65	4.23	4.07	4.15
7.	50% RDF + 50% N (WCS)	100% RDF	36.20	43.50	39.85	1.66	1.66	1.66	4.31	3.89	4.10
8.	75% RDF + 25% N (WCS)	75% RDF	32.55	41.85	37.20	1.54	1.57	1.55	4.08	3.97	4.02
9.	50% RDF + 50% N (GLM)	100% RDF	39.65	42.55	41.10	1.85	1.68	1.76	4.27	3.99	4.13
10.	75% RDF + 25% N (GLM)	75% RDF	40.88	44.30	42.59	1.57	1.73	1.65	4.23	4.06	4.14
	S.E. ±		2.09	2.64	-	1.11	0.13	-	0.10	0.04	0.09
	C.D. at 5%		6.07	7.67	-	0.31	0.37	-	0.30	0.11	0.29
	General mean		34.21	40.50	37.36	1.57	1.54	1.56	4.15	3.97	4.06

75 per cent RDF + 25 per cent N through FYM applied to sorghum, 50 per cent RDF + 50 per cent N through wheat cut straw to sorghum and 100 per cent RDF to wheat and 75 per cent RDF to wheat preceded by 75 per cent RDF + 25 per cent N substituted through wheat cut straw in sorghum and was at par with rest of the treatment in first year of experimentation. While in 2000, the same treatment was significantly superior to control and all rest of the treatments were at par and were significantly superior to control in respect of length of panicle per plant at harvest of wheat. This was followed by 100 per cent RDF to wheat and 100 per cent RDF to sorghum during both the seasons.

4.2.3.3 Number of spikelets per panicle

The mean number of spikelets per panicle produced (15.1) was 13.8 and 16.4 during 1999 and 2000, respectively (Table 28). The mean maximum (16.0) number of spikelets per panicle was recorded due to 100 per cent RDF to wheat preceded by 50 per cent RDF + 50 per cent N substitution through FYM in sorghum which was significantly more than those of control, 50 per cent RDF to sorghum and 100 per cent RDF to wheat, 75 per cent RDF to sorghum and wheat and 75 per cent RDF to wheat preceded by 75 per cent RDF + 25 per cent N through wheat cut straw applied to sorghum and was at par with rest of treatments during 1999. Whereas in second season same treatment registered maximum (18.1) number of spikelets per panicle. All the treatments preceded by use of organic and inorganic sources of nutrient at certain levels and sub-optimum level of fertilizers to succeeding crop of wheat were at par with each other but significantly more than control.

4.2.3.4 Number of grains per panicle

It was evident (Table 28) that the mean number of grains per panicle was 34.21 and 40.50 during 1999 and 2000, respectively. The differences in the mean number of grains per panicle due to levels of fertilizer and application of organic and inorganic fertilizers to preceding crop were significant during both the seasons of experimentation. The highest values of number of grains per panicle were registered to be 41.75 and 46.70 due to application of 100 per cent RDF to wheat and 50 per cent RDF + 50 per cent N through FYM to sorghum, respectively during first and second year, respectively. These values were significantly more than those obtained from control and 75 per cent RDF applied to wheat during first year and control during second year. However, the remaining treatments were at par with each other. The control treatment registered 8.90 and 13.73 grains per panicle during first and second year respectively, which were significantly less.

4.2.3.5 Grain weight per plant at harvest

It would be seen from Table 28 that the mean grain weight per plant was 1.57 and 1.54 g during first and second year, respectively. The differences in the mean grain weight per plant due to optimum (100 per cent RDF) and sub-optimum (75 per cent RDF) levels of fertilizers applied to wheat were significant and the highest grain weight of 1.96 and 1.79 g per panicle was registered due to 100 per cent RDF to wheat preceded by 50 per cent RDF + 50 per cent N substitution through FYM in sorghum crop during first and second year, respectively. This treatment was significantly superior to that of control and the treatments with 75 per cent RDF applied to wheat in first season. Whereas, in second year it was significantly superior to control only irrespective of preceding fertilizer treatments to sorghum. Rest of the treatments were at par with each other.

4.2.3.6 Hundred grain weight

The mean hundred grain weight of wheat registered in 1999 was 4.15 g, while it was 3.97 g in 2000 (Table 28). The highest and significantly superior treatment involving 100 per cent RDF during *kharif* and *rabi* season recorded 4.45 g hundred grain weight but was at par with all the values of other treatments except 75 per cent RDF and control preceded by 75 per cent RDF and 25 per cent N through where straw applied during first year. Whereas it was maximum (4.10 g) by 100 per cent RDF to wheat with 50 per cent RDF + 50 per cent N through FYM to sorghum and was at par with all the treatments except 100 and 75 per cent RDF to succeeding crop with preceded by 50 and 75 per cent RDF coupled with 50 and 25 per cent N substituted through wheat cut straw and control during second year. Control treatment recorded significantly lower hundred grain weight during both the years. Almost similar trend was observed when data on hundred grain weight were pooled for two seasons.

4.2.4 Yield studies

The data pertaining to mean grain, straw and biological yields of wheat, mean straw to grain ratio and mean harvest index of wheat as influenced by different treatments are presented in Table 29 and graphically depicted in Fig. 9.

4.2.4.1 Grain yield

The data in Table 29 indicated that the maximum and significantly higher (44.49 and 42.64 q ha^{-1}) grain yield was obtained due to application of 100 per cent RDF to wheat and preceded with 50 per cent RDF + 50 per cent N

Table 29. Effect of integrated nutrient management on grain, straw, total biomass per hectare, straw to grain ratio and harvest index of wheat

Sr. No.	Treatments		Grain yield (q ha^{-1})			Straw yield (q ha^{-1})			Yield of biomass (q ha^{-1})		
	Kharif sorghum	*Rabi* wheat	1999	2000	Pooled mean	1999	2000	Pooled mean	1999	2000	Pooled mean
1.	Control (No fertilizers)	Control (No fertilizers)	6.94	7.64	7.29	17.51	10.66	14.09	24.42	18.29	21.36
2.	50% RDF	100% RDF	36.14	38.73	37.44	46.01	63.05	54.53	82.15	101.77	91.96
3.	75% RDF	75% RDF	35.73	36.60	36.17	44.42	53.23	48.83	80.15	89.83	84.99
4.	100% RDF	100% RDF	38.56	42.20	40.38	54.69	61.28	57.99	93.24	103.48	98.36
5.	50% RDF + 50% N (FYM)	100% RDF	44.49	42.64	43.57	57.79	68.17	62.98	102.27	110.81	106.54
6.	75% RDF + 25% N (FYM)	75% RDF	37.79	36.50	37.15	46.01	63.73	54.87	83.80	100.47	92.14
7.	50% RDF + 50% N (WCS)	100% RDF	41.18	37.85	39.52	50.64	62.86	56.75	91.81	100.71	96.26
8.	75% RDF + 25% N (WCS)	75% RDF	35.82	36.44	36.13	45.83	56.58	51.21	81.66	93.01	87.34
9.	50% RDF + 50% N (GLM)	100% RDF	39.41	39.93	39.67	50.41	60.61	55.51	89.82	100.53	95.18
10.	75% RDF + 25% N (GLM)	75% RDF	35.85	38.62	37.24	45.14	55.98	50.56	81.00	94.60	87.80
	S.E. ±		0.75	0.65	1.09	0.92	0.59	3.38	1.623	0.817	3.40
	C.D. at 5%		2.17	1.89	3.49	2.67	1.72	10.81	4.708	2.372	10.85
	General mean		35.19	35.71	35.45	45.84	55.61	50.73	81.031	91.351	86.191

Table 29 (Contd..)

Sr. No.	Treatments: *Kharif* sorghum	Treatments: *Rabi* wheat	Straw to grain ratio: 1999	Straw to grain ratio: 2000	Straw to grain ratio: Mean	Harvest index (%): 1999	Harvest index (%): 2000	Harvest index (%): Mean
1.	Control (No fertilizers)	Control (No fertilizers)	2.53	1.42	1.98	28.33	41.66	35.00
2.	50% RDF	100% RDF	1.28	1.63	1.46	43.99	38.05	41.02
3.	75% RDF	75% RDF	1.25	1.46	1.36	44.58	40.72	42.65
4.	100% RDF	100% RDF	1.42	1.45	1.44	41.33	40.79	41.06
5.	50% RDF + 50% N (FYM)	100% RDF	1.34	1.61	1.48	43.51	38.46	40.99
6.	75% RDF + 25% N (FYM)	75% RDF	1.22	1.75	1.49	45.09	36.33	40.71
7.	50% RDF + 50% N (WCS)	100% RDF	1.23	1.66	1.45	44.85	37.59	41.22
8.	75% RDF + 25% N (WCS)	75% RDF	1.28	1.56	1.42	43.88	39.14	41.51
9.	50% RDF + 50% N (GLM)	100% RDF	1.28	1.52	1.40	43.88	39.71	41.80
10.	75% RDF + 25% N (GLM)	75% RDF	1.26	1.45	1.36	44.26	40.84	42.55
	S.E. ±		0.020	0.045	-	0.221	0.744	-
	C.D. at 5%		0.058	0.131	-	0.641	2.159	-
	General mean		1.41	1.55	1.48	42.37	39.33	40.85

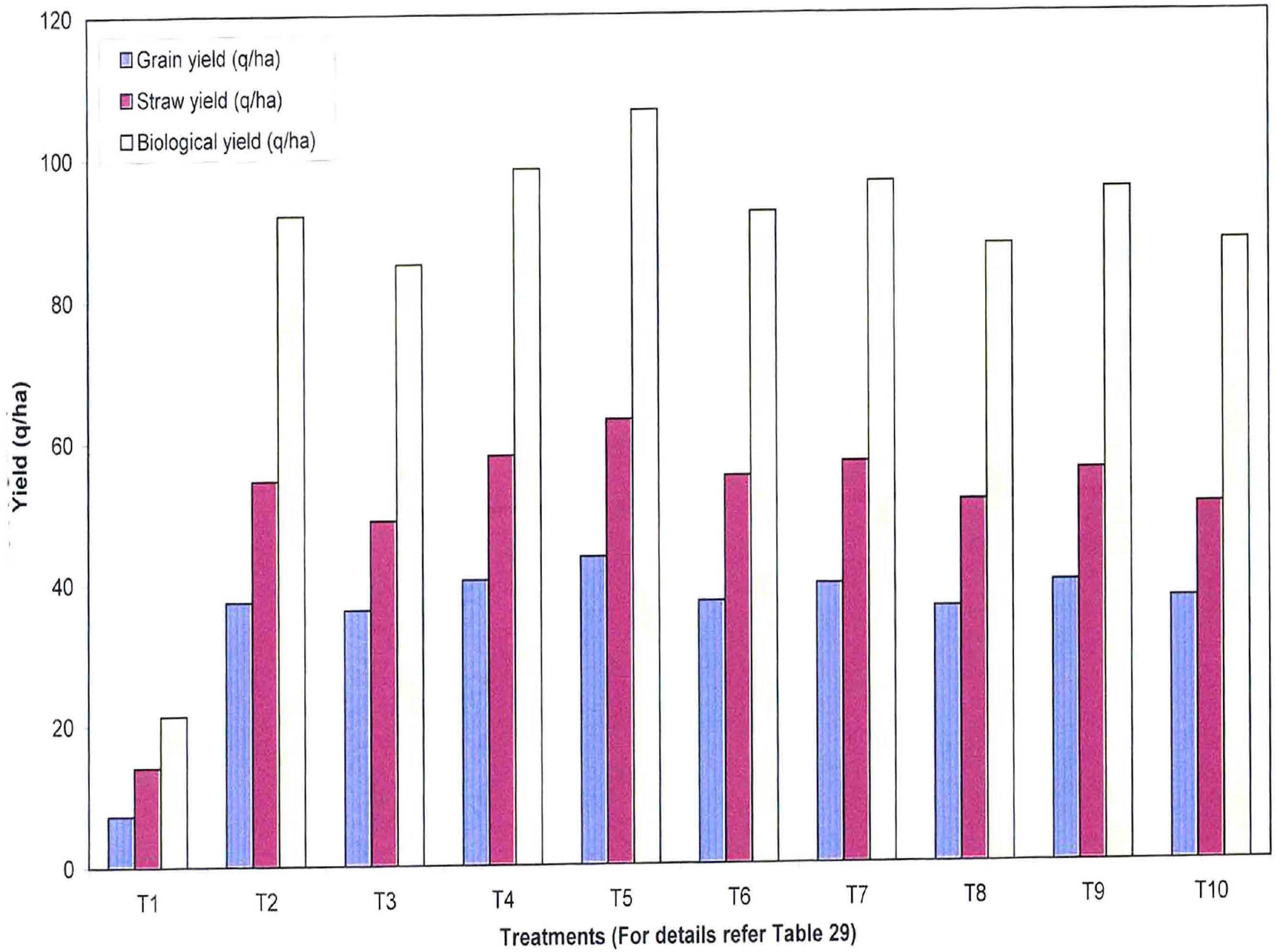


Fig. 9. Mean grain, straw and biological yield (q/ha) of wheat as influenced by different treatments

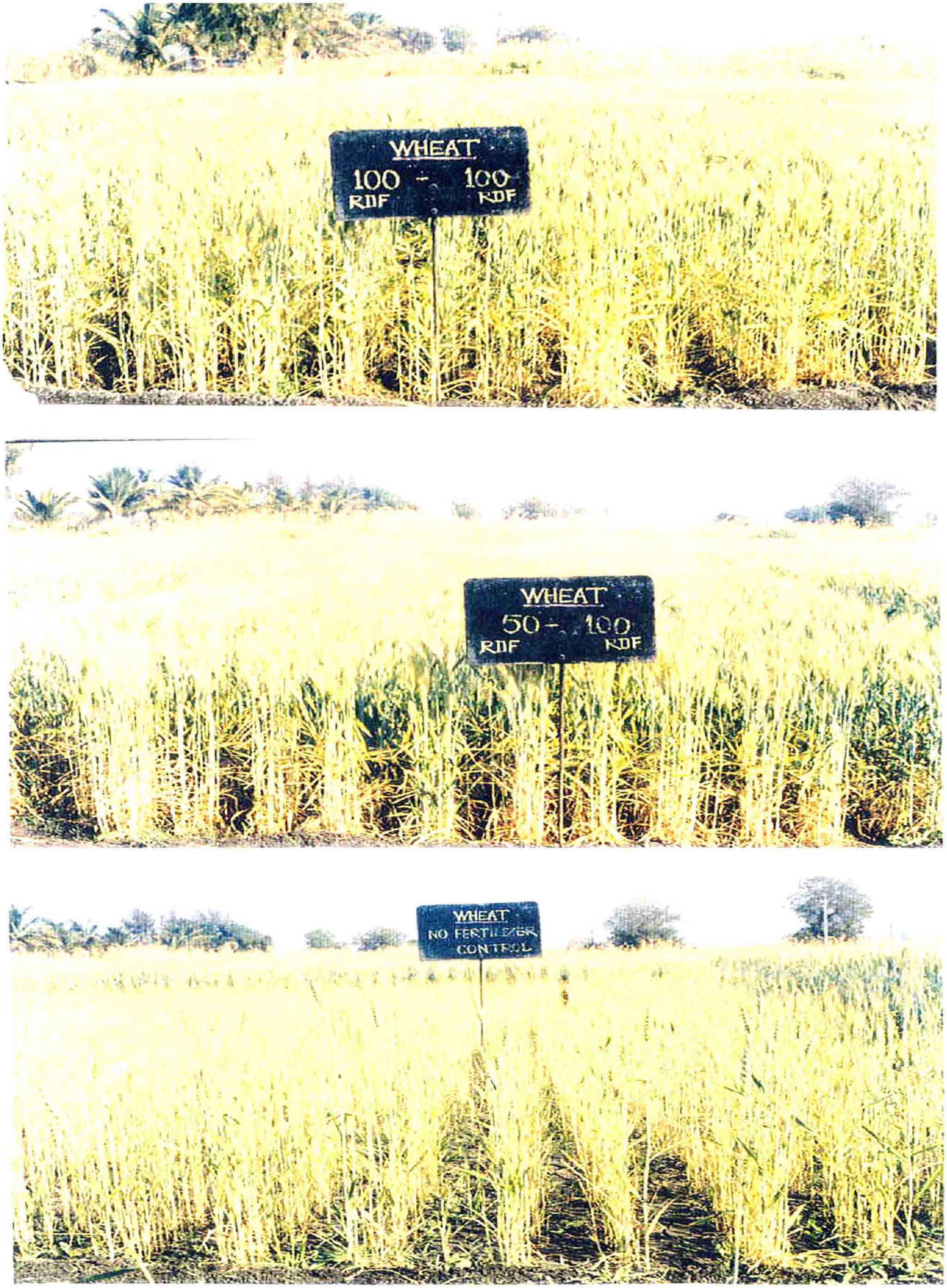


PLATE 3. Use of sub-optimum and optimum level of

PLATE 4. Use of organic sources coupled with inorganic fertilizers to preceding crop and inorganic fertilizer to wheat

through FYM to sorghum than those obtained from rest of the treatments in which optimum and sub-optimum levels were tried inclusive of control during first and second year of experimentation, except it was at par with 100 per cent RDF to sorghum and wheat in second year. Among the organic sources viz., wheat cut straw and gliricidia applied during *kharif* season to sorghum, residual effect was observed an increase in grain yield of wheat with the application of 100 per cent RDF by 0.85 to 2.62 q ha^{-1} in gliricidia and wheat cut straw application compared to 100 per cent RDF each to sorghum and wheat during first year of experimentation. Whereas, the wheat grain yield when preceded by 50 per cent RDF + 50 per cent N substituted through gliricidia was more (39.93 q ha^{-1}) and was on par with 75 per cent RDF + 25 per cent N through gliricidia (38.62 q ha^{-1}) applied during second year experiment. It was also interesting to note that wheat when preceded either by FYM, wheat cut straw and gliricidia applied 25 per cent in proportion and with 75 per cent RDF to wheat affected grain yield drastically, indicating superiority of higher quantity of either FYM, gliricidia or wheat cut straw during both the years. The control treatment recorded significantly lowest grain yield (6.94 and 7.64 q ha^{-1}) during the year 1999 and 2000. On the basis of pooled mean, it could be clearly indicated that application of 50 per cent inorganic fertilizers with 50 per cent N substituted through FYM applied to sorghum and 100 per cent RDF applied to wheat exhibited significant higher grain yield of wheat.

4.2.4.2 Straw yield

The data in Table 29 revealed that the maximum (62.98 q ha^{-1}) straw yield was obtained due to 100 per cent RDF to wheat and 50 per cent RDF + 50 per cent N through FYM applied to sorghum when data were pooled for two seasons. It was significantly more than that of control and 75 per cent RDF each of sorghum and wheat crop and was at par with rest of the treatments. Whereas, individual year data revealed that maximum mean per hectare straw yields obtained were 57.79 and 68.17 q ha^{-1} during first and second year of experimentation, respectively by the use of optimum (100 per cent RDF) levels of fertilizers to wheat and 50 per cent RDF + 50 per cent N through FYM to sorghum. These values were significantly superior over than those obtained from rest of the treatments during both the years. The straw yield registered with preceding use of organic sources viz., wheat cut straw and gliricidia was the highest compared with sub-optimum (75 per cent RDF) levels of fertilizers used during *kharif* during both the year. Further, it was noticed that straw yield level (q ha^{-1}) was higher in all the treatments during second year than the first year of experimentation. This might be due to congenial climatic condition reflected in profuse growth of crop.

4.2.4.3 Yield of biomass

The mean maximum biological yield of wheat was 102.27 and 110.81 q ha^{-1} during first and second season of experimentation, respectively (Table 29). The differences in the total biomass yield due to various levels of fertilizers tried were significant. The per hectare total biomass production obtained with recommended dose of fertilizer of 120 + 60 + 60 kg N, P_2O_5 and K_2O ha^{-1} for *rabi* and preceded with 50 per cent RDF + 50 per cent N through FYM was the highest and significantly more than that recorded in reduced levels of fertilizers. The mean biological yield differed significantly due to preceding of 50 per cent RDF + 50 pr cent N through wheat cut straw and gliricidia during both the year which were at par with each other. On pooled mean basis similar trend was observed in total biomass production due to various treatments under study.

In general, it is revealed that the yield of biomass of wheat increased by the use of combination of organic and inorganic sources of fertilizers during preceding *kharif* season applied to sorghum coupled with use of optimum dose (100 per cent RDF) of fertilizer to wheat crop. The residual nutrient status might be responsible for improving the yield of total biomass of succeeding crop of wheat in sorghum wheat cropping system.

4.2.4.4 Straw to grain ratio

The differences in straw to grain ratio due to different treatments were significant during both the years. Among the different treatments tried, maximum mean straw to grain ratio was observed to tune of 1.42 and 1.75 during first and second season, respectively (Table 29) which were obtained through the treatment of use of 100 per cent RDF for both the seasons during first year and 75 per cent RDF + 25 per cent N through FYM to sorghum and 75 per cent RDF to wheat during second year and it was significantly higher than rest of all the treatments tried during both the years except in 2000, it was at par with which comprising of 100 per cent RDF to wheat and preceded with the treatments consisting of 50 per cent RDF + 50 per cent N substitution through wheat cut straw and 100 per cent RDF to wheat and 50 per cent to sorghum during *kharif* season of second year of experimentation only.

4.2.4.5 Harvest index

The mean harvest index of wheat (Table 29) was 42.37 and 39.33 per cent, during first and second season, respectively. The differences in harvest index due to various levels of fertilizers tried during *rabi* and combined use of organic and inorganic source of nutrients to preceding *kharif* season were significant. The highest harvest index was obtained in 75 per cent RDF + 25 per cent N substitution through FYM to sorghum and 75 per cent RDF to wheat (45.09) and 75 per cent RDF to wheat preceded by 75 per cent RDF + 25 per cent N through gliricidia applied to sorghum (41.86) treatments comprising of 75 per cent RDF to wheat preceded with 25 per cent N through wheat cut straw and 75 per cent RDF only to *kharif* sorghum at first year and during second year, it was 75 per cent RDF to wheat and 75 per cent RDF + 25 per cent N through gliricidia to sorghum. These values were at par with 75 per cent RDF each of sorghum and wheat and 50 per cent RDF + 50 per cent N through wheat cut straw applied to sorghum and 100 per cent RDF to wheat treatments in 1999 and control, 75 per cent RDF each of sorghum and wheat, 100 per cent RDF each of sorghum and wheat, 75 per cent RDF + 25 per cent N through wheat cut straw applied to sorghum and 75 per cent RDF to wheat and 50 per cent RDF + 50 per cent N through gliricidia applied to sorghum and 100 per cent RDF applied to wheat crop in 2000 and significantly superior to remaining treatments.

4.2.4.6 Sorghum grain equivalence

The mean productivity of the cropping sequences were also judged by the total productivity in terms of sorghum grain equivalence. The data pertaining to the sorghum grain equivalence as influenced by various treatments tried in sorghum-wheat cropping sequences for the first and second years of experimentation are presented in Table 30.

The data from the Table 30 revealed that mean grain equivalence was 95.19 and 94.69 q ha^{-1} in first and second years of experimentation respectively. Maximum sorghum grain equivalence to the tune of 122.29 q ha^{-1} in first year and 114.24 q ha^{-1} in second year was observed due to application

Table 30. Effect of integrated nutrient management system on grain equivalence in terms of sorghum grains (q ha-1)

Sr. No.	Treatments		Grain equivalence (q ha^{-1})		
	Kharif sorghum	*Rabi* wheat	1999	2000	Pooled mean
1.	Control (No fertilizers)	Control (No fertilizers)	12.11	14.52	13.52
2.	50% RDF	100% RDF	90.10	102.97	96.54
3.	75% RDF	75% RDF	98.35	95.23	96.79
4.	100% RDF	100% RDF	110.06	113.51	111.79
5.	50% RDF + 50% N (FYM)	100% RDF	122.29	114.24	118.27
6.	75% RDF + 25% N (FYM)	75% RDF	104.75	101.93	103.34
7.	50% RDF + 50% N (WCS)	100% RDF	102.07	94.51	98.29
8.	75% RDF + 25% N (WCS)	75% RDF	100.22	97.17	98.70
9.	50% RDF + 50% N (GLM)	100% RDF	108.90	107.39	108.15
10.	75% RDF + 25% N (GLM)	75% RDF	103.06	105.44	104.25
	S.E. ±		1.62	2.25	3.06
	C.D. at 5%		4.69	6.53	9.79
	General mean		95.19	94.69	94.94

of 50 per cent RDF + 50 per cent N substitution through FYM to sorghum and 100 per cent RDF to wheat in sorghum-wheat crop sequence. These values were significantly superior over rest of the treatments except in second year 100 per cent RDF applied to each of sorghum and wheat crop which was at par with each other. In pooled means similar trend was also observed. Moreover, grain equivalence was spectacularly increased due to use of organic and inorganic sources of fertilizers as compared to sub-optimum (50 and 75 per cent RDF) levels of fertilizers without organic manures. Lowest grain equivalence (12.11 q ha^{-1}) was obtained in absolute control plot. During the second year of experimentation same trend was noticed in respect of grain equivalence in terms of sorghum grain.

4.2.4.7 Average productivity and sustainability yield index

The sustainability of cropping sequence was also judged by the total productivity in terms of total biological main produce of crops which remain stable or increased its stability in a crop sequence.

The data pertaining to average productivity of a crop (q ha^{-1} yr^{-1}) as influenced by the different treatments under study and sustainability yield index of the same are presented in Table 31 and graphically depicted in Fig. 10. The data on average productivity (q ha^{-1} yr^{-1}) of sorghum and wheat as influenced by addition of FYM, wheat cut straw and gliricidia leaf manure over last seventeen years and sustainability yield index (SYI) at the end of seventeenth year and data of pooled mean (1984-85 to 2000-2001) clearly indicated that the treatment involving different organic manures recorded the highest crop productivity and SYI. The mean maximum total productivity of sorghum and wheat averaged over 17 years was 50.63 and 37.31 q ha^{-1} yr^{-1},

Table 31. Effect of integrated nutrient management on average productivity (q ha^{-1} yr^{-1}) and sustainability yield index (SYI) of sorghum and wheat crop over years (17 years)

Sr. No.	Treatment		Average productivity (q ha^{-1} yr^{-1})				SYI	
	Kharif sorghum	*Rabi* wheat	Sorghum		Wheat		Sorghum	Wheat
			Grain	Fodder	Grain	Straw		
1.	Control (No fertilizers)	Control (No fertilizers)	3.08	21.19	5.09	10.14	-0.01	0.09
2.	50% RDF	100% RDF	38.42	67.21	33.08	44.42	0.49	0.66
3.	75% RDF	75% RDF	42.14	70.60	31.46	41.69	0.53	0.64
4.	100% RDF	100% RDF	48.17	79.20	35.41	47.93	0.59	0.72
5.	50% RDF + 50% N (FYM)	100% RDF	50.63	79.31	37.31	48.48	0.66	0.75
6.	75% RDF + 25% N (FYM)	75% RDF	44.94	74.54	32.65	45.32	0.58	0.67
7.	50% RDF + 50% N (WCS)	100% RDF	38.67	68.65	35.49	48.76	0.48	0.70
8.	75% RDF + 25% N (WCS)	75% RDF	41.76	72.67	31.85	44.07	0.49	0.64
9.	50% RDF + 50% N (GLM)	100% RDF	45.99	75.18	35.36	47.33	0.58	0.71
10.	75% RDF + 25% N (GLM)	75% RDF	44.00	72.24	31.47	43.45	0.55	0.64
	S.E. ±		0.50	0.60	0.24	0.35	-	-
	C.D. at 5%		1.39	1.65	0.65	0.97	-	-

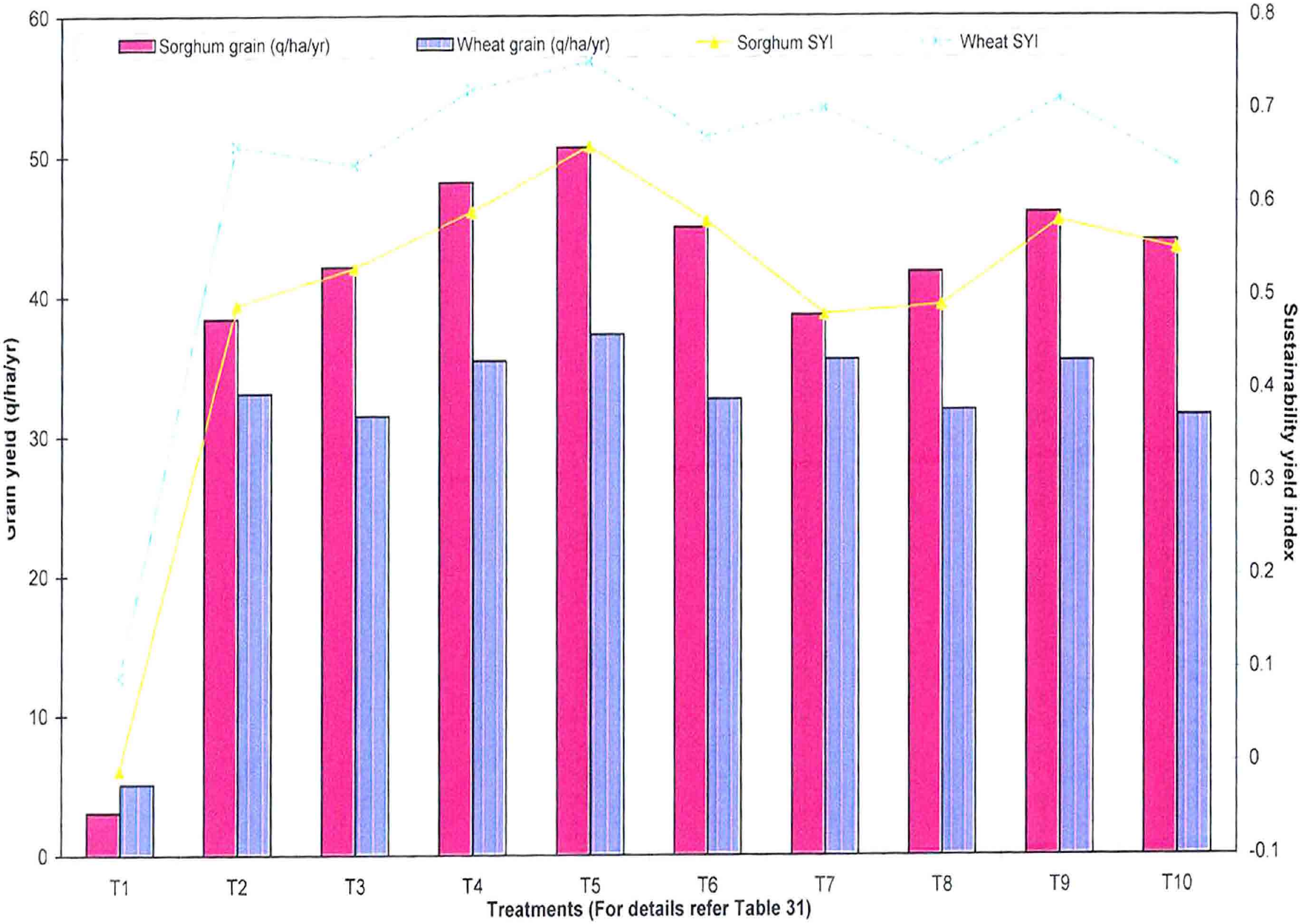


Fig. 10. Average grain productivity (q/ha/yr) and sustainability yield index (SYI) of sorghum and wheat as influenced by different treatments

respectively in treatment comprising of 50 per cent RDF + 50 per cent N through FYM to sorghum and 100 per cent RDF to wheat crop in sorghum-wheat sequence . The superiority of this treatment was observed since last 17 years. The highest values of sorghum and wheat as mentioned above were significantly superior over rest of the treatments. The productivity of both the crops in a sequence was at higher magnitude due to integrated nutrient management system compared to sub-optimum levels of inorganic fertilizers. However, it is interesting to note that this was followed by application of 100 per cent RDF to each of sorghum and wheat. Almost same trend was observed in fodder and straw yield of sorghum and wheat, respectively.

The values of sustainability yield indices (SYI) indicated the reduction in the treatment involving use of sub-optimum levels of inorganic fertilizers alone. However, SYI was improved or maintained in the treatments involving use of either FYM or gliricidia or wheat cut straw in combination with fertilizers every year to *kharif* season. Maximum SYI for sorghum (0.66) and wheat (0.75) was observed in the treatment consisting 50 per cent NPK dose + 50 per cent N through FYM for *kharif* and 100 per cent NPK dose for *rabi* crop involved in sequence.

4.3 Effect of integrated nutrient management on nutrient availability and soil properties

The data in respect of nutrient uptake of grain, fodder/straw, available nutrient and nutrient balance in the soil was assessed and reported herewith.

4.3.1 Uptake of nutrients - Sorghum

Nutrient content estimated in grain and fodder were used to compute N, P and K uptake by the crop. The data pertaining to NPK uptake (kg ha^{-1}) by sorghum grain, fodder as influenced by different treatments tried under study are presented in Table 32, 33 and 34, respectively.

4.3.1.1 Uptake of nitrogen

The data regarding quantity of nitrogen removed by sorghum grain and fodder and total uptake during first and second year of experimentation are presented in Table 32.

The response of sorghum to integrated nutrient management for nitrogen uptake in grain and fodder indicated that substitution of 50 per cent nitrogen through farm yard manure + 50 per cent RDF to sorghum crop significantly increased the nitrogen uptake during both the years of experimentation in grain and fodder than those recorded in rest of the treatments. Among the organic and inorganic treatments, the uptake of N due to use of gliricidia during both the years was next in order of merit.

Similar trend was observed for nitrogen uptake in sorghum fodder. However, the values of nitrogen uptake were numerically less during second year of experimentation. During both the seasons, the maximum (91.8 kg ha^{-1}) uptake of N through fodder was recorded where 50 per cent RDF + 50 per cent N substituted through FYM in sorghum. This was significantly more than those obtained from other treatments. The values of total uptake of nitrogen (kg ha^{-1}) removed by sorghum in the treatment of application of 50 per cent RDF + 50 per cent N substitution through FYM was 219.3 and 182.17 kg ha^{-1} during first and second year of experimentation, respectively which was significantly higher than rest of all the treatments tried. When data were pooled over seasons, it could be seen that same treatment (50 per cent RDF + 50 per cent N substitution through FYM) showed its superiority over rest of the treatments

Table 32. Effect of integrated nutrient management on uptake of nitrogen (kg ha^{-1}) by sorghum grain, fodder and total

Sr. No.	Treatments	Uptake of nitrogen (kg ha^{-1})								
		Grain			Fodder			Total		
		1999	2000	Mean	1999	2000	Mean	1999	2000	Pooled mean
1.	Control (No fertilizers)	3.37	5.96	4.67	7.57	15.55	11.56	10.94	21.51	16.23
2.	50% RDF	76.91	94.48	85.70	64.50	55.38	59.94	141.41	149.86	145.64
3.	75% RDF	104.03	84.80	94.42	82.44	57.03	69.74	186.50	141.83	164.17
4.	100% RDF	112.11	104.92	108.52	85.94	64.25	75.10	198.05	169.17	183.61
5.	50% RDF + 50% N (FYM)	127.50	108.71	118.11	91.80	73.46	82.63	219.30	182.17	200.74
6.	75% RDF + 25% N (FYM)	105.20	99.60	102.40	72.10	67.60	69.85	177.30	167.20	172.25
7.	50% RDF + 50% N (WCS)	87.50	77.63	82.57	63.50	57.42	60.46	151.00	135.03	143.02
8.	75% RDF + 25% N (WCS)	106.80	88.70	97.75	75.84	65.46	70.65	182.64	154.16	168.40
9.	50% RDF + 50% N (GLM)	112.60	101.00	106.80	76.74	58.13	67.44	189.34	159.13	174.24
10.	75% RDF + 25% N (GLM)	99.82	102.96	101.39	81.72	61.57	71.65	181.54	164.53	173.00
	S.E. ±	0.96	0.73	-	1.49	1.08	-	0.80	1.12	9.48
	C.D. at 5%	2.77	2.13	-	4.32	3.14	-	2.31	3.24	30.31
	General mean	93.58	86.88	90.23	70.22	57.59	63.91	163.80	144.46	154.13

except 100 per cent RDF, 75 per cent RDF + 25 per cent N through FYM, 50 per cent RDF + 50 per cent N through gliricidia and 75 per cent RDF + 25 per cent N through gliricidia.

4.3.1.2 Uptake of phosphorus

The values of phosphorus uptake by sorghum as influenced by integrated nutrient management in sorghum-wheat sequence are presented in Table 33. The uptake of phosphorus by sorghum was significant during both the years of experimentation. It was significantly higher in grain and fodder during first year of experimentation due to 100 per cent recommended dose of fertilizer application. Whereas, in the second year the phosphorus uptake by sorghum grain was significantly higher (12.75 kg ha^{-1}) at 50 per cent RDF + 50 per cent nitrogen substitution through FYM. In case of uptake of P by sorghum fodder, it was observed that 100 per cent RDF removed significantly higher phosphorus (26.22 kg ha^{-1}) than rest of the treatments during first year of experimentation. However, phosphorus uptake was significantly reduced in fertilizer application as 50 per cent RDF. The higher doses of phosphorus application maintained the equilibrium of phosphorus in soil and soil solution as result increased the availability of phosphorus in soil to the crops. During second season, almost similar trend in respect of uptake of P through fodder was noticed.

The application of fertilizer to sorghum crop as 50 per cent RDF + 50 per cent N through gliricidia, 75 per cent RDF + 25 per cent N through gliricidia and 75 per cent RDF + 25 per cent N through wheat cut straw were equally responded for phosphorus uptake by sorghum in both the years of experimentation.

Table 33. Effect of integrated nutrient management on uptake of phosphorus (kg ha^{-1}) by sorghum grain, fodder and total

Sr. No.	Treatments	Uptake of phosphorus (kg ha^{-1})								
		Grain			Fodder			Total		
		1999	2000	Mean	1999	2000	Mean	1999	2000	Pooled mean
1.	Control (No fertilizers)	2.76	0.34	1.55	1.92	2.22	2.07	4.68	2.56	3.62
2.	50% RDF	5.60	7.87	6.74	14.17	7.73	10.95	19.77	15.60	17.69
3.	75% RDF	8.30	7.85	8.08	21.03	11.41	16.22	29.33	19.26	24.30
4.	100% RDF	9.68	9.79	9.74	26.22	16.49	21.36	35.90	26.28	31.09
5.	50% RDF + 50% N (FYM)	9.22	12.75	10.99	24.55	14.94	19.75	33.77	27.69	30.73
6.	75% RDF + 25% N (FYM)	8.92	12.00	10.46	18.84	16.52	17.68	27.76	28.52	28.14
7.	50% RDF + 50% N (WCS)	8.20	11.00	9.60	15.88	10.42	13.15	24.10	21.44	22.77
8.	75% RDF + 25% N (WCS)	7.72	11.61	9.67	19.96	12.81	16.39	27.68	24.42	26.05
9.	50% RDF + 50% N (GLM)	8.80	12.05	10.43	21.80	10.33	16.07	30.60	22.38	26.49
10.	75% RDF + 25% N (GLM)	8.68	12.06	10.37	18.35	13.10	15.73	27.03	25.16	26.10
	S.E. ±	0.22	0.51	-	0.45	0.81	-	0.55	0.81	1.81
	C.D. at 5%	0.63	1.48	-	1.30	2.34	-	1.58	2.34	5.80
	General mean	7.79	9.73	8.76	18.27	11.60	14.94	26.06	21.33	23.70

In general, the higher doses of phosphorus application or in conjunction with organic manure (FYM) was found beneficial for total uptake of phosphorus by sorghum in integrated nutrient management of sorghum-wheat sequence, being maximum of 31.09 P kg ha^{-1} when pooled over the seasons due to application of 100 per cent RDF applied to sorghum which was followed by 50 per cent RDF – 50 per cent N substitution through FYM in sorghum.

4.3.1.3 Uptake of potassium

The data pertaining to the mean uptake of potassium by the grain and fodder of sorghum as influenced by different treatments are presented in Table 34.

The integrated nutrient management for sorghum-wheat sequence was found to be significant for potassium uptake by sorghum. The 50 per cent recommended dose of fertilizer alongwith 50 per cent substitution of nitrogen through FYM recorded significantly higher (17.36 kg ha^{-1}) potassium uptake by sorghum during 1999 year of experimentation. The fertilizer application to sorghum as 100 per cent RDF, 50 per cent RDF + 50 per cent N through gliricidia and 75 per cent RDF + 25 per cent N through gliricidia were found at par with each other.

The K uptake in sorghum crop was significantly higher (19.60 kg ha^{-1}) with 100 per cent recommended dose of fertilizer applied to sorghum during second year of experimentation. The potassium uptake in grain were found at par due to 75 per cent RDF + 25 per cent N through wheat cut straw, 50 per cent RDF + 50 per cent N through gliricidia and 75 per cent RDF + 25 per cent N through gliricidia, respectively during the year 2000 whereas in case of

Table 34. Effect of integrated nutrient management on uptake of potassium (kg ha^{-1}) by sorghum grain, fodder and total

Sr. No.	Treatments	Uptake of potassium (kg ha^{-1})								
		Grain			Fodder			Total		
		1999	2000	Mean	1999	2000	Mean	1999	2000	Pooled mean
1.	Control (No fertilizers)	4.30	0.85	2.58	16.20	31.10	23.65	20.50	31.95	26.23
2.	50% RDF	10.44	14.00	12.22	119.10	112.68	115.89	129.54	126.68	128.11
3.	75% RDF	13.11	13.35	13.23	142.16	114.10	128.13	155.30	127.45	141.38
4.	100% RDF	15.29	19.60	17.45	167.60	142.42	155.01	182.90	162.02	172.46
5.	50% RDF + 50% N (FYM)	17.36	15.70	16.53	183.13	135.97	159.55	200.50	151.67	176.09
6.	75% RDF + 25% N (FYM)	13.62	15.68	14.65	134.34	139.71	137.03	147.96	155.39	151.68
7.	50% RDF + 50% N (WCS)	11.72	13.18	12.45	115.50	116.15	115.83	127.22	129.33	128.28
8.	75% RDF + 25% N (WCS)	13.63	17.41	15.52	118.94	128.07	123.51	132.60	145.48	139.04
9.	50% RDF + 50% N (GLM)	15.11	17.61	16.36	138.66	118.85	128.76	153.80	136.46	145.13
10.	75% RDF + 25% N (GLM)	13.58	18.55	16.27	125.92	123.80	124.86	139.90	142.35	141.13
	S.E. ±	0.50	0.73	-	1.57	1.14	-	1.97	1.32	10.00
	C.D. at 5%	1.44	2.12	-	4.56	3.31	-	5.71	3.82	31.99
	General mean	12.82	14.59	13.71	126.16	116.28	121.22	139.00	130.87	134.94

potassium uptake in fodder by sorghum did not show consistent relations with integration of organic and inorganic fertilizer application. The average mean uptake of total potassium by sorghum crop was higher (176.09 kg ha^{-1}) in 50 per cent RDF + 50 per cent N substituted by FYM followed by 100 per cent RDF (172.46 kg ha^{-1}). Thus, the conjoint use of organic fertilizers and inorganic fertilizers or only inorganic fertilizer with optimum level were found beneficial for potassium uptake by sorghum.

4.3.1.4 Available nutrient status in soil

The data in respect of available nutrients viz., nitrogen, phosphorus and potassium status in soil as affected by different treatments tried, estimated after harvest of sorghum crop are presented in Table 35.

The data of the residual fertility of soil after the harvest of experimental *kharif* sorghum crop during the year 1999 and 2000 are presented in Table 35, revealed that the nutrient status in respect of nitrogen, phosphorus and potassium were found to be significant after harvest of sorghum during the years under experimentation. The values of nitrogen, phosphorus and potassium in soil were numerically higher in second year of experimentation as compared to previous year. The integration of organic (FYM) and inorganic fertilizers in the proportion 1:1 was found significantly superior to build up the nitrogen status in the soil after the harvest of sorghum during the year of experimentation. The application of 75 per cent RDF alongwith 25 per cent nitrogen substituted through FYM was found at par with 100 per cent RDF, 50 per cent RDF + 50 per cent N through wheat cut straw for building the nitrogen content in soil during 1999. However, during the second year of experimentation 100 per cent recommended dose of fertilizer was found on par

Table 35. Effect of integrated nutrient management on available N, P and K in soil (kg ha^{-1}) after harvest of sorghum

Sr. No.	Treatments	Available N (kg ha^{-1})			Available P (kg ha^{-1})			Available K (kg ha^{-1})		
		1999	2000	Pooled mean	1999	2000	Pooled mean	1999	2000	Pooled mean
1.	Control (No fertilizers)	108.20	110.40	109.30	8.36	8.47	8.42	440.00	460.00	450.00
2.	50% RDF	134.10	136.20	135.20	10.04	9.81	9.93	518.00	518.20	518.10
3.	75% RDF	137.20	135.10	136.20	13.66	14.72	14.19	537.60	540.80	539.20
4.	100% RDF	204.60	210.20	207.40	13.38	14.72	14.05	574.00	576.40	575.20
5.	50% RDF + 50% N (FYM)	236.80	240.50	238.70	18.96	16.95	18.00	630.00	645.10	637.60
6.	75% RDF + 25% N (FYM)	207.80	216.60	212.20	15.89	14.72	15.31	554.40	601.70	578.10
7.	50% RDF + 50% N (WCS)	199.10	210.10	204.60	15.33	18.96	17.15	554.40	595.40	574.90
8.	75% RDF + 25% N (WCS)	181.10	194.30	187.70	10.59	15.33	12.96	537.60	548.60	543.10
9.	50% RDF + 50% N (GLM)	192.90	207.00	200.00	13.94	17.25	15.60	529.20	546.20	537.70
10.	75% RDF + 25% N (GLM)	176.40	191.30	183.90	11.71	12.39	12.05	515.20	520.10	517.70
	S.E. ±	5.03	1.26	1.22	1.90	0.53	0.51	18.43	3.00	2.96
	C.D. at 5%	14.57	3.65	2.46	5.51	1.54	1.07	53.46	8.71	5.95
	General mean	178.00	185.20	181.60	13.18	14.33	13.76	539.00	555.30	547.20

with 50 per cent RDF + 50 per cent N through wheat cut straw and 50 per cent RDF + 50 per cent N through gliricidia leaves. On the pooled mean basis maximum and significantly more available N was observed in 50 per cent RDF + 50 per cent N substitution through FYM compared to other treatments.

The available phosphorus content of soil after harvest of the sorghum was found significantly more (18.96 kg ha^{-1}) due to 50 per cent RDF + 50 per cent N through FYM over control, 50 per cent RDF, 75 per cent RDF + 25 per cent N through gliricidia leaf manure and 75 per cent RDF + 25 per cent N through wheat cut straw. Whereas, it was at par with the rest of the treatments during the year 1999. The application of 50 per cent RDF + 50 per cent N through wheat cut straw recorded significantly higher (18.96 kg ha^{-1}) soil available phosphorus after the harvest of sorghum during 2000 which was significantly superior over rest of the treatments in second year. However, there was no consistent relationship in rest of the treatments for the soil available phosphorus. Pooled mean indicated that the use of farm yard manure for the substitution of 50 per cent nitrogen along with the 50 per cent nitrogen through inorganic fertilizer was found significantly superior over the rest of the treatments except 50 per cent RDF + 50 per cent N substitution through wheat cut straw. Whereas, there was no any specific trend for building the residual fertility of potassium in soil due to the integration of different sources of organics in combination with an inorganic fertilizers. However, it was maximum (637.60 kg ha^{-1}) in 50 per cent RDF + 50 per cent N through FYM indicating strong building up of availability of potassium in soil by use of FYM.

Thus, the conjoint use of farm yard manure as a substitute for 50 per cent nitrogen alongwith the 50 per cent recommended dose of inorganic fertilizers was found beneficial for building and sustaining the residual fertility of soil in respect of nitrogen, phosphorus and potassium after harvest of sorghum in sorghum-wheat crop sequence.

4.3.2 Uptake of nutrients - Wheat

The data pertaining to mean uptake of NPK (kg ha^{-1}) by wheat grain, straw and total as influenced by different treatments tried during first and second year of experimentation are presented in Table 36, 37 and 38, respectively.

4.3.2.1 Uptake of nitrogen

The nitrogen uptake of wheat as influenced by the integrated nutrient management for sorghum and graded levels of RDF for wheat are reported in Table 36.

The nitrogen uptake in grain by the wheat crop in sorghum-wheat crop sequence was found significantly higher (137.92 kg ha^{-1}) due to 100 per cent fertilizer application as per recommended dose to wheat and 50 per cent RDF + 50 per cent N through FYM to sorghum during first year of experimentation. Whereas, it was 109.72 kg ha^{-1} where 100 per cent RDF each to sorghum and wheat which was significantly superior over rest of the treatments during second year. Both these treatments showed their performance when averaged over two years. In case of uptake of N by straw indicated that maximum removal of nitrogen was observed in 100 per cent RDF to wheat preceded by 100 per cent RDF to sorghum (61.30 kg ha^{-1}) and 100 per cent RDF to wheat preceded by 50 per cent RDF + 50 per cent N through FYM applied to sorghum (77.71 kg ha^{-1}) during 1999 and 2000, respectively. These uptake

Table 36. Effect of integrated nutrient management on uptake of nitrogen (kg ha^{-1}) by wheat grain, straw and total

Sr. No.	Treatments		Uptake of nitrogen (kg ha^{-1})								
	Kharif sorghum	*Rabi* wheat	Grain			Straw			Total		
			1999	2000	Mean	1999	2000	Mean	1999	2000	Pooled mean
1.	Control (No fertilizers)	Control (No fertilizers)	15.50	14.21	14.86	13.50	8.10	10.80	29.00	22.31	25.66
2.	50% RDF	100% RDF	92.20	79.40	85.80	41.86	61.79	51.83	134.10	141.19	137.65
3.	75% RDF	75% RDF	90.10	79.06	84.58	48.85	59.62	54.24	138.95	138.68	138.82
4.	100% RDF	100% RDF	107.17	109.72	108.45	61.30	67.41	64.36	168.47	177.13	172.81
5.	50% RDF + 50% N (FYM)	100% RDF	137.92	101.48	119.70	58.94	77.71	68.33	196.90	179.19	188.05
6.	75% RDF + 25% N (FYM)	75% RDF	103.20	83.95	93.58	40.48	57.36	48.92	143.68	141.31	142.50
7.	50% RDF + 50% N (WCS)	100% RDF	127.70	87.81	107.76	51.65	57.83	54.74	179.40	145.64	162.52
8.	75% RDF + 25% N (WCS)	75% RDF	99.22	83.08	91.15	38.69	50.92	44.81	137.91	134.00	135.96
9.	50% RDF + 50% N (GLM)	100% RDF	109.20	91.84	100.52	45.86	56.97	51.42	155.10	148.81	151.96
10.	75% RDF + 25% N (GLM)	75% RDF	90.34	85.74	88.04	41.10	50.38	45.74	131.40	136.12	133.76
	S.E. ±		1.18	0.93	-	0.64	0.99	-	1.12	1.49	6.35
	C.D. at 5%		3.42	2.69	-	1.86	2.87	-	3.25	4.33	20.30
	General mean		97.26	81.63	89.45	44.22	54.81	49.52	141.49	136.44	138.97

values of nitrogen by straw were significantly superior over rest of the treatments. The total removal of nitrogen by wheat crop revealed that maximum of 196.90 kg ha^{-1} and 179.19 kg ha^{-1} N was removed by wheat fertilized with 100 per cent RDF applied wheat preceded by 50 per cent RDF + 50 per cent N through FYM applied to sorghum which was reflected on pooled means too (188.05 kg ha^{-1}).

4.3.2.2 Uptake of phosphorus

The phosphorus uptake of wheat as influenced by the integrated nutrient management for sorghum and optimum and sub-optimum levels of fertilizers for wheat are presented in Table 37.

It revealed from Table 37 that similar was the trend observed in case of phosphorus uptake by wheat crop as observed in case of nitrogen uptake by wheat crop during both the years of experimentation. The mean maximum values of uptake of P by grain, straw and total were 15.89, 28.87 and 44.75 kg ha^{-1}, respectively.

4.3.2.3 Uptake of potassium

The values of potassium uptake of wheat as influenced by the integrated nutrient management for sorghum and optimum and sub-optimum levels of fertilizers for wheat are presented in Table 38.

It revealed from Table 38 that similar trend was noticed in case of potassium uptake by wheat crop as observed in case of nitrogen and phosphorus uptake by wheat crop during the year 1999 and 2000 of experimentation. The maximum potassium removed by wheat grain and straw and its total were 16.76, 126.43 and 143.19 kg ha^{-1}, respectively due to 100 per

Table 37. Effect of integrated nutrient management on uptake of phosphorus (kg ha^{-1}) by wheat grain, straw and total

Sr. No.	Treatments		Uptake of phosphorus (kg ha^{-1})								
	Kharif sorghum	*Rabi* wheat	Grain			Straw			Total		
			1999	2000	Mean	1999	2000	Mean	1999	2000	Pooled mean
1.	Control (No fertilizers)	Control (No fertilizers)	1.66	1.68	1.67	9.45	4.05	6.75	11.11	5.73	8.42
2.	50% RDF	100% RDF	9.99	11.62	10.81	22.54	30.26	26.40	32.53	41.88	37.21
3.	75% RDF	75% RDF	10.00	11.71	10.86	21.32	27.15	24.24	31.32	38.86	35.09
4.	100% RDF	100% RDF	12.50	13.50	13.00	26.25	29.41	27.83	38.75	42.91	40.83
5.	50% RDF + 50% N (FYM)	100% RDF	15.57	16.20	15.89	27.73	30.00	28.87	43.30	46.20	44.75
6.	75% RDF + 25% N (FYM)	75% RDF	11.71	13.14	12.43	21.62	25.49	23.56	33.33	38.63	35.98
7.	50% RDF + 50% N (WCS)	100% RDF	11.53	15.14	13.34	22.28	25.14	23.71	33.81	40.28	37.05
8.	75% RDF + 25% N (WCS)	75% RDF	10.39	13.12	11.76	18.88	23.76	21.32	29.28	36.88	33.08
9.	50% RDF + 50% N (GLM)	100% RDF	12.61	14.38	13.50	24.70	29.09	26.90	37.31	43.47	40.39
10.	75% RDF + 25% N (GLM)	75% RDF	11.11	13.13	12.12	18.50	23.51	21.01	29.61	36.64	33.13
	S.E. ±		0.42	0.76	-	0.44	0.87	-	0.57	1.22	2.06
	C.D. at 5%		1.22	2.20	-	1.27	2.51	-	1.64	3.54	6.58
	General mean		10.71	12.36	11.54	21.33	24.79	23.06	32.04	37.15	34.60

Table 38. Effect of integrated nutrient management on uptake of potassium (kg ha^{-1}) by wheat grain, straw and total

Sr. No.	Treatments		Uptake of potassium (kg ha^{-1})								
	Kharif sorghum	*Rabi* wheat	Grain			Straw			Total		
			1999	2000	Mean	1999	2000	Mean	1999	2000	Pooled mean
1.	Control (No fertilizers)	Control (No fertilizers)	2.28	2.29	2.29	30.63	15.99	23.31	32.91	18.28	25.60
2.	50% RDF	100% RDF	14.80	14.72	14.76	90.62	133.67	112.15	105.42	148.39	126.91
3.	75% RDF	75% RDF	13.58	14.64	14.11	93.30	93.15	93.23	106.88	107.79	107.34
4.	100% RDF	100% RDF	14.91	17.30	16.11	120.32	107.24	113.78	135.23	124.54	129.89
5.	50% RDF + 50% N (FYM)	100% RDF	16.46	17.06	16.76	125.38	127.48	126.43	141.84	144.54	143.19
6.	75% RDF + 25% N (FYM)	75% RDF	13.60	13.87	13.74	96.60	112.80	104.70	110.20	126.67	118.44
7.	50% RDF + 50% N (WCS)	100% RDF	15.65	14.38	15.02	106.34	128.86	117.60	121.99	143.24	132.62
8.	75% RDF + 25% N (WCS)	75% RDF	12.54	14.58	13.56	96.73	113.16	104.95	109.30	127.74	118.52
9.	50% RDF + 50% N (GLM)	100% RDF	14.98	16.77	15.88	105.84	112.13	108.99	120.82	128.90	124.86
10.	75% RDF + 25% N (GLM)	75% RDF	13.98	15.45	14.72	103.82	116.44	110.13	117.80	131.89	124.85
	S.E. ±		0.26	0.50	-	0.48	2.76	-	0.48	2.82	8.36
	C.D. at 5%		0.75	1.44	-	1.39	8.02	-	1.40	8.18	26.73
	General mean		13.28	14.11	13.70	96.96	106.09	101.53	110.24	120.20	115.22

cent RDF applied to wheat preceded by 50 per cent RDF + 50 per cent N through FYM applied to sorghum.

In general, the application of organic manure as farm yard manure to substitute the 50 per cent nitrogen to that of 50 per cent recommended dose to the sorghum crop during *kharif* season was found to enhance the nutrient uptake by wheat crop during succeeding *rabi* season with 100 per cent recommended dose of inorganic fertilizers in sorghum-wheat cropping sequence during both the years of experimentation.

4.3.2.4 Available nutrient status in soil

The data in respect of available nutrients viz., nitrogen, phosphorus and potassium status in soil as influenced by different integrated nutrient management treatments tried, estimated after harvest of wheat crop are presented in Table 39.

The nutrient status of nitrogen, phosphorus and potassium after the completion of sorghum-wheat cropping sequence as influened by integrated nutrient management for sorghum during *kharif* season and optimum and sub-optimum levels of inorganic fertilizers for wheat crop during *rabi* season indicated that the integrated nutrient management for first crop and graded levels of recommended dose of fertilizers to second crop in sorghum-wheat sequence cropping was significantly influenced the residual fertility status of soil except for phosphorus during 1999 year of experimentation.

The conjoint use of organic source as farm yard manure and inorganic fertilizers in the 1:1 proportion to fulfill the requirement of recommended dose of fertilizers was very much useful to maintain the soil fertility in respect of

Table 39. Effect of integrated nutrient management on available N, P and K in soil (kg ha^{-1}) after harvest of wheat

Sr. No.	Treatments		Available N (kg ha^{-1})			Available P (kg ha^{-1})			Available K (kg ha^{-1})		
	Kharif sorghum	*Rabi* wheat	1999	2000	Pooled mean	1999	2000	Pooled mean	1999	2000	Pooled mean
1.	Control (No fertilizers)	Control (No fertilizers)	117.60	115.30	116.50	9.48	9.10	9.29	420.00	440.80	430.40
2.	50% RDF	100% RDF	153.70	142.30	148.00	13.38	11.28	12.33	520.80	519.30	520.10
3.	75% RDF	75% RDF	168.60	151.40	160.00	13.94	14.10	14.02	551.60	545.70	548.70
4.	100% RDF	100% RDF	189.70	195.60	192.70	13.94	14.26	14.10	607.60	590.20	598.90
5.	50% RDF + 50% N (FYM)	100% RDF	231.30	235.80	233.60	17.84	16.52	17.18	683.20	665.60	674.40
6.	75% RDF + 25% N (FYM)	75% RDF	217.90	215.70	216.80	15.10	14.88	14.99	616.00	608.00	612.00
7.	50% RDF + 50% N (WCS)	100% RDF	203.00	207.10	205.10	13.38	16.10	14.74	641.20	625.40	633.30
8.	75% RDF + 25% N (WCS)	75% RDF	196.00	195.90	196.00	13.94	15.15	14.55	593.60	570.90	582.30
9.	50% RDF + 50% N (GLM)	100% RDF	200.70	203.60	202.20	12.82	14.98	12.90	618.80	588.20	603.50
10.	75% RDF + 25% N (GLM)	75% RDF	191.30	188.90	190.10	11.71	12.86	12.29	568.40	534.80	551.60
	S.E. ±		6.80	3.97	3.43	1.46	0.49	0.46	17.20	1.84	1.83
	C.D. at 5%		19.74	11.52	8.81	N.S.	1.42	1.20	49.85	5.33	4.71
	General mean		187.00	185.20	186.10	13.55	13.92	13.74	581.90	568.90	575.40

available nitrogen, phosphorus and potassium after the harvest of two crops in the sorghum-wheat cropping sequence. The magnitude of sustaining the soil fertility in respect of nitrogen and phosphorus after the harvest of two crops in sorghum-wheat cropping sequence was the highest in 50 per cent substitution of nitrogen through FYM (233.60, 17.18 and 674.40 kg NPK ha^{-1}), followed by 25 per cent substitution of nitrogen by FYM and 50 per cent substitution of nitrogen through wheat cut straw and gliricidia leaf manure respectively coupled with inorganic fertilizer levels. While, in case of potassium, there was no consistency for potassium fertility due to integration of nutrient through organic and inorganic fertilizers.

In general, sustainability of nutrient fertility of soil after completion of the sorghum-wheat cropping sequence was possible by using the different sources of organic manures irrespective of inorganic fertilizer. The trend in sustaining the residual fertility due to organic manures was in the order of FYM > gliricidia leaf manure > wheat cut straw. However, in second crop of wheat in sorghum-wheat sequence with 100 per cent recommended dose of fertilizers was found beneficial to sustain the residual soil fertility followed by 75 per cent recommended dose of fertilizer.

4.3.3 Nutrient balance sheet

The nutrient balance after harvest of sorghum and wheat crop considered in sorghum-wheat crop sequence was assessed during the study period to check the gain or deficit observed due to use of organic and inorganic fertilizers. The nutrients viz., nitrogen, phosphorus and potassium balance sheet as affected by different treatments tried is presented in Tables 40 to 45, respectively after harvest of sequential crops.

4.3.3.1 Nitrogen balance sheet

The added and inherent soil nutrient utilized by sorghum crop in sorghum-wheat crop sequence was significantly influenced by the integrated nutrient management for sorghum crop. The data presented in Table 40 indicated that the application of 50 per cent RDF in combination with 50 per cent nitrogen through farm yard manure (39.2 kgN ha^{-1}), 100 per cent recommended dose of fertilizers (13.4 kgN ha^{-1}) and 50 per cent RDF alongwith 50 per cent N through wheat cut straw (5.9 kgN ha^{-1}) were found beneficial to provide the nutrients to sorghum crop during their growth period. This might be due to the addition of organic manures as a substitute for nitrogen governing the phenomenon of mineralization of nutrients. However, the influence of fertility levels on N balance indicate that the use of 50 per cent and 75 per cent recommended dose of fertilizers to sorghum crop showed the negative values of N status in soil. These results showed that 50 or 25 per cent reduction in nutrient viz., nitrogen to sorghum crop severely suffered their growth and development. Whereas, use of wheat cut straw and gliricidia alongwith 75 per cent recommended dose of fertilizers were not beneficial for supply balance nutrient to sorghum crop.

The nutrient balance of nitrogen to wheat crop as influenced by the 100 and 75 per cent recommended dose of fertilizers are presented in Table 41. The use of 100 per cent recommended dose of fertilizers to wheat crop where 100 per cent RDF each of both crops and 50 per cent RDF + 50 per cent N substitution through FYM was applied to previous sorghum crop and 100 per cent RDF to wheat, respectively were found to deficient in supply of nutrient to crop in the tune of -14.9, -14.6 and -5.5, -4.7 kg/ha during 1999 and 2000 year of experimentation, respectively. The negative values of nitrogen indicated that

Table 40. Balance sheet of available nitrogen as influenced by different treatments after *kharif* sorghum

Sr. No.	Treatments	Initial nutrient status A			Nutrient added B			Nutrient uptake C			Expected nutrient balance D (A+B)-C		
		1999	2000	Mean	1999	2000	Mean	1999	2000	Mean	1999	2000	Mean
1.	Control (No fertilizers)	108.2	117.6	112.9	0.0	0.0	0.0	10.9	21.5	16.2	97.3	96.1	96.7
2.	50% RDF	148.9	153.7	151.3	60.0	60.0	60.0	141.4	149.9	145.7	67.5	63.8	65.7
3.	75% RDF	163.9	168.6	166.3	90.0	90.0	90.0	186.5	141.8	164.2	67.4	116.8	92.1
4.	100% RDF	199.9	189.7	194.8	120.0	120.0	120.0	203.9	182.2	193.1	116.0	127.5	121.8
5.	50% RDF + 50% N (FYM)	130.5	231.3	180.9	120.0	120.0	120.0	213.4	169.2	191.3	37.1	182.1	109.6
6.	75% RDF + 25% N (FYM)	207.8	217.9	212.9	120.0	120.0	120.0	177.3	167.2	172.3	150.5	170.7	160.5
7.	50% RDF + 50% N (WCS)	194.4	203.0	198.7	120.0	120.0	120.0	151.0	135.0	143.0	163.4	188.0	175.7
8.	75% RDF + 25% N (WCS)	190.5	196.0	193.3	120.0	120.0	120.0	182.6	154.2	168.4	127.9	161.8	144.9
9.	50% RDF + 50% N (GLM)	197.6	200.7	199.2	120.0	120.0	120.0	189.3	159.1	174.2	128.3	161.6	145.0
10.	75% RDF + 25% N (GLM)	189.8	191.3	190.6	120.0	120.0	120.0	181.5	164.5	173.0	128.3	146.8	137.6

Table 40 (Contd…)

Sr. No.	Treatments	Actual nutrient status			Apparent gain/loss			Difference between initial and final status		
		E			E-D			E-A		
		1999	2000	Mean	1999	2000	Mean	1999	2000	Mean
1.	Control (No fertilizers)	108.2	110.4	109.3	10.9	14.3	12.6	0.0	-7.2	-3.6
2.	50% RDF	134.1	136.2	135.2	66.6	72.4	69.5	-14.8	-17.5	-16.2
3.	75% RDF	137.2	135.1	136.2	69.8	18.3	44.1	-26.7	-33.5	-30.1
4.	100% RDF	206.6	210.2	208.4	90.6	82.7	86.7	6.3	20.5	13.4
5.	50% RDF + 50% N (FYM)	236.8	240.5	238.7	199.7	58.4	129.1	69.2	9.2	39.2
6.	75% RDF + 25% N (FYM)	207.8	216.6	212.2	57.3	45.9	51.6	0.0	-1.3	-0.7
7.	50% RDF + 50% N (WCS)	199.1	210.1	204.6	35.7	22.1	28.9	4.7	7.1	5.9
8.	75% RDF + 25% N (WCS)	181.1	194.3	187.7	53.2	32.5	42.9	-9.4	-1.7	-5.6
9.	50% RDF + 50% N (GLM)	192.9	207.0	200.0	64.6	45.4	55.0	-4.7	6.3	0.8
10.	75% RDF + 25% N (GLM)	176.4	191.3	183.9	48.1	44.5	46.3	-13.4	0.0	-6.7

Table 41. Balance sheet of available N (kg ha^{-1}) as influenced by different treatments after sorghum-wheat cropping (at the end of wheat crop)

Sr. No.	Treatments		Initial nutrient status			Nutrient added			Nutrient uptake			Expected nutrient balance		
	Kharif sorghum	*Rabi* wheat	A			B			C			D =(A+B)-C		
			1999	2000	Mean	1999	2000	Mean	1999	2000	Mean	1999	2000	Mean
1.	Control (No fertilizers)	Control (No fertilizers)	108.2	110.4	109.3	0.0	0.0	0.0	29.0	22.3	25.7	79.2	88.1	83.7
2.	50% RDF	100% RDF	134.1	136.2	135.2	120.0	120.0	120.0	134.1	141.2	137.7	120.0	115.0	117.5
3.	75% RDF	75% RDF	137.2	135.1	136.2	90.0	90.0	90.0	139.0	138.7	138.9	88.2	86.4	87.3
4.	100% RDF	100% RDF	204.6	210.2	207.4	120.0	120.0	120.0	168.5	177.1	172.8	156.1	153.1	154.6
5.	50% RDF + 50% N (FYM)	100% RDF	236.8	240.5	238.7	120.0	120.0	120.0	196.9	179.2	188.1	159.9	181.3	170.6
6.	75% RDF + 25% N (FYM)	75% RDF	207.8	216.6	212.2	90.0	90.0	90.0	143.7	141.3	142.5	154.1	165.3	159.7
7.	50% RDF + 50% N (WCS)	100% RDF	199.1	210.1	204.6	120.0	120.0	120.0	179.4	145.6	162.5	139.7	184.5	162.1
8.	75% RDF + 25% N (WCS)	75% RDF	181.1	194.3	187.7	90.0	90.0	90.0	137.9	134.0	136.0	133.2	150.3	141.8
9.	50% RDF + 50% N (GLM)	100% RDF	192.9	207.0	200.0	120.0	120.0	120.0	155.1	148.8	152.0	157.8	178.0	168.0
10.	75% RDF + 25% N (GLM)	75% RDF	176.4	191.3	183.9	90.0	90.0	90.0	131.4	136.1	133.8	135.0	145.2	140.1

Table 41 (Contd…)

Sr. No.	Treatments		Actual nutrient status			Apparent gain/loss			Difference between initial and final status		
			E			E-D			E-A		
	Kharif sorghum	*Rabi* wheat	1999	2000	Mean	1999	2000	Mean	1999	2000	Mean
1.	Control (No fertilizers)	Control (No fertilizers)	117.6	115.3	116.5	38.4	27.2	32.8	9.4	4.9	7.2
2.	50% RDF	100% RDF	153.7	142.3	148.0	33.7	27.3	30.5	19.6	6.1	12.9
3.	75% RDF	75% RDF	168.6	151.4	160.0	80.4	65.0	72.7	31.4	16.3	23.9
4.	100% RDF	100% RDF	189.7	195.6	192.7	33.6	42.5	38.1	-14.9	-14.6	-14.8
5.	50% RDF + 50% N (FYM)	100% RDF	231.3	235.8	233.6	71.4	54.5	63.0	-5.5	-4.7	-5.1
6.	75% RDF + 25% N (FYM)	75% RDF	217.9	215.7	216.8	63.8	50.4	57.1	10.1	-0.9	4.6
7.	50% RDF + 50% N (WCS)	100% RDF	203.0	207.1	205.1	63.3	22.6	43.0	3.9	-3.0	0.5
8.	75% RDF + 25% N (WCS)	75% RDF	196.0	195.9	196.0	62.8	45.3	54.1	14.9	1.6	8.3
9.	50% RDF + 50% N (GLM)	100% RDF	200.7	203.6	202.2	42.9	25.4	34.2	7.8	-3.4	2.2
10.	75% RDF + 25% N (GLM)	75% RDF	191.3	188.9	190.1	56.3	43.7	50.0	14.9	-2.4	6.3

the wheat crop fulfill its need of nitrogen apart from added and inherent nutrient status.

4.3.3.2 Phosphorus balance sheet

The data pertaining to the phosphorus nutrient balance to the sorghum crop in sorghum-wheat cropping system as influenced by the integrated nutrient management for sorghum crop are presented in Table 42.

The conjoint use of organic and inorganic fertilizers as well as inorganic fertilizers alone did not showed consistent relationship in respect of phosphorus nutrient balance to sorghum crop. However, highest P nutrient apparent loss was noticed in the treatment 50 per cent RDF + 50 per cent N substituted through FYM (-63.0 and -78.2 kg ha^{-1}) followed by 75 per cent RDF + 25 per cent N through FYM (-52.0 and –54.19 kg ha^{-1}) during the year 1999 and 2000, respectively of experimentation.

The phosphorus nutrient balance to wheat crop in sorghum-whet crop sequence as influenced by use of optimum and sub-optimum levels of fertilizers for wheat are presented in Table 43. The application of optimum and sub-optimum dose of fertilizer to wheat preceded by conjoint use of organic and inorganic fertilizers to *kharif* sorghum did not show consistent relationship in respect of phosphorus nutrient balance to wheat crop. However, significant phosphorus balance was not available in soil after harvest of wheat in sorghum-wheat crop sequence during study period.

4.3.3.3 Potassium balance sheet

The effects of inorganic fertilizers alone and in combination with organic fertilizers on nutrient supply of potassium for sorghum crop are recorded in Table 44.

Table 42. Balance sheet of available P (kg ha^{-1}) as influenced by different treatments after *kharif* sorghum

Sr. No.	Treatments	Initial nutrient status A			Nutrient added B			Nutrient uptake C			Expected nutrient balance D=(A+B)-C		
		1999	2000	Mean	1999	2000	Mean	1999	2000	Mean	1999	2000	Mean
1.	Control (No fertilizers)	6.13	9.48	7.81	0.0	0.0	0.0	4.68	2.56	3.62	1.45	6.92	4.19
2.	50% RDF	11.71	13.38	12.55	30.0	30.0	30.0	19.77	15.60	17.69	21.94	27.78	24.86
3.	75% RDF	12.27	13.94	13.11	45.0	45.0	45.0	29.33	19.26	24.30	27.94	39.68	33.81
4.	100% RDF	13.38	13.94	13.66	60.0	60.0	60.0	35.90	26.28	31.09	37.48	47.66	42.57
5.	50% RDF + 50% N (FYM)	16.72	17.84	17.28	99.0	105.0	102.0	33.77	27.69	30.73	81.95	95.15	88.55
6.	75% RDF + 25% N (FYM)	15.61	15.10	15.36	80.0	82.0	81.0	27.76	28.52	28.14	67.85	69.58	68.72
7.	50% RDF + 50% N (WCS)	16.73	13.38	15.06	50.0	50.0	50.0	24.10	21.44	22.77	42.63	41.94	42.29
8.	75% RDF + 25% N (WCS)	15.10	13.94	14.52	55.0	55.0	55.0	27.68	24.42	26.05	42.42	44.52	43.47
9.	50% RDF + 50% N (GLM)	13.94	12.82	13.38	48.0	56.0	52.0	30.60	22.38	26.49	31.34	46.44	38.89
10.	75% RDF + 25% N (GLM)	11.71	11.71	11.71	54.0	58.0	56.0	27.03	25.16	26.10	38.68	44.55	41.62

Table 42 (Contd…)

Sr. No.	Treatments	Actual nutrient status			Apparent gain/loss			Difference between initial and final status		
		E			E-D			E-A		
		1999	2000	Mean	1999	2000	Mean	1999	2000	Mean
1.	Control (No fertilizers)	8.36	8.47	8.42	6.91	1.6	4.3	2.2	-1.0	0.6
2.	50% RDF	10.04	9.81	9.93	-11.90	-18.00	-15.0	-1.7	-3.6	-2.7
3.	75% RDF	13.66	14.72	14.19	-14.30	-25.00	-19.7	1.4	0.8	1.1
4.	100% RDF	13.38	14.72	14.05	-24.10	-32.90	-28.5	0.0	0.8	0.4
5.	50% RDF + 50% N (FYM)	18.96	16.95	17.96	-63.00	-78.20	-70.6	2.2	-0.9	0.7
6.	75% RDF + 25% N (FYM)	15.89	14.72	15.31	-52.00	-54.19	-53.5	0.3	-0.4	-0.1
7.	50% RDF + 50% N (WCS)	15.33	18.96	17.15	-27.30	-23.00	-25.2	-1.4	5.6	2.1
8.	75% RDF + 25% N (WCS)	10.59	15.33	12.96	-31.80	-29.20	-30.5	-4.5	1.4	-1.6
9.	50% RDF + 50% N (GLM)	13.94	17.25	15.60	-17.40	-29.20	-23.3	0.0	4.4	2.2
10.	75% RDF + 25% N (GLM)	11.71	12.39	12.05	-27.00	-32.20	-29.6	0.0	0.7	0.4

Table 43. Balance sheet of available P (kg ha^{-1}) as influenced by different treatments after sorghum-wheat cropping (at the end of wheat crop)

Sr. No.	Treatments		Initial nutrient status			Nutrient added			Nutrient uptake			Expected nutrient balance		
	Kharif sorghum	*Rabi* wheat	A			B			C			D=(A+B)-C		
			1999	2000	Mean	1999	2000	Mean	1999	2000	Mean	1999	2000	Mean
1.	Control (No fertilizers)	Control (No fertilizers)	8.36	8.47	8.42	0.0	0.0	0.0	11.11	5.73	8.42	-2.75	2.74	0.00
2.	50% RDF	100% RDF	10.04	9.81	9.93	60.0	60.0	60.0	32.53	41.88	37.21	37.51	27.93	32.72
3.	75% RDF	75% RDF	13.66	14.72	14.19	45.0	45.0	45.0	31.32	38.86	35.09	27.34	20.86	24.10
4.	100% RDF	100% RDF	13.38	14.72	14.05	60.0	60.0	60.0	35.75	42.91	40.83	34.63	31.81	33.22
5.	50% RDF + 50% N (FYM)	100% RDF	18.96	16.95	18.00	60.0	60.0	60.0	43.30	46.20	44.75	35.66	30.75	33.21
6.	75% RDF + 25% N (FYM)	75% RDF	15.89	14.72	15.31	45.0	45.0	45.0	33.33	38.63	35.98	27.06	21.09	24.08
7.	50% RDF + 50% N (WCS)	100% RDF	15.33	18.96	17.15	60.0	60.0	60.0	33.81	40.28	37.05	41.52	38.68	40.10
8.	75% RDF + 25% N (WCS)	75% RDF	10.59	15.33	12.96	45.0	45.0	45.0	29.28	36.88	33.08	26.31	23.45	24.88
9.	50% RDF + 50% N (GLM)	100% RDF	13.94	17.25	15.60	60.0	60.0	60.0	37.31	43.47	40.39	36.63	33.78	35.21
10.	75% RDF + 25% N (GLM)	75% RDF	11.71	12.39	12.05	45.0	45.0	45.0	29.61	36.64	33.13	27.10	20.75	23.93

Table 43 (Contd…)

Sr. No.	Treatments		Actual nutrient status			Apparent gain/loss			Difference between initial and final status		
	Kharif sorghum	*Rabi* wheat	E			E-D			E-A		
			1999	2000	Mean	1999	2000	Mean	1999	2000	Mean
1.	Control (No fertilizers)	Control (No fertilizers)	9.48	9.10	9.29	6.73	6.36	6.55	1.12	0.74	0.93
2.	50% RDF	100% RDF	13.38	11.28	12.33	-24.13	-16.65	-20.39	3.34	1.47	2.41
3.	75% RDF	75% RDF	13.94	14.10	14.02	-13.40	-6.76	-10.08	0.28	-0.62	-0.17
4.	100% RDF	100% RDF	13.94	14.26	14.10	-20.69	-17.55	-19.12	0.56	-0.46	0.05
5.	50% RDF + 50% N (FYM)	100% RDF	17.84	16.52	17.18	-17.82	-14.23	-16.03	-1.12	-0.43	-0.78
6.	75% RDF + 25% N (FYM)	75% RDF	15.10	14.88	14.99	-11.96	-6.21	-9.09	-0.29	0.16	-0.07
7.	50% RDF + 50% N (WCS)	100% RDF	13.38	16.10	14.74	-28.14	-22.58	-25.36	-1.95	-2.86	-2.41
8.	75% RDF + 25% N (WCS)	75% RDF	13.94	15.15	14.55	-12.37	-8.30	-10.34	3.35	-0.18	1.59
9.	50% RDF + 50% N (GLM)	100% RDF	12.82	14.98	13.90	-23.81	-18.80	-21.31	-1.12	-2.27	-1.70
10.	75% RDF + 25% N (GLM)	75% RDF	11.71	12.86	12.29	-15.39	-7.89	-11.64	0.00	0.47	0.24

Table 44. Balance sheet of available K (kg ha^{-1}) as influenced by different treatments after *kharif* sorghum

Sr. No.	Treatments	Initial nutrient status			Nutrient added			Nutrient uptake			Expected nutrient balance		
		A			B			C			D=(A+B)-C		
		1999	2000	Mean	1999	2000	Mean	1999	2000	Mean	1999	2000	Mean
1.	Control (No fertilizers)	425.6	420.0	233.8	0.0	0.0	0.0	20.50	31.95	26.23	405.1	388.1	396.6
2.	50% RDF	532.6	520.8	526.7	30.0	30.0	30.0	129.54	126.68	128.11	433.1	424.1	428.6
3.	75% RDF	548.8	551.6	550.2	45.0	45.0	45.0	155.30	127.45	141.38	438.5	469.2	453.9
4.	100% RDF	590.8	607.6	599.2	60.0	60.0	60.0	182.90	162.02	172.46	467.9	505.6	486.8
5.	50% RDF + 50% N (FYM)	674.8	683.2	679.0	114.0	121.0	117.5	200.50	151.67	176.09	588.3	652.5	620.4
6.	75% RDF + 25% N (FYM)	618.8	616.0	617.4	87.0	90.0	88.5	147.96	155.39	151.68	557.8	550.6	554.2
7.	50% RDF + 50% N (WCS)	672.0	641.2	656.6	212.0	199.0	205.5	127.22	129.33	128.28	756.8	710.9	733.9
8.	75% RDF + 25% N (WCS)	635.6	593.6	614.6	136.0	129.0	132.5	132.60	145.48	139.04	639.0	577.1	578.1
9.	50% RDF + 50% N (GLM)	610.4	618.8	614.6	342.0	453.0	397.5	153.80	136.46	145.13	798.6	935.3	867.0
10.	75% RDF + 25% N (GLM)	537.6	568.4	553.0	201.0	256.0	228.5	139.90	142.35	141.13	598.7	682.1	640.4

Table 44 (Contd…)

Sr. No.	Treatments	Actual nutrient status			Apparent gain/loss			Difference between initial and final status		
		E			E-D			E-A		
		1999	2000	Mean	1999	2000	Mean	1999	2000	Mean
1.	Control (No fertilizers)	440.0	460.0	450.0	34.9	71.9	53.4	14.4	40.0	27.2
2.	50% RDF	518.0	518.2	518.1	84.9	94.1	89.5	-14.6	-2.6	-8.6
3.	75% RDF	537.6	540.8	539.2	99.1	71.6	85.4	-11.2	-10.8	-11.0
4.	100% RDF	574.0	576.4	575.2	106.1	70.8	88.5	-16.8	-31.2	-24.0
5.	50% RDF + 50% N (FYM)	630.0	645.1	637.6	41.7	-7.4	17.2	-44.8	-38.2	-41.5
6.	75% RDF + 25% N (FYM)	554.4	601.7	578.1	-3.4	51.1	23.9	-64.4	-14.3	-39.4
7.	50% RDF + 50% N (WCS)	554.4	595.4	574.9	-202.4	-115.5	-159.0	-117.6	-45.8	-81.7
8.	75% RDF + 25% N (WCS)	537.6	548.0	543.1	-101.4	-28.5	-65.0	-98.0	-45.0	-71.5
9.	50% RDF + 50% N (GLM)	529.2	546.2	537.7	-269.4	-389.1	-329.3	-81.2	-72.6	-76.9
10.	75% RDF + 25% N (GLM)	515.2	520.1	517.7	-83.5	-162.0	-122.8	-22.4	-48.3	-35.4

The data from Table 44, revealed that the supply of potassium either through organic manures or an inorganic fertilizers get fixed in soil as a result unavailable to crop and hence all the values of potassium nutrient balance of sorghum crop showed the negative values. The fixation of potassium is a natural phenomenon occurred in soil to maintain the equilibrium of potassium. However, it was more pronounced in 50 per cent RDF + 50 per cent N substitution through wheat-straw (-117.6 kg ha^{-1}) followed by 75 per cent RDF + 25 per cent N through wheat cut straw (-98.0 kg ha^{-1}) and 50 per cent RDF + 50 per cent N through gliricidia (-81.2 kg ha^{-1}) applied to *kharif* sorghum during first year of experimentation. Whereas, it was more pronounced during second year of experimentation in 50 per cent RDF + 50 per cent N through gliricidia (-72.6 kg ha^{-1}) followed by 75 per cent RDF + 25 per cent N through gliricidia (-48.3 kg ha^{-1}) applied during *kharif* season.

The potassium nutrient status for wheat crop in *rabi* season as influenced by 75 per cent and 100 per cent recommended dose of fertilizer are presented in Table 45. It was observed from the Table 45 that the application either 75 per cent recommended dose or 100 per cent recommended dose to wheat crop in sorghum-wheat crop sequence was found beneficial to maintain the nutrient balance in respect of potassium. It was in the range from 2.8 to 89.6 kg ha^{-1} and 1.1 to 42.0 kg ha^{-1} during first and second year of experimentation, respectively.

4.3.4 Soil properties

The physical and chemical properties of soil as influenced by different treatments were studied after harvest of sorghum and wheat crop during the period of experimentation. The chemical soil properties viz., pH, EC, organic

Table 45. Balance sheet of available K (kg ha^{-1}) as influenced by different treatments after sorghum-wheat cropping (at the end of wheat crop)

Sr. No.	Treatments		Initial nutrient status			Nutrient added			Nutrient uptake			Expected nutrient balance		
	Kharif sorghum	*Rabi* wheat	A			B			C			D=(A+B)-C		
			1999	2000	Mean	1999	2000	Mean	1999	2000	Mean	1999	2000	Mean
1.	Control (No fertilizers)	Control (No fertilizers)	440.0	460.0	450.0	0.0	0.0	0.0	32.91	18.28	25.60	407.1	441.7	424.4
2.	50% RDF	100% RDF	518.0	518.2	518.1	60.0	60.0	60.0	105.42	148.39	126.91	472.6	429.8	451.2
3.	75% RDF	75% RDF	537.6	540.8	539.2	45.0	45.0	45.0	106.88	107.79	107.34	475.7	478.0	476.9
4.	100% RDF	100% RDF	574.0	576.4	575.2	60.0	60.0	60.0	135.23	124.54	129.89	498.8	511.9	505.4
5.	50% RDF + 50% N (FYM)	100% RDF	630.0	645.1	637.6	60.0	60.0	60.0	141.84	144.51	143.19	548.2	560.6	554.4
6	75% RDF + 25% N (FYM)	75% RDF	554.4	601.7	578.1	45.0	45.0	45.0	110.20	126.67	118.44	489.2	520.0	504.6
7.	50% RDF + 50% N (WCS)	100% RDF	554.4	595.4	574.9	60.0	60.0	60.0	121.99	143.24	132.62	492.4	515.2	502.3
8.	75% RDF + 25% N (WCS)	75% RDF	537.6	548.6	543.1	45.0	45.0	45.0	109.30	127.74	118.52	473.3	465.9	469.6
9.	50% RDF + 50% N (GLM)	100% RDF	529.2	546.2	537.7	60.0	60.0	60.0	120.82	128.90	124.86	468.4	477.3	472.9
10.	75% RDF + 25% N (GLM)	75% RDF	515.2	520.1	517.7	45.0	45.0	45.0	117.80	131.89	124.85	442.4	433.2	437.8

Table 45 (Contd…)

Sr. No.	Treatments		Actual nutrient status			Apparent gain/loss			Difference between initial and final status		
	Kharif sorghum	*Rabi* wheat	E			E-D			E-A		
			1999	2000	Mean	1999	2000	Mean	1999	2000	Mean
1.	Control (No fertilizers)	Control (No fertilizers)	420.0	440.8	430.4	12.9	-0.9	6.0	-20.0	-19.2	-19.6
2.	50% RDF	100% RDF	520.8	519.3	500.1	48.2	89.5	68.9	2.8	1.1	2.0
3.	75% RDF	75% RDF	551.6	545.7	548.7	75.9	67.7	71.8	14.0	4.9	9.5
4.	100% RDF	100% RDF	607.6	590.2	598.9	108.8	78.3	93.6	33.6	13.8	23.7
5.	50% RDF + 50% N (FYM)	100% RDF	683.2	665.6	674.4	135.0	105.0	120.0	53.2	20.5	36.9
6.	75% RDF + 25% N (FYM)	75% RDF	616.0	608.0	612.0	126.8	88.0	107.4	61.6	6.3	34.0
7.	50% RDF + 50% N (WCS)	100% RDF	641.2	625.4	633.3	148.8	113.2	131.0	86.8	30.0	58.4
8.	75% RDF + 25% N (WCS)	75% RDF	593.6	570.9	582.3	120.3	105.0	112.7	56.0	22.3	39.2
9.	50% RDF + 50% N (GLM)	100% RDF	618.8	588.2	603.5	150.4	110.9	130.7	89.6	42.0	65.8
10.	75% RDF + 25% N (GLM)	75% RDF	568.4	534.8	551.6	126.0	101.6	113.8	53.2	14.7	34.0

carbon and physical properties viz., bulk density, infiltration rate, hydraulic conductivity, water stable aggregates and organic matter were studied and the data in respect of all above properties are presented in Table 46 to 49, respectively.

4.3.4.1 Chemical properties

4.3.4.1.1 Soil reaction (pH)

The data on soil reaction before sowing of *kharif* sorghum, after harvest of sorghum and wheat as influenced by the integrated nutrient management to sorghum crop and use of optimum and sub-optimum levels of fertilizers to wheat crop in sorghum-wheat crop sequence are presented in Table 46.

The conjoint use of organic and inorganic fertilizers to sorghum and wheat crop did not influenced soil reaction significantly during both years of experimentation. However, the results indicated that pH of soil remained more or less unaffected under various treatments as compared to initial soil reaction measured in terms of pH.

4.3.4.1.2 Electrical conductivity (EC)

The data on electrical conductivity before sowing and after harvest of sorghum and wheat in sequence are presented in Table 47. Electrical conductivity of the soil at the initial and post harvest had not undergone any appreciable change due to continuous application of chemical fertilizers and manures over the years. However, there was little numerical increase in electrical conductivity in soil by the conjoint application of organic and inorganic fertilizers.

Table 46. Effect of integrated nutrient management on soil reaction in soil

Sr. No.	Treatments		Soil reaction (pH)								
	Kharif	*Rabi*	Before sorghum			After sorghum/ Before wheat			After wheat		
			1999	2000	Mean	1999	2000	Mean	1999	2000	Mean
1.	Control (No fertilizers)	Control (No fertilizers)	8.2	8.1	8.15	8.0	8.2	8.1	8.1	8.2	8.15
2.	50% RDF	100% RDF	8.1	8.1	8.1	8.1	8.1	8.1	8.1	8.2	8.15
3.	75% RDF	75% RDF	8.2	8.1	8.15	8.0	8.0	8.0	8.1	8.3	8.2
4.	100% RDF	100% RDF	8.2	8.2	8.2	8.0	8.1	8.05	8.2	8.2	8.2
5.	50% RDF + 50% N (FYM)	100% RDF	8.1	8.1	8.1	8.1	8.0	8.05	8.1	8.1	8.1
6.	75% RDF + 25% N (FYM)	75% RDF	8.1	8.1	8.1	8.2	8.1	8.15	8.1	8.1	8.1
7.	50% RDF + 50% N (WCS)	100% RDF	8.2	8.1	8.15	8.1	8.0	8.05	8.1	8.2	8.15
8.	75% RDF + 25% N (WCS)	75% RDF	8.1	8.1	8.1	8.1	8.1	8.1	8.1	8.1	8.1
9.	50% RDF + 50% N (GLM)	100% RDF	8.2	8.1	8.15	8.1	8.1	8.1	8.1	8.1	8.1
10.	75% RDF + 25% N (GLM)	75% RDF	8.1	8.1	8.1	8.1	8.1	8.1	8.1	8.2	8.15
	S.E. ±		0.058	0.071	-	0.063	0.044	-	0.071	0.084	-
	C.D. at 5%		N.S.	N.S.	-	N.S.	N.S.	-	N.S.	N.S.	-
	General mean		8.15	8.1	8.13	8.1	8.1	8.1	8.1	8.2	8.15
	Initial value				8.15			8.1			-

Table 47. Effect of integrated nutrient management on electrical conductivity (dSm^{-1}) in soil

Sr. No.	Treatments *Kharif*	Treatments *Rabi*	Before sorghum 1999	Before sorghum 2000	Before sorghum Mean	After sorghum/ Before wheat 1999	After sorghum/ Before wheat 2000	After sorghum/ Before wheat Mean	After wheat 1999	After wheat 2000	After wheat Mean
1.	Control (No fertilizers)	Control (No fertilizers)	0.26	0.25	0.26	0.28	0.26	0.27	0.25	0.25	0.25
2.	50% RDF	100% RDF	0.25	0.25	0.25	0.29	0.30	0.30	0.25	0.26	0.26
3.	75% RDF	75% RDF	0.25	0.26	0.26	0.28	0.28	0.28	0.26	0.24	0.25
4.	100% RDF	100% RDF	0.26	0.25	0.26	0.27	0.30	0.29	0.25	0.25	0.25
5.	50% RDF + 50% N (FYM)	100% RDF	0.25	0.24	0.25	0.28	0.32	0.30	0.24	0.26	0.25
6.	75% RDF + 25% N (FYM)	75% RDF	0.23	0.25	0.24	0.29	0.30	0.30	0.25	0.28	0.27
7.	50% RDF + 50% N (WCS)	100% RDF	0.25	0.23	0.24	0.30	0.34	0.32	0.23	0.30	0.27
8.	75% RDF + 25% N (WCS)	75% RDF	0.25	0.25	0.25	0.30	0.32	0.31	0.25	0.24	0.25
9.	50% RDF + 50% N (GLM)	100% RDF	0.24	0.23	0.24	0.29	0.32	0.31	0.23	0.24	0.24
10.	75% RDF + 25% N (GLM)	75% RDF	0.23	0.24	0.24	0.30	0.30	0.30	0.24	0.26	0.25
	S.E. ±		0.013	0.010	-	0.010	0.012	-	0.010	0.008	-
	C.D. at 5%		N.S.	N.S.	-	N.S.	0.036	-	N.S.	0.022	-
	General mean		0.25	0.24	0.25	0.29	0.30	0.30	0.24	0.26	0.25
	Initial value				0.35			0.29			-

4.3.4.1.3 Organic carbon

Organic carbon contents of soil before and after harvest of each crop in sequence are presented in Table 48. The organic carbon content of soil after the harvest of sorghum as well as wheat crop was significantly influenced by conjoint use of organic and inorganic fertilizers to sorghum and also by the graded levels of recommended dose of fertilizers to wheat crop. The use of organic source of nutrient as farm yard manure, wheat cut straw and gliricidia leaves as the substitute for nitrogen along with an inorganic fertilizers were found beneficial to increase the organic carbon content of soil. However, after the harvest of wheat crop the level of organic carbon was maintained in all the treatments. Organic carbon content varied from 0.38 to 0.73 per cent before sowing of sorghum and was slightly increased at harvest of crop.

The values of organic carbon content were significantly more in the treatment where organic sources viz., FYM, wheat cut straw and gliricidia leaves were used as a source of nitrogen along with the inorganic source of fertilizers.

4.3.4.2 Physical properties of soil

The physical properties of the soils viz., bulk density, infiltration rate, hydraulic conductivity, water stable aggregates and organic matter content were measured at the harvest of wheat of the year 2000-2001 and data are furnished in Table 49.

4.3.4.2.1 Bulk density

The data presented in Table 49 indicated that bulk density was increased slightly with increased levels of inorganic fertilizers, whereas

Table 48. Effect of integrated nutrient management on organic carbon content (%) in soil

Sr. No.	Treatments *Kharif*	Treatments *Rabi*	Organic carbon (%) Before sorghum 1999	2000	Mean	After sorghum/ Before wheat 1999	2000	Mean	After wheat 1999	2000	Mean
1.	Control (No fertilizers)	Control (No fertilizers)	0.37	0.38	0.38	0.39	0.40	0.40	0.38	0.39	0.39
2.	50% RDF	100% RDF	0.45	0.45	0.45	0.46	0.46	0.46	0.45	0.46	0.46
3.	75% RDF	75% RDF	0.50	0.53	0.50	0.51	0.52	0.52	0.53	0.53	0.53
4.	100% RDF	100% RDF	0.53	0.53	0.53	0.56	0.56	0.56	0.53	0.55	0.54
5.	50% RDF + 50% N (FYM)	100% RDF	0.73	0.72	0.73	0.72	0.74	0.73	0.72	0.73	0.73
6.	75% RDF + 25% N (FYM)	75% RDF	0.71	0.73	0.72	0.67	0.70	0.69	0.73	0.74	0.74
7.	50% RDF + 50% N (WCS)	100% RDF	0.71	0.71	0.71	0.64	0.70	0.67	0.71	0.69	0.70
8.	75% RDF + 25% N (WCS)	75% RDF	0.68	0.70	0.69	0.66	0.68	0.67	0.70	0.68	0.69
9.	50% RDF + 50% N (GLM)	100% RDF	0.69	0.72	0.71	0.67	0.68	0.68	0.72	0.70	0.71
10.	75% RDF + 25% N (GLM)	75% RDF	0.65	0.68	0.67	0.62	0.64	0.63	0.68	0.67	0.68
	S.E. ±		0.008	0.023	-	0.019	0.017	-	0.023	0.010	-
	C.D. at 5%		0.024	0.066	-	0.054	0.050	-	0.066	0.029	-
	General mean		0.60	0.62	0.61	0.59	0.61	0.60	0.62	0.61	0.62
	Initial value				0.64			-			-

Table 49. Effect of integrated nutrient management on physical properties of soil after end of sequence (2001).

Sr. No.	Treatments *Kharif* sorghum	*Rabi* wheat	Bulk density ($Mg\ m^{-3}$)	Infiltration rate ($cm\ hr^{-1}$)	Hydraulic conductivity ($cm\ hr^{-1}$)	WSA MWD (mm)	Organic matter (%)
1.	Control (No fertilizers)	Control (No fertilizers)	1.32	0.80	1.44	0.70	0.67
2.	50% RDF	100% RDF	1.31	0.78	1.42	0.72	0.79
3.	75% RDF	75% RDF	1.29	0.76	1.40	0.72	0.89
4.	100% RDF	100% RDF	1.30	0.76	1.42	0.75	0.96
5.	50% RDF + 50% N (FYM)	100% RDF	1.25	0.89	1.86	0.86	1.27
6.	75% RDF + 25% N (FYM)	75% RDF	1.28	0.85	1.84	0.82	1.20
7.	50% RDF + 50% N (WCS)	100% RDF	1.22	0.92	1.94	0.96	1.20
8.	75% RDF + 25% N (WCS)	75% RDF	1.24	0.90	1.90	0.92	1.17
9.	50% RDF + 50% N (GLM)	100% RDF	1.26	0.88	1.76	0.84	1.17
10.	75% RDF + 25% N (GLM)	75% RDF	1.29	0.84	1.72	0.82	1.10
	S.E. ±		0.012	0.014	0.008	0.012	0.014
	C.D. at 5%		0.034	0.039	0.0024	0.036	0.041
	General mean		1.28	0.84	1.67	0.81	1.04
	Initial value		1.32	0.76	1.63	0.74	1.10

application of FYM, wheat cut straw and gliricidia in conjunction with chemical fertilizers reduced the bulk density. The bulk density was increased with increased dose of NPK fertilizers from 50 per cent to 100 per cent recommended dose of fertilizer to both the crops. However, the bulk density reduced to 1.25, 1.22 and 1.26 Mg m^{-3} in respect of 50 per cent N substituted through FYM, wheat cut straw and gliricidia GM respectively to sorghum as against 1.32 Mg m^{-3} under control (untreated plot).

4.3.4.2.2 Infiltration rate

In almost all the treatments receiving FYM, wheat cut straw and gliricidia leaf manure in conjunction with inorganic fertilizers judiciously every year to sorghum, the infiltration rate of the soil remarkably increased as compared to other treatments (Table 49). However, FYM, wheat cut straw and gliricidia applied to soil registered higher infiltration rate with the range from 0.88 to 0.92 cm hr^{-1}. On the other hand, there was short change in infiltration rate due to continuous use of chemical fertilizers observed in the range from 0.76 to 0.78 cm hr^{-1}.

4.3.4.2.3 Hydraulic conductivity

The hydraulic conductivity of the soil was significantly affected due to addition of organic manures viz., wheat cut straw, FYM and gliricidia leaf manure. The hydraulic conductivity of soil was higher (1.94 cm hr^{-1}) in treatment involving 50 per cent RDF + 50 per cent N through wheat cut straw during *kharif* and 100 per cent RDF during *rabi* and significantly more than the rest of the treatments (Table 49). The treatment comprising of 50 per cent RDF + 50 per cent N through FYM and 100 per cent RDF (1.86 cm hr^{-1}) and 75 per cent RDF + 25 per cent N through FYM and 75 per cent RDF (1.84 cm hr^{-1})

was found to be superior over use of gliricidia in proportion with 50 per cent (1.76 cm hr^{-1}) and 25 per cent (1.72 cm hr^{-1}) for substitution of N in combination with inorganic fertilizers. Use of inorganic fertilizers with varying levels during both the season reduces the hydraulic conductivity of soil. It was ranged from 1.40 to 1.42 cm hr^{-1} in optimum and sub-optimum levels of inorganic fertilizers tried.

4.3.4.2.4 Water stable aggregates

The data on water stable aggregates as influenced by various treatments are presented in Table 49. Increased fertilizer levels from 50 to 100 per cent to both the crops, decrease in water stable aggregates and ranged from 0.72 to 0.75 mm which indicated that the anti-effects of chemical fertilizers on soil structure. Whereas water stable aggregates increased markedly from 0.82 to 0.96 mm due to use of FYM, wheat cut straw and gliricidia manure along with chemical fertilizers showing significant impact of organic manure in improvement of soil structure thereby providing better environment for root development and aeration.

4.3.4.2.5 Organic matter content in soil

Incorporation of organic manures viz., FYM, wheat cut straw and gliricidia in soil in combination with balanced dose of chemical fertilizers showed a contrasting and striking feature on organic matter content in soil after end of experimentation as compared to the effects of chemical fertilizers alone (Table 49). However, cumulative effect of NPK fertilizers over years maintained the level of organic matter in soil (0.79 to 0.96%) as that of unfertilized plot (0.67%). Supplementation of N either through FYM, wheat cut straw and gliricidia GM in conjoint with chemical fertilizers invariably increased the organic matter status of soil (1.10 to 1.27%).

In general, continuous application of fertilizers in combination with organic manures viz., FYM, wheat cut straw and gliricidia leaf manure in continuous cropping improved the infiltration rate, size of water stable aggregates, organic matter content of soil and decreased bulk density of soil over their initial values.

4.3.5 Micronutrient status of soil

After end of the experimentation soils were examined for DTPA extractable Fe, Mn, Zn and Cu content. The results are presented in Table 50.

4.3.5.1 Fe content

The data presented in Table 50 revealed that the Fe content in soil after harvest of wheat crop considered in sorghum-wheat sequence affected significantly due to the different treatments under study. The Fe status was found significantly more (5.91 mg kg^{-1}) due to 100 per cent RDF to each of sorghum and wheat than rest of the treatments. This was followed by 50 per cent RDF to sorghum and 100 per cent RDF to wheat (5.87 mg kg^{-1}). The treatment involving 50 per cent RDF + 50 per cent N through wheat cut straw for sorghum and 100 per cent RDF for wheat was found low in Fe content in soil (4.45 mg kg^{-1}) after harvest of wheat crop.

4.3.5.2 Mn content

The Mn content in soil after harvest of sequenced crop of wheat was 24.89 mg kg^{-1} in treatment consisting of 50 per cent RDF + 50 per cent N through FYM for sorghum and 100 per cent RDF for wheat which was significantly higher than rest of the treatments followed by 75 per cent RDF +

Table 50. Effect of integrated nutrient management on micronutrient content in soil (mg kg^{-1})

Sr. No.	Treatments		DTPA extractable micronutrient (mg kg^{-1})			
	Kharif	*Rabi*	Fe	Mn	Zn	Cu
1.	Control (No fertilizers)	Control (No fertilizers)	5.49	16.76	0.46	2.01
2.	50% RDF	100% RDF	5.87	18.05	0.60	2.16
3.	75% RDF	75% RDF	5.56	16.24	0.59	2.63
4.	100% RDF	100% RDF	5.91	20.75	0.64	2.25
5.	50% RDF + 50% N (FYM)	100% RDF	5.25	24.89	0.84	2.38
6.	75% RDF + 25% N (FYM)	75% RDF	4.56	22.35	0.74	2.28
7.	50% RDF + 50% N (WCS)	100% RDF	4.45	21.81	0.65	2.34
8.	75% RDF + 25% N (WCS)	75% RDF	4.99	19.20	0.69	2.25
9.	50% RDF + 50% N (GLM)	100% RDF	5.49	16.05	0.47	1.89
10.	75% RDF + 25% N (GLM)	75% RDF	5.45	19.12	0.51	2.24
	S.E. ±		0.079	0.051	0.013	0.014
	C.D. at 5%		0.229	0.148	0.039	0.042
	General mean		5.30	19.52	0.62	2.24
	Initial value		12.95	22.10	0.87	3.27

25 per cent N through FYM to sorghum and 75 per cent RDF to wheat (22.35 mg kg^{-1}). The use of organic source of fertilizer showed increasing trend in Mn content in soil (Table 50).

4.3.5.3 Zn content

The data in respect of Zn content in soil (Table 50) revealed that the integrated nutrient management for *kharif* crop and use of optimum and sub-optimum levels of fertilizers to *rabi* crop showed higher level of Zn content in soil than only inorganic fertilizer application. The treatment involving 50 per cent RDF + 50 per cent N through FYM and 100 per cent RDF was significantly superior (0.84 mg kg^{-1}) over rest of all the treatments followed by the treatment 75 per cent RDF + 25 per cent N through FYM (0.74 mg kg^{-1}). The 50 per cent RDF + 50 per cent N through gliricidia to sorghum and 100 RDF to wheat showed minimum value (0.47 mg kg^{-1}) in respect of Zn content in soil. However, use of recommended dose of fertilizer for *kharif* as well as *rabi* crops increased the Zn content in soil.

4.3.5.4 Cu content

The data (Table 50) indicated that the Cu content in soil was at higher magnitude (2.63 mg kg^{-1}) due to 75 per cent RDF to each of the sorghum and wheat crop which was significantly more than rest of the treatments under study followed by 50 per cent RDF + 50 per cent N through FYM to sorghum and 100 per cent RDF to wheat (2.38 mg kg^{-1}). However, Cu content in soil as affected by the treatments involving use of organic sources viz., FYM, wheat cut straw and gliricidia in conjunction with the inorganic fertilizers during *kharif* season and only inorganic fertilizers with optimum and sub-optimum levels for *rabi* did not showed significant difference in between the treatments tried.

In general, content of DTPA Fe, Cu in soil were higher in the treatment involving inorganic levels of fertilizers whereas Mn and Zn values were lower in 50 per cent N substitution through either FYM, wheat cut straw or gliricidia over the reduced dose of fertilizers. However, the DTPA extractable micronutrients were built up over their initial status except Fe.

4.3.6 Microbial status of soil

The microbial status of the soil at the end of second year after harvest of wheat in sorghum-wheat sequence as influenced by the integrated nutrient management was measured and presented in Table 51.

The total microbial biomass in soil was observed significantly more (53.46 µg/g soil) due to application of farm yard manure for the substitution of 50 per cent nitrogen alongwith 50 per cent RDF for sorghum and 100 per cent RDF for wheat in sorghum-wheat sequence, which was significantly more than the rest of the treatments this was closely followed by use of gliricidia for the substitution as 50 per cent nitrogen along with 50 per cent RDF for sorghum and 100 pr cent RDF for wheat (51.67 µg/g soil). However, the use of an inorganic fertilizers without organic manures reduced the microbial biomass significantly as compared to the conjoint use of organic and inorganic fertilizers.

The differences in bacterial population were significant due to various treatments under study. The use of 50 per cent RDF in combination with gliricidia leaf manure for the substitution of 50 per cent nitrogen for sorghum and 100 per cent RDF for wheat crop recorded maximum (31.7 CFU 10^4/g soil) bacterial count which was significantly more than the rest of the treatments. Further, critical study revealed that use of organic sources viz., FYM, wheat

Table 51. Effect of integrated nutrient management system on microbial status in soil after 2001 of sorghum and wheat crop sequence

Sr. No.	Treatment		Microbial biomass (µg/g soil)	Bacteria (CFU 10^4/g soil)	Fungi (CFU 10^3/g soil)	Acteno-mycetes (CFU 10^3/g soil)	Azotobacter (CFU 10^3/g soil)	'P' solubilizers (CFU 10^2/g soil)
	Kharif sorghum	*Rabi* wheat						
1.	Control (No fertilizers)	Control (No fertilizers)	31.90	11.3	12.9	31.9	7.0	10.5
2.	50% RDF	100% RDF	39.40	23.1	39.6	49.0	12.9	18.2
3.	75% RDF	75% RDF	38.00	19.7	32.8	46.7	10.4	15.2
4.	100% RDF	100% RDF	41.82	25.8	38.2	52.6	13.5	18.7
5.	50% RDF + 50% N (FYM)	100% RDF	53.46	28.9	45.9	68.1	17.3	24.8
6.	75% RDF + 25% N (FYM)	75% RDF	46.12	26.1	42.8	56.2	14.9	22.6
7.	50% RDF + 50% N (WCS)	100% RDF	49.32	27.3	47.5	64.4	16.5	22.1
8.	75% RDF + 25% N (WCS)	75% RDF	44.98	26.9	42.4	58.8	14.5	22.8
9.	50% RDF + 50% N (GLM)	100% RDF	51.67	31.7	43.1	65.9	16.9	24.6
10.	75% RDF + 25% N (GLM)	75% RDF	45.40	25.2	40.5	55.6	13.2	20.4
	S.E. ±		0.47	0.44	0.31	0.33	0.31	0.30
	C.D. at 5%		1.37	1.28	0.89	0.97	0.90	0.87
	General mean		44.21	24.6	38.6	54.9	13.7	20.00

cut straw and gliricidia in combination with inorganic fertilizers enhanced the bacterial count as compared to inorganic fertilizers only. The combined use of 50 per cent RDF and 50 per cent nitrogen substitution through wheat cut straw was found beneficial for fungi population in soil (47.5 CFU 10^3/g soil). However, the population of actenomycetes, azotobacter and phosphorus solubilizing organisms were significantly higher due to use of 50 per cent RDF and 50 per cent nitrogen through FYM to sorghum and 100 per cent RDF to wheat crop in sorghum wheat cropping sequence. It was 68.1 CFU 10^3/g soil, 17.3 CFU 10^3/g soil and 24.8 CFU 10^2/g soil, respectively.

In general, the conjoint use of organic and inorganic fertilizers as a source of nutrients in sorghum-wheat cropping sequence were beneficial for improving and sustaining the microbial biomass as well as population in soil. The use of inorganic fertilizers alone to sorghum-wheat cropping sequence has an adverse effect on microbial biomass and their population in soil.

4.3.7 Quality studies

The quality parameters viz., protein content of sorghum and wheat as influenced by integrated nutrient management for sorghum-wheat cropping sequence is reported in Table 52.

The data in Table 52 indicated that an integrated nutrient management for sorghum-wheat cropping sequence was significantly influenced the protein content in both the crops during the year of experimentation except in sorghum during 1999. There were no consistent relationship in the values of protein content of sorghum and wheat by the use of organic and inorganic fertilizers. However, they were slightly higher in conjoint use of organic and inorganic fertilizers as compared to inorganic alone.

Table 52. Effect of integrated nutrient management system on protein content (%) in grains of sorghum and wheat crop

Sr. No.	Treatments		Protein (%)					
			Sorghum			Wheat		
	Kharif sorghum	*Rabi* wheat	1999	2000	Pooled mean	1999	2000	Pooled mean
1.	Control (No fertilizers)	Control (No fertilizers)	13.8	13.1	13.5	12.8	10.6	11.7
2.	50% RDF	100% RDF	13.8	13.5	13.7	14.2	11.7	13.0
3.	75% RDF	75% RDF	14.9	13.5	14.2	14.4	12.3	13.4
4.	100% RDF	100% RDF	13.8	13.9	13.9	15.2	14.8	15.0
5.	50% RDF + 50% N (FYM)	100% RDF	14.7	13.4	14.1	17.7	13.6	15.7
6.	75% RDF + 25% N (FYM)	75% RDF	14.0	13.5	13.8	15.6	13.1	14.4
7.	50% RDF + 50% N (WCS)	100% RDF	14.0	13.3	13.7	17.7	13.3	15.5
8.	75% RDF + 25% N (WCS)	75% RDF	14.7	13.4	14.1	15.8	13.0	14.4
9.	50% RDF + 50% N (GLM)	100% RDF	14.4	13.6	14.0	15.8	13.1	14.5
10.	75% RDF + 25% N (GLM)	75% RDF	12.9	13.9	13.4	14.4	12.7	13.6
	S.E. ±		0.39	0.12	0.36	0.37	0.14	0.57
	C.D. at 5%		N.S.	0.35	1.14	1.08	0.41	1.84
	General mean		14.1	13.5	13.8	15.3	12.8	14.1

The data pertaining to protein yields q ha^{-1} of sorghum and wheat as influenced by various treatments are presented in Table 53. It could be clearly indicated that on the basis of pooled mean, application of 50 per cent RDF + 50 per cent N substitution through FYM registered maximum protein yield of sorghum (7.26 q ha^{-1}) and of wheat (6.82 q ha^{-1}). The values of protein yield of sorghum due to organic and inorganic sources of fertilizers were at higher magnitude than those of reduced levels of only inorganic fertilizers and control. Almost similar trend was noticed in case of protein yield of wheat.

4.4 Effect of integrated nutrient management on economic evaluation

The data pertaining to the gross monetary returns (Rs. ha^{-1}), cost of cultivation (Rs. ha^{-1}), net monetary returns (Rs. ha^{-1}) and B:C ratio of different crops under study and cropping sequence as a whole as influenced by different treatments are presented and given below.

4.4.1 Economic evaluation of sorghum

The parameters studied were gross monetary return, cost of cultivation, net monetary return (Rs. ha^{-1}) and B:C ratio worked out and presented in Table 54.

4.4.1.1 Gross monetary returns

The data of mean gross monetary returns presented in Table 54 revealed that maximum gross monetary returns of sorghum averaged over two years was Rs. 25620 ha^{-1} due to application of 100 per cent RDF to sorghum this was followed by (Rs. 25487 ha^{-1}) 50 per cent RDF + 50 per cent N through FYM to sorghum. The gross monetary returns of sorghum ranged from Rs.18800 to Rs. 23299 due to use of organic and inorganic sources of fertilizers and these values were higher than reduced levels of inorganic fertilizers alone and control.

Table 53. Effect of integrated nutrient management system on protein yield (q ha^{-1}) in grains of sorghum and wheat crop

Sr. No.	Treatments		Protein yield (q ha^{-1})					
			Sorghum			Wheat		
	Kharif sorghum	*Rabi* wheat	1999	2000	Pooled mean	1999	2000	Pooled mean
1.	Control (No fertilizers)	Control (No fertilizers)	0.21	0.37	0.29	0.88	0.81	0.85
2.	50% RDF	100% RDF	4.82	5.90	5.36	5.13	4.53	4.83
3.	75% RDF	75% RDF	6.51	5.30	5.91	5.13	4.51	4.82
4.	100% RDF	100% RDF	7.06	6.79	6.93	5.83	6.28	6.06
5.	50% RDF + 50% N (FYM)	100% RDF	7.95	6.56	7.26	7.85	5.79	6.82
6.	75% RDF + 25% N (FYM)	75% RDF	6.56	6.22	6.39	5.89	4.79	5.34
7.	50% RDF + 50% N (WCS)	100% RDF	5.49	4.85	5.17	7.27	5.02	6.15
8.	75% RDF + 25% N (WCS)	75% RDF	6.67	5.55	6.11	5.65	4.74	5.20
9.	50% RDF + 50% N (GLM)	100% RDF	7.04	6.31	6.68	6.22	5.23	5.73
10.	75% RDF + 25% N (GLM)	75% RDF	6.23	6.44	6.34	5.15	4.89	5.02
	S.E. ±		0.27	0.24	0.38	0.17	0.10	0.42
	C.D. at 5%		0.77	0.69	1.22	0.49	0.30	1.33
	General mean		5.85	5.43	5.64	5.50	4.66	5.08

Table 54. Effect of integrated nutrient management on gross monetary returns, net monetary returns and benefit : cost ratio of sorghum

Sr. No.	Treatments	Gross monetary returns (Rs. ha^{-1})			Cost of cultivation (Rs.ha^{-1})	Net monetary returns (Rs. ha^{-1})			Benefit : cost ratio		
		1999	2000	Mean		1999	2000	Mean	1999	2000	Mean
1.	Control (No fertilizers)	1106	2096	1601	15227	-14122	-13131	-13627	0.07	0.14	0.11
2.	50% RDF	17627	21167	19397	16496	1131	4671	2901	1.07	1.29	1.18
3.	75% RDF	21907	19219	20563	17130	4777	2089	3433	1.28	1.12	1.20
4.	100% RDF	27429	23810	25620	17764	9665	5871	7768	1.55	1.34	1.45
5.	50% RDF + 50% N (FYM)	27150	23824	25487	19245	7905	4579	6242	1.41	1.24	1.33
6.	75% RDF + 25% N (FYM)	23234	22600	22917	18505	4729	4095	4412	1.26	1.22	1.24
7.	50% RDF + 50% N (WCS)	19427	18173	18800	19286	141	-1113	-486	1.01	0.95	0.98
8.	75% RDF + 25% N (WCS)	22510	20261	21386	18525	3985	1936	2961	1.22	1.11	1.17
9.	50% RDF + 50% N (GLM)	24326	22272	23299	17875	6451	4397	5424	1.36	1.25	1.31
10.	75% RDF + 25% N (GLM)	23838	22329	23084	17819	6019	4510	5265	1.34	1.25	1.30
	S.E. ±	892	796	-	-	892	789	-	0.049	0.045	-
	C.D. at 5%	2587	2311	-	-	2587	2289	-	0.143	0.131	-
	General mean	20855	19595	20225	-	3068	1790	2429	1.16	1.09	1.13

4.4.1.2 Cost of cultivation

The cost of cultivation of sorghum (Table 54) was not analysed statistically, inferences are, therefore, drawn on the basis of mean values.

It is evident that, the costs of organic sources viz. FYM, wheat cut straw and gliricidia applied in 50 per cent proportion are Rs. 19245, Rs. 19286 and Rs. 17875 ha^{-1} which were higher due to additional expenditure done on purchase and application charges of these organic sources. However, the cost of inorganic fertilizers was low (Rs. 17764 ha^{-1}) applied in optimum level (100 per cent RDF). The cost of cultivation reduced proportionately with every successive reduction in level of inorganic fertilizers. In absolute control in which no organic and inorganic fertilizers were applied and saved the cost of application recorded low (Rs. 15227 ha^{-1}) cost of cultivation.

4.4.1.3 Net monetary returns

The data in respect of the economic evaluation of the *kharif* sorghum on the basis of mean net monetary returns of sorghum crop as influenced by different treatments tried are presented in Table 54.

The data regarding the net monetary returns indicated that the maximum mean net monetary returns were Rs. 9665 and Rs. 5871 ha^{-1} during the year 1999 and 2000, respectively; which were closely followed by the treatment comprising of 50 per cent RDF + 50 per cent N through FYM (Rs. 7905 and Rs. 4579 ha^{-1}) applied during both the years, respectively. The treatment involving 100 per cent recommended dose i.e. 120 + 60 + 60 kg N, P_2O_5 and K_2O ha^{-1} to both the crops recovered significantly higher net monetary returns and treatment involving the organic sources viz., FYM and gliricidia were at par with this superior treatment in respect of net monetary returns. Among the organic sources, wheat cut straw has showed very poor performance in respect of net monetary returns obtained during both the years of experimentation. Reduced levels of inorganic fertilizers showed the reducing trend in net monetary returns during both the years of experimentation.

4.4.1.4 Benefit cost ratio

The data in Table 54, it would be seen that average mean maximum B:C ratio was Rs. 1.45 per rupee spent on input whereas it was 1.55 and 1.34 during first and second year of study, respectively observed in treatment 100 per cent RDF applied to sorghum. The B:C ratio obtained from application of 100 per cent RDF for the first year was significantly superior over rest of the treatments and was followed by 50 per cent RDF + 50 per cent N through FYM applied during first year. However, in second year even though the trend was similar, there was no consistency in B : C ratio, the second best treatment was 50 or 75 per cent RDF + 50 or 25 per cent N through gliricidia applied to sorghum during second year of study. The wheat cut straw application seemed to be not beneficial in respect of B:C ratio as compared to other sources applied to *kharif* sorghum. This source has not given the immediate effect to the current crop but it will be found effective during later period. Similar trend also noticed due to use of sub-optimum levels of fertilizers applied to sorghum during both the years of experimentation.

4.4.2 Economic evaluation of wheat

The same parameters were studied in wheat during *rabi* season and are presented in Table 55.

Table 55. Effect of integrated nutrient management on gross monetary returns, net monetary returns and benefit : cost ratio of wheat

Sr. No.	Treatment		Gross monetary returns (Rs. ha^{-1})			Cost of cultivation (Rs.ha^{-1})	Net monetary returns (Rs. ha^{-1})			Benefit : cost ratio		
	Kharif sorghum	*Rabi* wheat	1999	2000	Mean		1999	2000	Mean	1999	2000	Mean
1.	Control (No fertilizers)	Control (No fertilizers)	4846	5174	5010	12744	-7899	-7570	-7735	0.38	0.41	0.40
2.	50% RDF	100% RDF	24412	26435	25424	15281	9131	11154	10143	1.60	1.73	1.67
3.	75% RDF	75% RDF	24110	24854	24482	14647	9463	10207	9835	1.65	1.70	1.68
4.	100% RDF	100% RDF	26138	28657	27398	15281	10857	13376	12117	1.71	1.88	1.80
5.	50% RDF + 50% N (FYM)	100% RDF	30073	29079	29576	15281	14792	13798	14295	1.97	1.91	1.94
6.	75% RDF + 25% N (FYM)	75% RDF	25481	25002	25242	14647	10834	10355	10595	1.74	1.71	1.73
7.	50% RDF + 50% N (WCS)	100% RDF	27777	25861	26819	15281	12496	10580	11538	1.82	1.69	1.76
8.	75% RDF + 25% N (WCS)	75% RDF	24206	24642	24424	14647	9559	9995	9777	1.66	1.68	1.67
9.	50% RDF + 50% N (GLM)	100% RDF	26568	27164	26866	15281	11287	11883	11585	1.74	1.78	1.76
10.	75% RDF + 25% N (GLM)	75% RDF	24235	26223	25229	14647	9588	11576	10582	1.66	1.79	1.73
	S.E. ±		501	450	-	-	501	450	-	0.033	0.031	-
	C.D. at 5%		1454	1305	-	-	1454	1305	-	0.097	0.089	-
	General mean		23784	24309	24047	-	9011	9535	9273	1.59	1.63	1.61

4.4.2.1 Gross monetary returns

The data of mean gross monetary returns presented in Table 55 revealed that average mean maximum gross monetary returns of wheat was Rs.29576 ha^{-1}. During first year the maximum and significant gross monetary returns of Rs. 30.073 ha^{-1} were recorded in the treatment 100 per cent RDF to wheat preceded by 50 per cent RDF + 50 per cent N through FYM applied to sorghum. The rest of all the treatments could not reach the significance level. The other organic sources viz., wheat cut straw and gliricidia used with 50 per cent RDF to sorghum and 100 per cent RDF to wheat were on par with each other in respect of gross monetary returns during first year of experimentation whereas reducing the optimum levels of fertilizer during *kharif* and *rabi* season resulted in reduction in gross monetary returns during the same year.

During the second year of experimentation, it was observed that mean maximum and significantly higher (Rs. 29079 ha^{-1}) gross monetary returns were registered in 100 per cent RDF at *rabi* and 50 per cent RDF + 50 per cent N through FYM applied to sorghum which was closely followed by 100 per cent RDF applied (Rs. 28657 ha^{-1}) during both the season crops. Further, the trend noticed in between the rest of all treatments were similar as observed during first year of experimentation.

4.4.2.2 Cost of cultivation

Data in Table 55 pertaining to the cost of cultivation of wheat were not analysed statistically. Inferences are, therefore, based on mean values. It revealed that the higher (Rs. 15281 ha^{-1}) cost of cultivation was recorded where 100 per cent recommended dose of fertilizers applied to wheat, it was due to use of optimum level of fertilizer increased the cost of fertilizers applied.

While in case of sub-optimum level it was only Rs. 14647 ha^{-1} and in control it was Rs. 12744 ha^{-1} where no expenditure was incurred on fertilizers.

4.4.2.3 Net monetary returns

From benefit point of view, the net monetary returns were worked out which indicated that the average mean maximum net monetary returns (Rs. 14295 ha^{-1}) were obtained by the treatment consisting of 100 per cent RDF to wheat and preceded by 50 per cent RDF + 50 per cent N through FYM applied to sorghum. This was significantly superior over rest of all the treatments tried during first year of study. Further, it was noticed that the treatments preceded by the application of wheat cut straw and gliricidia applied in combination with 50 per cent RDF to sorghum and 100 per cent RDF to wheat were on par to each other and rest of treatments were not affected significantly in respect of net monetary returns during the year 1999. However, during the year 2000, similar trend was observed in decreasing the net monetary returns per hectare compared to superior treatment except the treatment comprising of application of 100 per cent RDF during both the seasons was on par with the significant treatment. Reduced levels of fertilizers showed reducing trend and absolute control resulted in loss in net profit ha^{-1} during both the years of experimentation.

4.4.2.4 Benefit cost ratio

It could be seen that average mean maximum B:C ratio was Rs. 1.94 per rupee spent on inputs. It was Rs. 1.97 and 1.91 during the first and second year of study, respectively. These B:C ratios were found to be significantly superior over all other treatments under study during both the years of experimentation. This highest B:C ratio was recorded by the treatment consisting of 50 per cent RDF + 50 per cent N through FYM to sorghum succeeded with 100 per cent RDF to wheat applied during the year 1999 and 2000. The reducing levels of inorganic fertilizers during *kharif* and *rabi* season, reduces the B:C ratio. However, when compared to other sources viz., wheat cut straw and gliricidia loppings with reduced level of RDF applied to *kharif* crop it was increased to some extent but not reached to the level of significance.

4.4.3 Economic evaluation of sorghum-wheat crop sequence

The economic parameters viz., gross and net monetary returns, total cost of cultivation of sequence and benefit : cost ratio were studied for judging the profitability of the sequence. The data recorded treatmentwise are presented in Table 56 and graphically depicted in Fig. 11 .

4.4.3.1 Gross monetary returns

The data on mean gross monetary returns (Rs. ha^{-1}) on pooled mean basis (Table 56) revealed that average mean maximum gross returns recorded by the sequence was Rs. 55066 ha^{-1} due to 50 per cent RDF + 50 per cent N through FYM for sorghum and 100 per cent RDF to wheat crop. The sorghum-wheat cropping sequence had registered significantly higher gross monetary returns of Rs. 57228 ha^{-1} during first year and Rs. 52903 ha^{-1} during second year of study by the same treatment. These maximum gross returns were obtained from the treatment consisting 50 per cent RDF + 50 per cent N through FYM applied to sorghum and 100 per cent RDF to wheat applied to the respective crops of the sequence during each year. However, the treatment receiving 100 per cent RDF during both the season for both the crops was ranking second which was on par with gross returns obtained from the

Table 56. Effect of integrated nutrient management system on gross monetary returns, net monetary returns and benefit:cost ratio of sorghum and wheat crop sequence

Sr. No.	Treatments		Total gross monetary returns (Rs. ha^{-1})			Total cost of cultivation (Rs. ha^{-1})	Total net monetary returns (Rs. ha^{-1})			Benefit : cost ratio		
	Kharif	Rabi	1999	2000	Pooled mean		1999	2000	Pooled mean	1999	2000	Mean
1.	Control (No fertilizers)	Control (No fertilizers)	5952	6992	6472	27971	-22019	-20979	-21499	0.21	0.25	0.23
2.	50% RDF	100% RDF	42039	47602	44821	31777	10262	15825	13044	1.32	1.50	1.41
3.	75% RDF	75% RDF	46023	44073	45048	31777	14246	12296	13271	1.45	1.39	1.42
4.	100% RDF	100% RDF	51542	52467	52005	33045	18497	19422	18960	1.56	1.59	1.58
5.	50% RDF + 50% N (FYM)	100% RDF	57228	52903	55066	34526	22702	18377	20540	1.66	1.53	1.60
6.	75% RDF + 25% N (FYM)	75% RDF	48718	47602	48160	33152	15566	14450	15008	1.47	1.44	1.46
7.	50% RDF + 50% N (WCS)	100% RDF	47204	44034	45619	34567	12637	9467	11052	1.37	1.28	1.33
8.	75% RDF + 25% N (WCS)	75% RDF	46175	45276	45726	33172	13543	12104	12824	1.41	1.37	1.39
9.	50% RDF + 50% N (GLM)	100% RDF	50981	49436	50209	33156	17824	16280	17052	1.54	1.49	1.52
10.	75% RDF + 25% N (GLM)	75% RDF	48038	48552	48295	32466	15572	16086	15829	1.48	1.50	1.49
	S.E. ±		722	1053	1378	-	722	1053	1378	0.021	0.032	-
	C.D. at 5%		2095	3056	4405	-	2096	3056	4405	0.062	0.092	-
	General mean		44444	43894	44159	-	11883	11333	11608	1.35	1.33	1.34

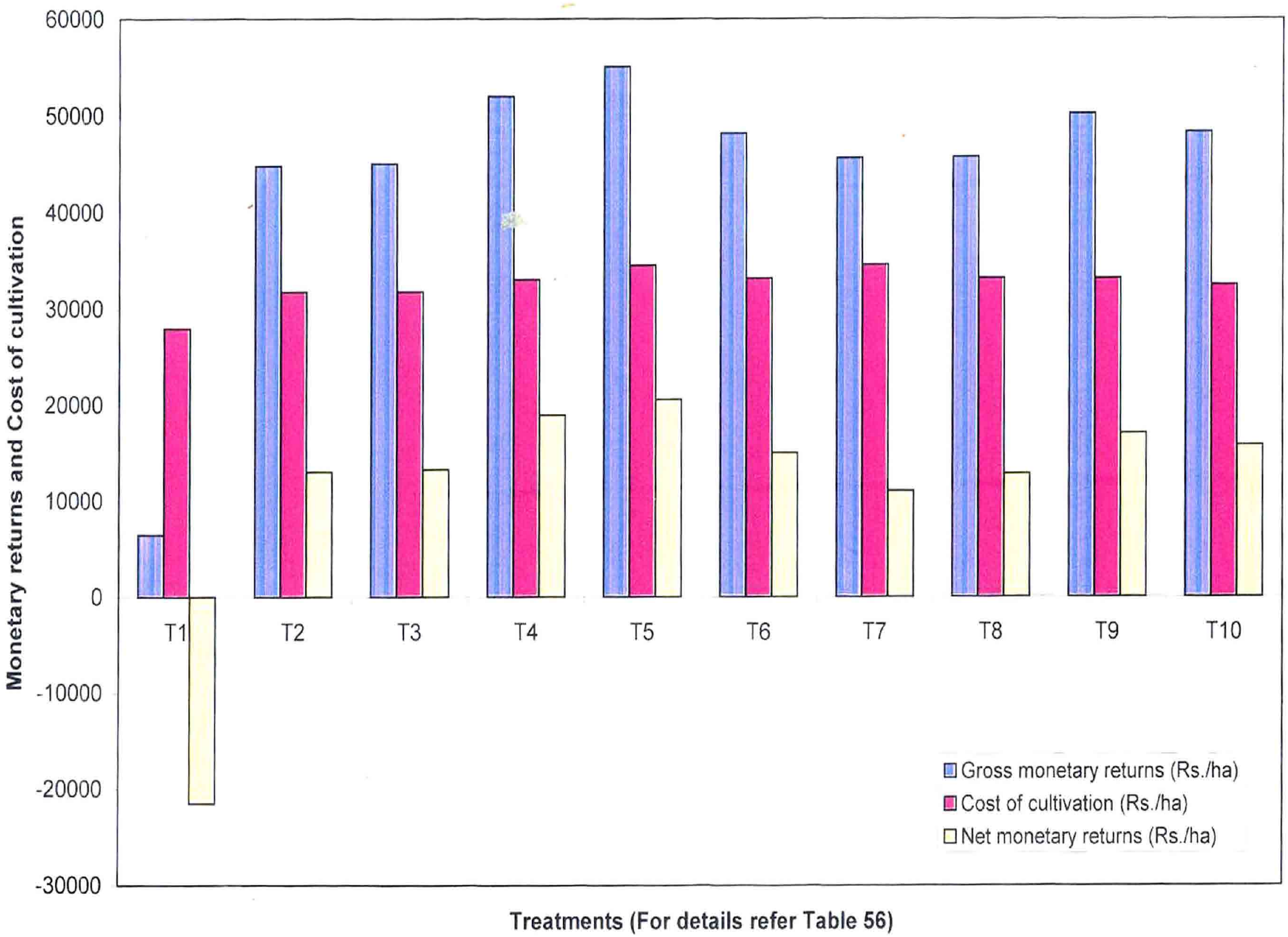


Fig. 11. Mean gross monetary returns, cost of cultivation and net monetary returns (Rs./ha) of sorghum-wheat crop sequence as influenced by different treatments

treatment comprising 50 per cent RDF + 50 per cent N through gliricidia applied to *kharif* sorghum and 100 per cent RDF to wheat (Rs. 50981 ha^{-1}). Among the organic sources, wheat cut straw applied before *kharif* crops associated with the inorganic fertilizers and optimum or sub-optimum level of fertilizer to *rabi* crop yielded poorly which reflected in lowering the gross monetary returns. Almost same trend in respect of gross monetary returns was noticed during the second year of experimentation. Absolute control had registered 8 to 9 times lower gross returns than 100 per cent RDF to wheat preceded by 50 per cent RDF + 50 per cent N substitution through FYM for sorghum.

4.4.3.2 Cost of cultivation of sequence

The cost of cultivation of sorghum-wheat sequence were not analysed statistically. Inferences are therefore based on mean values. It revealed from the data reported in Table 56 that the higher (Rs. 34567 ha^{-1}) cost of cultivation was recorded where 50 per cent recommended dose of fertilizer combined with 50 per cent N through wheat cut straw applied to sorghum and 100 per cent RDF to wheat in a year. However, this was followed by treatment comprising of FYM for substitution of N in a sequence (Rs. 34526 ha^{-1}). This might be because of higher rates of FYM. For other treatments the cost of cultivation was ranged from Rs. 31777 to 33172 ha^{-1} in a year for sorghum-wheat crop sequence.

4.4.3.3 Net monetary returns

The mean maximum net monetary returns from sorghum-wheat cropping sequence were Rs. 22702 and Rs. 19422 ha^{-1} during 1999 and 2000. These highest values of net returns Rs. ha^{-1} were recorded by the treatments involving 50 per cent RDF + 50 per cent N through FYM to sorghum and 100 per cent RDF to wheat applied during first year and 100 per cent RDF for both the crops applied during second year, respectively and these values were significantly higher than rest of all the treatments tried during study and were at par with each other during second year. Among the organic sources viz., FYM, wheat cut straw and gliricidia tested for the N substitution, FYM ranked the first and gliricidia was the second one. Wheat cut straw had adverse effect on the net monetary returns from sequence. Use of sub-optimum levels of fertilizers reduced the level of net monetary returns of the sequence during both the years. Absolute control had registered the negative values in respect of net monetary returns.

4.4.3.4 Benefit : cost ratio

The average mean maximum benefit : cost ratio of sorghum-wheat cropping sequence was 1.60 per rupee spent on input whereas it was 1.66 and 1.53 during the first and second year, respectively. The higher benefit : cost ratio was obtained due to use of 50 per cent RDF + 50 per cent N through FYM to sorghum and 100 per cent RDF to wheat which was significantly higher than rest of all the treatments studied except treatment involving 100 per cent RDF during both the seasons and they were on par with each other during second year of experimentation. Among the organic sources of gliricidia and wheat cut straw was found to be significantly beneficial in respect of benefit : cost ratio during both the years. The respective values were 1.54 and 1.37 during the year 1999 and 1.49 and 1.28 during the year 2000. Reduced levels of fertilizer, reduced the values of benefit : cost ratio.

4.5 Effect of integrated nutrient management on energy studies

The data pertaining to energy output (MJ ha^{-1}), energy input (MJ ha^{-1}), energy balance (MJ ha^{-1}), energy balance per unit input (MJ ha^{-1}) and energy use efficiency of sorghum, wheat and sorghum-wheat crop sequence as influenced by different treatments are presented in Table 57 to 59, respectively.

4.5.1 Energy studies of sorghum

The energy parameters studied were ouput energy, input energy, energy balance, energy balance per unit input (MJ ha^{-1}) and energy use efficiency worked out and presented in Table 57.

4.5.1.1 Energy output

The mean maximum energy output of sorghum from the treatment of application of 50 per cent RDF + 50 per cent N through FYM was 263918 MJ ha^{-1} and 206915 MJ ha^{-1} during first year while in second season it was due to 100 per cent RDF to sorghum. These values were significantly higher than other treatments tried.

Among the organic sources used for N substitution, FYM ranked first followed by gliricidia during first season and FYM ranked first followed by wheat cut straw during second year in respect of energy output (MJ ha^{-1}). Reduction in optimum levels of fertilizer showed decreasing trend in energy output than organic sources coupled with inorganic fertilizer.

4.5.1.2 Energy input

Energy values (Table 57) revealed that maximum mean energy input obtained was 35507 MJ ha^{-1} and 36861 MJ ha^{-1} during the first and second season of sorghum, where the organic source of gliricidia leaves were added into the soil. This was followed by the treatment of 100 per cent RDF applied to sorghum (22625 MJ ha^{-1} during first season and 22000 MJ ha^{-1} during

Table 57. Effect of integrated nutrient management system on energy output, energy input, energy balance, energy balance per unit input and energy use efficiency of sorghum in sorghum and wheat crop sequence

Sr. No.	Treatments		Energy output ($MJ\ ha^{-1}$)			Energy input ($MJ\ ha^{-1}$)		
	Kharif sorghum	*Rabi* wheat	1999	2000	Mean	1999	2000	Mean
1.	Control (No fertilizers)	Control (No fertilizers)	22597	44152	33375	12857	12232	12545
2.	50% RDF	100% RDF	178746	180195	179471	17752	17127	17440
3.	75% RDF	75% RDF	214095	171776	192936	20194	19569	19882
4.	100% RDF	100% RDF	243712	206915	225314	22625	22000	22313
5.	50% RDF + 50% N (FYM)	100% RDF	263918	206545	235232	17752	21225	19489
6.	75% RDF + 25% N (FYM)	75% RDF	216470	202981	209726	20194	21618	20906
7.	50% RDF + 50% N (WCS)	100% RDF	187367	171277	179322	22000	21097	21549
8.	75% RDF + 25% N (WCS)	75% RDF	210895	188997	199946	22313	21560	21937
9.	50% RDF + 50% N (GLM)	100% RDF	233828	184360	209109	35507	36861	36184
10.	75% RDF + 25% N (GLM)	75% RDF	220993	186062	203528	29072	29442	29257
	S.E. ±		4955	10127	-	-	-	-
	C.D. at 5%		14377	29385	-	-	-	-
	General mean		119265	174326	146796	22027	22273	22150

Table 57 (Contd…)

Sr. No.	Treatments		Energy balance ($MJ\ ha^{-1}$)			Energy balance/unit input ($MJ\ ha^{-1}$)			Energy use efficiency		
	Kharif sorghum	*Rabi* wheat	1999	2000	Mean	1999	2000	Mean	1999	2000	Mean
1.	Control (No fertilizers)	Control (No fertilizers)	9740	31920	20830	2.26	2.61	2.44	1.76	3.61	2.69
2.	50% RDF	100% RDF	160994	163068	162031	9.07	9.52	9.30	9.94	10.52	10.23
3.	75% RDF	75% RDF	193901	152207	173054	9.23	7.78	8.51	10.60	8.78	9.69
4.	100% RDF	100% RDF	221087	184915	203001	9.77	8.41	9.09	10.77	9.41	10.09
5.	50% RDF · 50% N (FYM)	100% RDF	241166	185320	213243	13.59	8.73	11.16	14.59	9.73	12.16
6.	75% RDF + 25% N (FYM)	75% RDF	196276	181362	188819	9.72	8.39	9.06	10.72	9.39	10.06
7.	50% RDF + 50% N (WCS)	100% RDF	165337	150180	157759	7.52	7.12	7.32	8.52	8.12	8.32
8.	75% RDF + 25% N (WCS)	75% RDF	188582	167437	178010	8.45	7.77	8.11	9.45	8.77	9.11
9.	50% RDF + 50% N (GLM)	100% RDF	198351	147499	172925	5.59	4.00	4.80	6.59	5.00	5.80
10.	75% RDF · 25% N (GLM)	75% RDF	191921	156620	174271	6.60	5.32	5.96	7.60	5.05	6.33
	S.E. ±		5048	10127	-	0.518	0.467	-	0.260	0.466	-
	C.D. at 5%		14649	29385	-	1.502	1.356	-	0.753	1.352	-
	General mean		176738	152053	164396	8.18	6.96	7.57	9.05	7.84	8.45

second season). Decreasing trend in energy input was observed in use of sub-optimum doses of fertilizer to sorghum. Absolute control registered the lowest energy input values during both the *kharif* seasons.

4.5.1.3 Energy balance

The data pertaining to the energy balance studies in sorghum indicated that the maximum energy balance was registered by sorghum crop due to application of 50 per cent RDF + substitution of 50 per cent N through FYM. The values were 241166 MJ ha^{-1} and 185320 MJ ha^{-1} during first and second year of experimentation, respectively. These values were significantly over rest of the treatments except in second year it was at par with 50 per cent RDF, 100 per cent RDF, 75 per cent RDF + 25 per cent N through FYM, 75 per cent RDF + 25 per cent N through wheat cut straw and 75 per cent RDF + 25 per cent N through gliricida applied to sorghum. In a nutshell, 50 per cent RDF + 50 per cent N through FYM applied to sorghum during both the years found to be significant in respect of energy balance.

4.5.1.4 Energy balance per unit input

The average mean maximum energy balance per unit input for both the years was 11.16 MJ ha^{-1} obtained from the treatment involving 50 per cent RDF + 50 per cent N through FYM (Table 57) whereas it was 13.59 and 8.73 MJ ha^{-1} during the first and second *kharif* seasons and was significantly superior over all other treatments during first year and closely followed by 50 and 100 per cent RDF levels and 75 per cent RDF + 25 per cent N through FYM applied during second year of experimentation. The energy balance per unit input was decreased and was in the range from 4.00 to 6.60 MJ ha^{-1} in the treatments where gliricidia leaf manure was incorporated with the soil during both the years. No doubt, absolute control registered the least values of energy balance per unit input during both the years.

4.5.1.5 Energy use efficiency

The average mean maximum value of energy use efficiency was 12.16 and it was 14.59 and 9.73 during first and second year of experimentation, respectively (Table 57). The significantly higher energy use efficiency was noticed from the treatment involving 50 per cent RDF coupled with 50 per cent N through FYM during first season of sorghum whereas during second season it was at par with the treatments applied 50, 75 and 100 per cent RDF and 75 per cent RDF coupled with 25 per cent N through wheat cut straw or FYM. The use of gliricidia leaf manure in combination with 50 or 75 per cent RDF decreased the energy use efficiency during both the years. The lowest energy use efficiency was observed in control treatment.

4.5.2 Energy studies of wheat

The energy parameters studied under *kharif* sorghum were considered in *rabi* wheat also and presented in the Table 58.

4.5.2.1 Energy out put

The mean maximum energy output of wheat was 137628 MJ ha^{-1} and 147893 MJ ha^{-1} registered by the treatment comprising of 50 per cent RDF + 50 per cent N through FYM to sorghum and 100 per cent RDF applied to wheat during first and second year, respectively. This was found to be significantly superior over all other remaining treatments during both the years. However, the energy output registered 125036, 123821 and 120943 MJ ha^{-1} by the treatments 100 per cent RDF during *rabi* season preceded by 100 per cent

Table 58. Effect of integrated nutrient management system on energy output, energy input, energy balance, energy balance per unit input and energy use efficiency of wheat in sorghum and wheat crop sequence

Sr. No.	Treatments		Energy output (MJ ha^{-1})			Energy input (MJ ha^{-1})		
	Kharif sorghum	*Rabi* wheat	1999	2000	Mean	1999	2000	Mean
1.	Control (No fertilizers)	Control (No fertilizers)	32079	24546	28313	12401	13023	12712
2.	50% RDF	100% RDF	110633	135739	123186	22169	22792	22481
3.	75% RDF	75% RDF	108046	120337	114192	19727	20350	20039
4.	100% RDF	100% RDF	125036	138632	131834	22169	22792	22481
5.	50% RDF + 50% N (FYM)	100% RDF	137628	147893	142761	22169	22792	22481
6.	75% RDF + 25% N (FYM)	75% RDF	113054	133308	123181	19727	20350	20039
7.	50% RDF + 50% N (WCS)	100% RDF	123821	134212	129017	22169	22792	22481
8.	75% RDF + 25% N (WCS)	75% RDF	109946	124285	117116	19727	20350	20039
9.	50% RDF + 50% N (GLM)	100% RDF	120943	134449	127696	22169	22792	22481
10.	75% RDF + 25% N (GLM)	75% RDF	109125	126742	117934	19727	20350	20039
	S.E. ±		2185	1113	-	-	-	-
	C.D. at 5%		6339	3228	-	-	-	-
	General mean		109031	122014	115523	20215	20838	20527

Table 58 (Contd...)

Sr. No.	Treatments		Energy balance (MJ ha^{-1})			Energy balance/unit input (MJ ha^{-1})			Energy use efficiency		
	Kharif sorghum	*Rabi* wheat	1999	2000	Mean	1999	2000	Mean	1999	2000	Mean
1.	Control (No fertilizers)	Control (No fertilizers)	19678	11523	15601	1.59	0.88	1.24	2.59	1.88	2.24
2.	50% RDF	100% RDF	88464	112947	100706	3.99	4.96	4.48	4.99	5.96	5.48
3.	75% RDF	75% RDF	88319	99986	94153	4.48	4.92	4.70	5.48	5.92	5.70
4.	100% RDF	100% RDF	102867	115840	109354	4.64	5.08	4.86	5.64	6.08	5.86
5.	50% RDF + 50% N (FYM)	100% RDF	115459	125102	120281	5.21	5.49	5.35	6.21	6.49	6.35
6.	75% RDF + 25% N (FYM)	75% RDF	93327	112958	103143	4.73	5.55	5.14	5.73	6.55	6.14
7.	50% RDF + 50% N (WCS)	100% RDF	101652	111420	106536	4.59	4.89	4.74	5.59	5.89	5.74
8.	75% RDF + 25% N (WCS)	75% RDF	92719	103935	98327	4.70	5.11	4.91	5.57	6.11	5.84
9.	50% RDF + 50% N (GLM)	100% RDF	98774	111658	105216	4.45	4.90	4.68	5.46	5.90	5.68
10.	75% RDF + 25% N (GLM)	75% RDF	89398	106392	97895	4.53	5.23	4.88	5.53	6.23	5.88
	S.E. ±		2324	1113	-	0.116	0.056	-	0.109	0.056	-
	C.D. at 5%		6743	3231	-	0.336	0.162	-	0.316	0.162	-
	General mean		89066	101176	95121	4.29	4.70	4.50	5.28	5.70	5.49

RDF, 50 per cent RDF + 50 per cent N through wheat cut straw and 50 per cent RDF + 50 per cent N through gliricidia, respectively and they were observed at par to each other during first year and non-significant results were observed during second year. Reduced levels of fertilizers during *kharif* followed by optimum and sub-optimum levels of fertilizers during *rabi* showed decreasing rate in energy output. The control treatment registered 32079 and 24546 MJ ha^{-1} energy output values during both the years of study.

4.5.2.2 Energy input

The energy values obtained from the various inputs applied during study period are worked out and presented in Table 58. It was noticed that maximum mean energy input of 22169 and 22792 MJ ha^{-1} during first and second years of experimentation, respectively. These values were obtained where treatments applied 100 per cent recommended dose of fertilizer to wheat. However, 19727 and 20350 MJ ha^{-1} energy input was recorded for first and second year by the treatments applied 75 per cent recommended dose of fertilizer. Whereas, decreased values were recorded by the control treatment.

4.5.2.3 Energy balance

Energy balance obtained from the various treatments (Table 58) indicated that the maximum mean energy balance obtained was 115459 MJ ha^{-1} and 125102 MJ ha^{-1} during first and second year of *rabi* season. These values were found to be significant over all other treatments tried during both the years. These significant energy balance values were obtained due to the treatment 100 per cent RDF to *rabi* wheat preceded by the 50 per cent RDF + 50 per cent N through FYM applied to *kharif* sorghum of both the year of experimentation. The energy balance recorded by the treatment applied 100 per cent RDF for wheat preceded by 100 per cent RDF, 50 per cent RDF + 50 per cent N through wheat cut straw and gliricidia to *kharif* sorghum were at par to each other during first and second year of study. However, use of sub-optimum levels of fertilizers showed reducing trend in energy balance for both the year of experiment. The control plots recorded minimum values of energy balance during both the years.

4.5.2.4 Energy balance per unit input

The average mean maximum energy balance per unit input for both the year was 5.35 MJ ha^{-1} which obtained from the treatment involving 100 per cent RDF to *rabi* season preceded by 50 per cent RDF + 50 per cent N through FYM applied to previous sorghum crop during both the year (Table 58). It was maximum of 5.21 MJ ha^{-1} during first year and 5.55 MJ ha^{-1} during second year registered due to treatment comprising with 100 and 75 per cent RDF to *rabi* wheat which was preceded by 50 and 75 per cent RDF coupled with 50 and 25 per cent N through FYM applied to *kharif* sorghum to respective years only. It was interesting to note that sub-optimum level of inorganic fertilizer i.e. 75 per cent RDF applied to *rabi* wheat which preceded by the sub-optimum levels of fertilizers coupled either with or without organic sources of wheat cut straw or gliricidia leaves were found to be at par with each other in respect of energy balance per unit input during first and second year of study. It was also noticed that decreasing in optimum levels of RDF decreased the energy balance per unit input for both the years.

4.5.2.5 Energy use efficiency

The average mean maximum energy use efficiency was 6.35 recorded by the treatment consisting 100 per cent RDF to wheat preceded by 50 per cent

RDF + 50 per cent N through FYM applied to sorghum during both the years. It was obtained 6.21 and 6.55 during 1999 and 2000 from the treatment applied optimum and sub-optimum levels of fertilizer to wheat preceded by 50 per cent RDF + 50 per cent N through FYM and 75 per cent RDF and 25 per cent N through FYM, respectively. The energy use efficiency recorded by the above treatment was found to be significantly superior over rest of all the treatments except treatment comprising of 100 per cent RDF to *rabi* and 50 per cent RDF + 50 per cent N through FYM during second year only. Among the organic sources used to preceding season, in a proportion with 75 per cent RDF coupled with 25 per cent N through organic sources viz., FYM, wheat cut straw and gliricidia and 75 per cent RDF to succeeding season recorded 6.55, 6.11 and 6.23 energy use efficiency which was at par with each other during second year only, whereas flexibility observed during first year. The non-significant results were observed in the treatments where optimum and sub-optimum levels of fertility in *rabi* and preceded by optimum and sub-optimum levels without organic sources during *kharif* season that means the energy use efficiency was decreased to some extent in these treatments. The energy use efficiency obtained in the control treatment during both the years was 2.59 and 1.88, respectively.

4.5.3 Energy studies of sorghum-wheat crop sequence

The data pertaining to energy output (MJ ha^{-1}), energy input (MJ ha^{-1}), energy balance (MJ ha^{-1}), energy balance per unit input (MJ ha^{-1}) and energy use efficiency of the crop sequence as influenced by different treatments tried during study period are presented in Table 59 and depicted graphically in Fig. 12.

Table 59. Effect of integrated nutrient management system on energy output, energy input, energy balance, energy balance per unit input and energy use efficiency in sorghum and wheat crop sequence

Sr. No.	Treatments		Energy output (MJ ha^{-1})			Energy input (MJ ha^{-1})		
	Kharif sorghum	*Rabi* wheat	1999	2000	Pooled mean	1999	2000	Mean
1.	Control (No fertilizers)	Control (No fertilizers)	54675	68697	61686	25251	25206	25229
2.	50% RDF	100% RDF	289378	315934	302656	39916	39870	39893
3.	75% RDF	75% RDF	322141	292112	307127	39916	39870	39893
4.	100% RDF	100% RDF	368748	345546	357147	44788	44512	44650
5.	50% RDF + 50% N (FYM)	100% RDF	401546	354438	377992	43943	43968	43956
6.	75% RDF + 25% N (FYM)	75% RDF	329524	336288	332906	41929	41919	41924
7.	50% RDF + 50% N (WCS)	100% RDF	311188	305489	308339	44163	43840	44002
8.	75% RDF + 25% N (WCS)	75% RDF	320841	313282	317062	42034	41861	41948
9.	50% RDF + 50% N (GLM)	100% RDF	354801	318809	336805	57670	59604	58637
10.	75% RDF + 25% N (GLM)	75% RDF	330118	312805	321462	48793	49743	49268
	S.E. ±		5483	10672	11621	-	-	-
	C.D. at 5%		15909	30967	37143	-	-	-
	General mean		308296	296340	302318	42840	43039	42940

Table 59 (Contd…)

Sr. No.	Treatments		Energy balance (MJ ha^{-1})			Energy balance/unit input (MJ $^{ha-1}$)			Energy use efficiency		
	Kharif sorghum	*Rabi* wheat	1999	2000	Pooled mean	1999	2000	Mean	1999	2000	Pooled mean
1.	Control (No fertilizers)	Control (No fertilizers)	29924	43492	36708	1.17	1.73	1.45	2.17	2.73	2.45
2.	50% RDF	100% RDF	249462	276064	262763	6.25	6.92	6.59	7.25	7.92	7.59
3.	75% RDF	75% RDF	282225	252242	267234	7.07	6.33	6.70	8.07	7.33	7.70
4.	100% RDF	100% RDF	323960	301035	312498	7.23	6.77	7.00	8.23	7.77	8.00
5.	50% RDF + 50% N (FYM)	100% RDF	357603	310471	334037	8.14	7.06	7.60	9.14	8.06	8.60
6.	75% RDF + 25% N (FYM)	75% RDF	287595	294369	290982	6.86	7.02	6.94	7.86	8.02	7.94
7.	50% RDF + 50% N (WCS)	100% RDF	267025	261649	264337	6.05	5.67	6.01	7.05	6.97	7.01
8.	75% RDF + 25% N (WCS)	75% RDF	278807	271421	275114	6.63	6.49	6.56	7.63	7.49	7.56
9.	50% RDF + 50% N (GLM)	100% RDF	297131	259205	278168	5.15	4.35	4.75	6.15	5.35	5.75
10.	75% RDF + 25% N (GLM)	75% RDF	281325	263062	272194	5.77	5.29	5.53	6.77	6.29	6.53
	S.E. ±		5481	10673	11756	0.122	0.241	-	0.122	0.241	0.29
	C.D. at 5%		15904	30969	37574	0.353	0.700	-	0.353	0.700	0.93
	General mean		265456	253301	259379	6.03	5.79	5.91	7.03	6.79	6.91

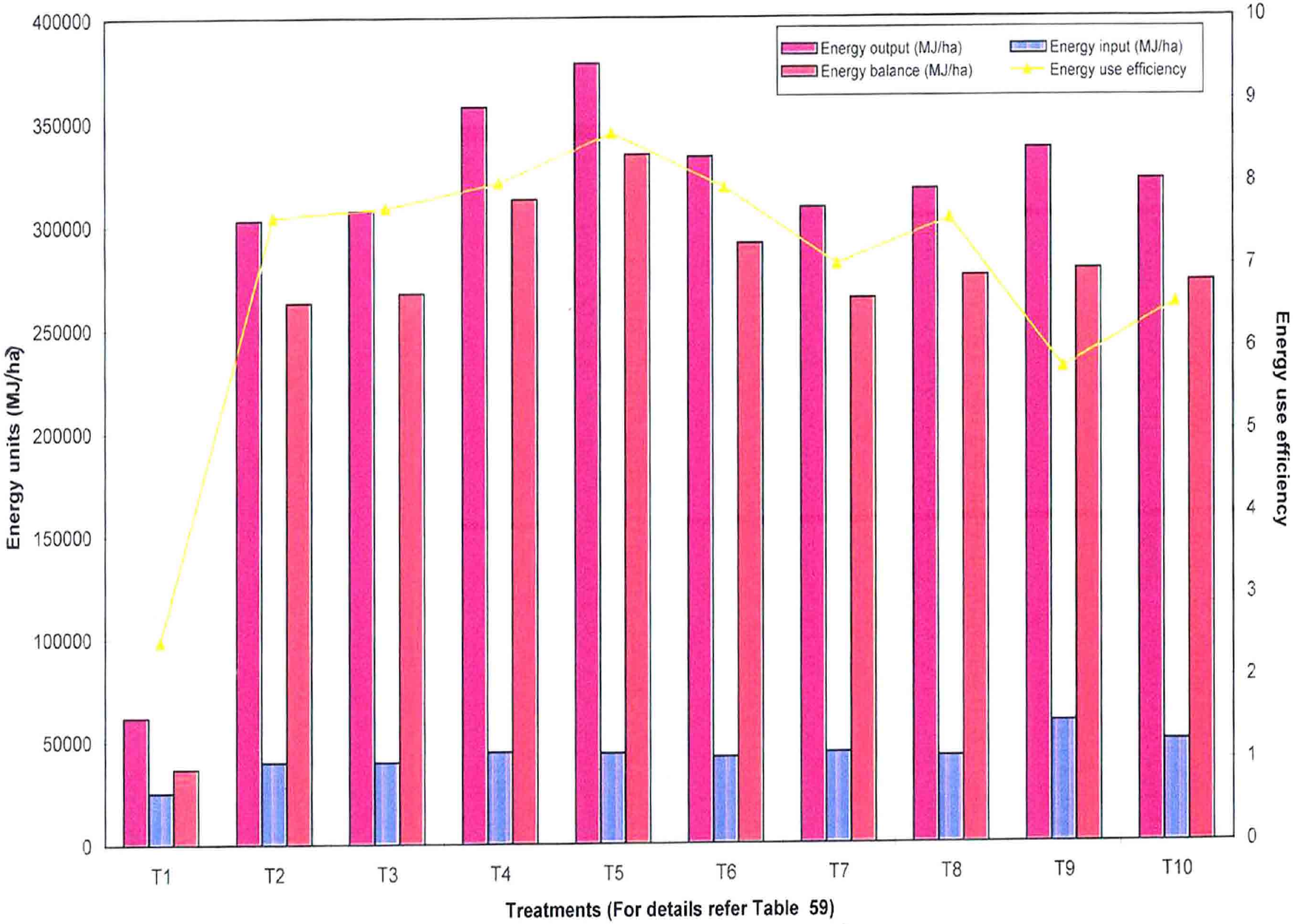


Fig. 12. Mean energy output, energy input, energy balance (MJ/ha) and energy use efficiency of sorghum-wheat crop sequence as influenced by different treatments

4.5.3.1 Energy output of crop sequence

The data pooled over seasons, indicated that average mean maximum energy output was 377992 MJ ha^{-1} whereas yearwise it was 401546 MJ ha^{-1} and 354438 MJ ha^{-1} during the year 1999 and 2000, respectively (Table 59). These values were registered in the treatment comprising of 50 per cent RDF + 50 per cent N through FYM to sorghum and 100 per cent RDF to wheat and were significantly higher than the other treatments tried during first year and were at par with the treatments comprising of 100 per cent RDF for both the crops during both the seasons and 75 per cent RDF + 25 per cent N through FYM to *kharif* sorghum and 75 per cent RDF to *rabi* wheat applied during the year 2000 (i.e. 345546 MJ ha^{-1} and 336288 MJ ha^{-1}, respectively). The organic sources viz., wheat cut straw and gliricidia compared with each other, the gliricidia use in combination with inorganic fertilizers performed better than the wheat cut straw during both the years. Higher energy output was evolved by application of gliricidia (354801 MJ ha^{-1}) than wheat cut straw (320841 MJ ha^{-1}) during first (318809 MJ ha^{-1}) and (313282 MJ ha^{-1}) during second year study, 100 per cent RDF to both the season found significantly superior over sub-optimum levels of fertilizers during both the years. The absolute control recorded minimum energy output values during both the years of study.

4.5.3.2 Energy input of crop sequence

The energy values presented in Table 59, revealed that average maximum mean energy input obtained was 58637 MJ ha^{-1} whereas yearwise it was 57670 and 59604 MJ ha^{-1} during first and second year of study. These values were registered through application of gliricidia leaves into the sequence, whereas other sources viz., FYM and wheat cut straw used recorded 43943 and 43968 MJ ha^{-1} and 44163 and 43840 MJ ha^{-1}, respectively during first and second year of study. The application of 100 per cent recommended dose to each crop in a sequence recorded higher energy input values (44788 and 44512 MJ ha^{-1}) than organic sources considered for N substitution except gliricidia manuring and use of sub-optimum levels of inorganic fertilizers to sequential crops during both the years of experimentation. The control treatment registered minimum (25251 and 25206 MJ ha^{-1}) energy input values during study period.

4.5.3.3 Energy balance of crop sequence

The data presented in Table 59 revealed that the mean highest energy balance registered by the sorghum-wheat crop sequence was 334037 MJ ha^{-1} (pooled mean over two years) and yearwise, it was 357603 MJ ha^{-1} during 1999 and 310471 MJ ha^{-1} during 2000 obtained due to 100 per cent RDF to wheat preceded by 50 per cent RDF + 50 per cent N through FYM to sorghum. The mean energy balance differed significantly due to the different treatments tried during first year whereas they were at par with the treatments comprising of 100 per cent RDF to both the crops and 75 per cent RDF + 25 per cent N through FYM to sorghum and 75 per cent RDF to wheat applied during second year of experimentation. The energy balance of the crop sequence obtained by other organic sources viz., wheat cut straw and gliricidia leaves used for N substitution ranged from 267025 to 297131 MJ ha^{-1} and from 261649 to 263062 MJ ha^{-1} during first and second year, respectively. Thus, gliricidia was found to be more effective in respect of energy balance. In other treatments having no use of organic source and the fertilizers were used only in a reduced proportions to RDF exhibited decreasing trend in energy balance of the sequence during both the years and was significantly deceased the energy balance due to sub-optimum levels of fertilizers applied to both the crops in a sequence. The absence of fertilizer and manure showed minimum energy balance of crops or crop sequence.

4.5.3.4 Energy balance per unit input

The maximum mean energy balance per unit input on pooled mean basis for both the years was 7.60 MJ ha^{-1} obtained due to the application of 50 per cent RDF coupled with 50 per cent N through FYM to *kharif* sorghum and 100 per cent RDF to wheat (Table 59). The mean maximum energy balance per unit input was 8.14 and 7.06 MJ ha^{-1} obtained by the same treatment during the year 1999 and 2000, respectively. This energy balance per unit input was significantly higher than that registered in the rest of all the treatments during first year and it was at par with the treatment involving 50 per cent RDF + 100 per cent RDF (6.92), 100 per cent RDF + 100 per cent RDF (6.77), 75 per cent RDF + 25 per cent N through FYM to *kharif* and 75 per cent RDF to *rabi* (7.02) and 75 per cent RDF + 25 per cent N through wheat cut straw during *kharif* and 75 per cent RDF during *rabi* (6.49) applied during second year of experimentation. The gliricidia leaves in combination with sub-optimum levels of fertilizers during *kharif* and 100 per cent and 75 per cent RDF during *rabi* crop registered the lowest energy balance per unit input during both the years. This might be due to higher energy input values added to sequence. Control treatment has recorded the least value of energy balance per unit input for both the years of experimentation.

4.5.3.5 Energy use efficiency of crop sequence

The two years average mean energy use efficiency value of the crop sequence was 8.60 and yearwise it was 9.14 and 8.06 for the year 1999 and 2000, respectively (Table 59).

The energy use efficiency obtained by the treatment consisting of 50 per cent RDF + 50 per cent N through FYM applied to *kharif* sorghum and 100 per cent RDF applied to wheat during both the years of study was significantly higher than the other treatments tried during first year and it was at par with the treatments comprising of 50 per cent RDF at *kharif* to sorghum and 100 per cent RDF to *rabi* wheat (7.92), 100 per cent RDF to both the crops during both the seasons (7.77), 75 per cent RDF + 25 per cent N through FYM during *kharif* and 75 per cent RDF to wheat (8.02) and 75 per cent RDF + 25 per cent N through wheat cut straw during *kharif* and 75 per cent RDF to wheat (7.49) applied during the second year of experiment. The use of gliricidia leaf manure in combination with 50 or 75 per cent RDF during *kharif* and 100 or 75 per cent RDF during *rabi* decreased the energy use efficiency during both the years. Decreasing trend in energy use efficiency was also noticed where decreasing levels of inorganic fertilizers were used in experiment during both the years. The energy use efficiency was very low in absolute control treatment.

5. DISCUSSION

Sorghum-wheat cropping system has become very important production system and contributes to about one third of cereal production. Among the various crop sequences identified, sorghum-wheat in irrigated uplands is the most productive and profitable sequence even though it is cereal-cereal based system. This system is most popular among the farmers owing to the fact that these two cereals are highly productive because of advent of new hybrids in sorghum and dwarf high yielding varieties in wheat. The farmers are also aware of the new hybrids and the dwarf varieties required higher doses of fertilizer to get high yields because of the high productivity of both these crops in this system, the average monetary returns are also high. However, to make this system more sustainable new agrotechniques pertaining to integrated nutrient management system are required to be developed.

For development of integrated nutrient management for major cropping systems to make them more productive and sustainable, a field experiment on "Integrated nutrient management system for productivity potential of sorghum-wheat sequence under irrigated conditions" was conducted at Main Centre for Cropping Systems Research Project (AICARP), Rahuri (Maharashtra). It involves the use of chemical fertilizers alone and in conjunction with organic manures viz., farm yard manure, wheat cut straw and gliricidia leaves. Complementary use of available renewable heritages of plant nutrients alongwith the mineral fertilizers is of great important for maintenance of soil physical and chemical fertility on sustainable basis. The important soil physical characteristics comprising of soil structure, soil porosity, water holding capacity, hydraulic conductivity and bulk density, etc. However, the use of organic manures, crop residues and green manuring along with fertilizers is receiving attention in the intensive farming under integrated nutrient management system concept. The shift in the emphasis from yield per unit area for each crop to yield per unit area per unit time and per unit input has resulted in an intensive cropping programme which rapidly depletes the soil nutrient and thus decreases crop production. It has now become amply clear that there should be judicious use of organics and inorganic material to restore soil fertility as well as enhancing the crop productivity. In the recent past review indicated the nutrient uptake far exceeds than the addition in the soil. In view of this the present investigation was carried out to study the long term effects of the use of fertilizers and organic manures in crop sequence on the contents of available nutrients and micronutrients, physical properties of soil, total crop productivity, economics, energy budgeting and sustainability of sorghum-wheat sequence in vertisol. The present investigation was undertaken during the year 1999 and 2000 *kharif* and *rabi* seasons. The results of the present investigation are reported in previous chapter and thoroughly discussed in this chapter.

Soil, weather and crop development

The analysis of soil of the experimental plot at the commencement of experiment showed that the soil was medium black with clay in texture, low in available nitrogen (153 kg ha^{-1}), medium in available phosphorus (14 kg ha^{-1}) and rich in available potassium content (496 kg ha^{-1}) and slightly alkaline in reaction. The soils are grouped under the order vertisol. The experimental field was fairly uniform with 0.6 to 0.9 m depth and well drained. It was thus suitable to grow sorghum crop during *kharif* season and wheat during *rabi* season. The sorghum during *kharif* and wheat in *rabi* were sown in time during both the years of experimentation. The emergence and plant stand was satisfactory for sorghum and wheat during both the years.

The climate is one of the important parameters, which mostly decides the growth and yield of crops. During the entire growth period of sorghum (June to October), the mean maximum temperature ranged from 27.9°C to 35.5°C and mean minimum temperature ranged from 13.4°C to 22.8°C during 1999, while the corresponding values for the year 2000 were 28.1°C to 33.4°C and 13.5°C to 22.8°C, respectively. The mean relative humidity during morning and evening ranged from 74 to 91 and 43 to 75 per cent during 1999 and corresponding values for 2000 were 78 to 93 and 28 to 78 per cent, resepectively (Fig 1. and Fig. 2).

The receipt of rainfall during *kharif* was 730.2 mm and 644.7 mm with 48 and 29 rainy days during 1999 and 2000, respectively. The distribution of rainfall during the growth period of *kharif* crop was satisfactory during 1999 and 2000 year of experimentation. This has helped in inducing optimum growth of sorghum crop.

During *rabi* season (November to March) the mean maximum temperature ranged from 26.5°C to 35.3°C in 1999 and 24.4°C to 35.0°C in 2000, respectively. The corresponding values of the mean minimum temperature were 6.6°C to 15.9°C and 7.7°C to 16.0°C during first and second year of experimentation, respectively. The mean relative humidity varied from 56 to 97 and 48 to 87 per cent during morning hours and it ranged from 15 to 44 and 17 to 44 per cent during evening hours in the year 1999 and 2000, respectively (Table 1 and 2). During *rabi* 1999 no rainfall was received, however, during 2000 very meagre quantity of rainfall (7.8 mm) was received in two rainy days i.e. at the tillering stage of crop, benefitted the growth of wheat, resulting in improving the productive tillering nature of wheat to some extent in the second year as compared to first year. By and large, during both the years, the season was congenial for growth and productivity of *kharif* and *rabi* crops. However, there was mild incidence of shootfly and earhead webworm on sorghum during both the years and the crop was protected by adopting timely plant protection schedule resultantly this has not caused any notable reduction in the productivity of sorghum. During both the seasons of wheat, the crop was not suffered due to any pest and disease and hence not affected its growth and productivity.

In this chapter attempts have been made to discuss the effect of integrated nutrient management system on the cereal-cereal base crop sequence (sorghum and wheat) on the growth and yield attributes, their yields, protein content, monetary returns, uptake of nutrients, nutrient balance, energy balance and sorghum grain equivalence have been assessed and discussed by considering following six categories.

1. Effect of integrated nutrient management system on sorghum crop.
2. Effect of integrated nutrient management system on wheat crop.
3. Effect of integrated nutrient management system on sorghum-wheat crop sequence.
4. Effect of integrated nutrient management on the nutrient availability and soil properties.
5. Effect of integrated nutrient management on economic evaluation.
6. Effect of integrated nutrient management on energy studies.

5.1 Effect of integrated nutrient management system on sorghum crop.

Initial and final plant stand of sorghum was maintained (Table 12) at 99.6 per cent to initial mean during season of experimentation and did not differ significantly at both the stages due to integrated nutrient management system. This has formed common seat for comparison of different treatments eliminating the population as a source of variation.

The sorghum reached up its growth in terms of plant height upto harvest in both the seasons and attained the maximum (Table 13) plant height to the tune of 204.70 and 155.65 cm per plant during first and second year of experimentation, respectively. However, the growth in terms of height was at the faster rate during thirty to ninety days after sowing during both the seasons and continued thereafter upto harvest but at the lower rate and reached its maximum at harvest. It has been observed that sorghum attained more height by the application of inorganic fertilizers in conjunction with organic manures at 25 and 50 per cent N substitution through gliricidia leaf manure and FYM. Whereas, the substitution of nitrogen through wheat cut straw had an adverse effect on height of sorghum during its growth period. This might be attributed to artifact that for decomposition of straw the available N in the soil would have been utilized by soil microbes which resultantly affected the growth in terms of plant in height of sorghum (Bangar, 1994). Similar behaviour of sorghum in integrated nutrient management system was reported by earlier workers such as Gangwar and Singh (1992) and Kumar (1993). Nitrogen is well recognized as a promoter of vegetative growth. Thus increased availability of N through different N management practices in general resulted in higher values of plant height during the seasons of investigation. A significant improvement in height of sorghum was recorded with application of nitrogen

(Kumar, 1993; Deshmukh *et al.*, 1996 and Barik *et al.*, 1998). Tallest plant was observed in 75 per cent RDF + 25 per cent N substituted through green leaf manure i.e. gliricidia at the early stage of the crop but in the subsequent three stages it was noticed with the N substituted through FYM at 50 or 25 per cent level. This might be due to higher quantity of gliricidia applied to crop which resultantly showed their beneficial effect during early stage whereas FYM is the slow releasing N source found beneficial during subsequent stages of crop.

The number of functional leaves and total leaf area per unit ground area is an important indicator of total source available to the plant for the production of photosynthates, which accumulate in the developing sink (grain). All the N management techniques recorded substantially higher number of leaves and subsequently LAI compared to control during the two seasons of investigation. Nitrogen application increased number of leaves per plant (Kumar, 1993; Dashora, 1998) and thus increases LAI reported by Kumawat and Bansal (1996) and Barik *et al.* (1998). Amongst the organic sources used for substitution of nitrogen the source viz., FYM and gliricidia performed better than the wheat cut straw at 30 and 60 days after sowing during both the years of experimentation. Kumar (1993) also reported that application of FYM 20 t ha^{-1} increased the leaf area. Maximum leaf area (48.29 dm^2) was due to 100 per cent RDF to sorghum at 60 DAS which might be due to immediate availability and maximum utilization of all nutrients applied through inorganic fertilizers (Table 15). Same trend in LAI was observed during both the years of experimentation. Similar results were also reported by earlier researchers (Hirpara *et al.*, 1992; Kumawat and Bansal, 1996 and Dahsora, 1998). Such an increase in LAI when compared to that in control plot was quite obvious due to low availability of N in control plot and hence adequate nutrient supply from inorganic and organic sources of N resulted in better performance of the LAI.

Early flowering of sorghum started in the treatment where 50 per cent RDF + 50 per cent substitution of N through FYM during both the years of experimentation closely followed by gliricidia used with 75 per cent RDF whereas wheat cut straw application along with inorganic fertilizers prolonged the flowering by 5 to 10 days. While in case of varying levels of inorganic fertilizers delayed the 50% flowering by about 2 to 3 days during both the years. In control treatment, where no application of nutrients was done to the crop, delayed the 50 per cent flowering by about 15 to 17 days than the other treatments (Table 17). A significant reduction in days to bloom with increasing levels of nitrogen was also reported by Devasenapathy and Subbarayalu (1986); Poonia (1997) and Dashora (1998). It could be pointed out that the use of applied fertilizer of any kind hastened the flowering and was beneficial for early maturity and harvesting so that, the field can be vacated early for succeeding crop in the sequence.

Nitrogen application strategy showed remarkably higher dry matter production compared to control. The findings were in line with the earlier results of Kudosomannar *et al.* (1980). At early part of the crop growth comparable dry matter production was observed among inorganic and organic sources of N fertilizers used indicating the sufficiency of lower N doses as the crop takes time for re-establishment before being able to utilize the applied N. In the next three stages, application of N either in inorganic form or coupled with organic sources recorded considerably the highest dry matter production. Such improvement in dry matter production could be attributed to optimum availability of N at the later crop growth period. Amongst the organic sources viz., FYM, wheat cut straw and gliricidia used for N substitution along with the inorganic fertilizers, the higher dry matter production per plant of sorghum was attained by the source of FYM during all the intervals of the crop growth. Similar findings corroborate the results reported by Brechelt (1991), Gangwar and Singh(1992) and Kumar (1993). However, when compared with different levels (50, 75 and 100 per cent RDF) of inorganic fertilizers applied to the crop, higher dry matter production was observed with the treatment 75 per cent RDF at 30 DAS (4.62 g) while it was higher from 100 per cent RDF at 60 DAS (74.21 g), 90 DAS (223.34 g) and at harvest (230.42 g) (Table 18). These findings confirmed the earlier report of Reddy *et al.*(1988); Raj and Patel (1989); Malik *et al.* (1992) and Dashora (1998).

The performance of sorghum as assessed by important yield attributes viz., length and girth of earhead, weight of earhead, grain weight per earhead, number of grains per earhead and test weight of sorhgum grains (Table 19 and 20) indicated that the values of the parameters viz., length and girth were significantly more in treatment of 50 per cent RDF + 50 per cent N through fYM (30.45 and 29.30 cm and 28.60 and 28.85 cm at 90 DAS and at harvest during 1999 and 2000, respectively. Whereas corresponding values of girth of earhead were in the order of 21.45 and 15.90 cm and 19.40 and 17.55 cm. The girth of earhead of sorghum reduced down at harvest which was maximum in the treatment where 50 per cent RDF + 50 per cent N through FYM applied during first year and 75 per cent RDF + 25 per cent N through FYM applied during second year which were significantly superior than 25 or 50 per cent N through wheat cut straw along with 75 or 100 per cent RDF. The length of earhead at harvest was also higher due to 50 per cent RDF + 50 per cent N through FYM (29.30 cm) and by the treatment comprising of 50 per cent RDF

+ 50 per cent N through FYM (30.00 cm) during first and second year of experimentation, respectively. This might be due to the timely availability of nutrients and moisture to the crop during their growth period which ultimately reflected on improvement in the productivity of crop. The data on mean weight of earhead revealed that maximum weight (101.51 g) was registered in the treatment 50 per cent RDF + 50 per cent N through FYM applied during first year was significantly superior over only 50 per cent RDF + 50 per cent N through wheat cut straw and control and 119.80 g in which 75 per cent RDF + 25 per cent N through FYM added during second year and was significantly higher than weight obtained by 75 per cent RDF + 25 per cent N through wheat cut straw and control (Table 20). Similar trend was noticed in grain weight per earhead of sorghum during both the year of experiments. The number of grains per earhead was maximum (3451) due to 50 per cent RDF + 50 per cent N through FYM during first year and it was maximum and significantly higher (3487) in the treatment comprising of 100 per cent RDF during second year, thus indicating that the use of either inorganic or organic source along with inorganic fertilizers did not affect the number of grains per earhead of sorghum. These findings are in conformity with these reported by Jadhav (1994), Mohmmad *et al.* (1995), Kumawat and Bansal (1996) and Singh *et al.* (1996). According to individual year data on 100 grain weight, it was noted that maximum hundred grain weight of sorghum was registered by the treatment consisting of only 100 per cent RDF (2.529 g) and 75 per cent RDF (2.760 g) of inorganic fertilizers applied during first and second year of experimentation. These findings were almost similar to those of earlier workers like Jadhav (1994) and Mohmmad *et al.* (1995). The minimum availability of N in control plot resulted in poor growth performance of the crop, which was ultimately reflected in the lowest yield attributes among all the N management methods. The ear length, ear girth, ear weight, grain weight per ear, grain number per ear and test weight of sorghum grains were substantially higher in integrated nutrient management system than control. This might be due to better availability of N from organic and inorganic sources at different critical physiological stages which might be favoured better growth of sorghum. However, remarkable variation in earhead and grain weight and number of grains per earhead was observed during the two years of experimentation which might be due to seasonal effect.

In cereal-cereal base crop sequence, nutrient management is of greater importance as it stimulates better crop growth and higher grain production. Nutrients should be made available to the crop in right quantity and on time for economizing nutrient use. Ensuring adequate availability of N during crop growth is a pre-requisite for higher grain yield. In present study, use of organic sources like FYM, wheat cut straw and gliricidia leaf manure combined with inorganic sources of nutrients are compared with varying levels of inorganic fertilizers matches the crop demand at different physiological stages and reduces the losses through denitrification and volatilization as reflected in recording the highest grain yield. Thus the increased availability of nutrients at distinct physiological phases would have supported for better assimilation of photosynthates towards grain. Increase in grain yield can also be attributed to favourable effect of accelerating the growth and yield characters. The data in respect of grain yield of sorghum revealed that the application of 50 per cent RDF coupled with 50 per cent N through FYM produced the highest (54.25 and 49.03 q ha^{-1}) grain yield during 1999 and 2000, respectively (Table 21). Whereas treatment comprising of 50 or 25 per cent N substituted through gliricidia manure combined with 50 or 75 per cent RDF ranked second to superior treatment. However, 100 per cent RDF was at par with superior treatment for both the years. From this, it could be clearly inferred that there is scope for reduction in fertilizer dose at certain level when combined with organic source like FYM or gliricidia leaf manure. These findings confirmed the earlier reports of Raghuvanshi and Umat (1994); Singh *et al.* (1996); Patil (1997); Dashora (1998); Patil *et al.* (1999) and Patidar (2000). In the case of fodder yield, the treatment involving use of 50 per cent recommended dose of fertilizers in conjunction with 50 per cent N through FYM recorded significantly superior yield than all other treatments during first year only.

It is implicit from the above inferences that nitrogen management methods had pronounced effect on the fodder yield of sorghum. Among the N substitution through organic manures like FYM, wheat cut straw and gliricidia, it could be observed that FYM ranked the first followed by gliricidia and wheat cut straw application over the years. Thus, in the long run, the dose of NPK fertilizers could be reduced to 50 per cent by substitution of N through these organic sources. The mean maximum biological yield produced was 140.15 q ha^{-1} obtained due to 50 per cent RDF + 50 per cent N through FYM followed by 100 per cent RDF (134.35 q ha^{-1}), however other treatments were non-significant. It might be due to the yield fluctuations reflected owing to the seasonal effect.

The fodder to grain ratio obtained from organic sources viz., FYM, wheat cut straw and gliricidia leaves applied to sorghum crop along with 50 per cent RDF was in the range from 1.85 to 1.89 and 1.39 to 1.79 during first and second year study, respectively. However, for varying levels of fertilizers viz., 50, 75 and 100 per cent RDF, the corresponding values were 2.03, 1.91 and 1.84 during first year and 1.47, 1.62 and 1.53 in the second year respectively.

This might be due to decreased grain and fodder yields by different levels of inorganic fertilizers used (Table 21).

The treatments comprising the application of organic sources viz., FYM, wheat cut straw and gliricidia for N substitution along with 75 per cent RDF recorded higher mean harvest indices of 37.38, 36.91 and 39.21, respectively and it was lowered down to 38.82 to 33.38 where inorganic fertilizer levels were tried. The decrease or increase in harvest indices due to use of organic or inorganic sources of fertilizers were dependent on yield levels of grain and fodder for which seasonal effect was also responsible for variation in yields to some what extent. Similar results have also been reported by Meghwanshi (1992); Kumawat and Bansal (1996); Poonia (1997); Sharma and Jain (1997) and Dashora (1998).

5.2 Effect of integrated nutrient management system on wheat crop

The initial plant population was uniform in all the treatments during both years. The differences in initial plant population were not significant due to different treatments under study. Thus eliminated the population as a source of variation. For second year the number of plants/m length was lower as compared to first year. The mean plant population per meter length was 82.93 (Table 22). The plant height of wheat was significantly higher with an advancement in age of the crop and reached maximum at harvest. The differences in mean plant height recorded at various phases of crop growth were significant due to levels of fertilizers applied for both the crops included in sequence. The mean plant height was maximum during entire growth of crop due to application of 120+60+ 60 kg N, P_2O_5 and K_2O ha^{-1} (RDF) (84.12 cm) than the rest of the reduced levels tried during both the years of experimentation. Similar results were also reported by Patel *et al.* (1995), Wadile (1995) and Auti (1996).

The functional leaves per plant increased to the tune of 6.51 to 7.09 with an advancement in the age of the plant upto 60 DAS in both the years (Table 24). The number of functional leaves increased due to application of organic sources viz., FYM and gliricidia to preceding crop and reducing trend was noticed due to wheat cut straw application to previous crop. Among the inorganic fertilizers used in 50, 75 and 100 per cent RDF levels for first crop and 75 to 100 per cent levels of RDF to second crop showed somewhat reducing trend in number of leaves in wheat as compared to organic sources applied to previous crop of sorghum. This could be attributed to the significant residual effect of organic sources applied in sequence. These findings are in line with the earlier reports of Auti (1980), Nikam (1985) and Barve (1987).

The leaf area per plant was increased rapidly upto 60 DAS and thereafter decreased subsequently due to 100 per cent RDF during first and second year, respectively. It was in higher order from 1.01 to 2.01 dm^2 and 0.77 to 1.01 dm^2 at 30 DAS for both the year. At 60 DAS, maximum leaf area (4.35 dm^2 and 2.89 dm^2) was recorded by the treatment 100 per cent RDF to wheat which was preceded by 50 per cent N through FYM and 50 per cent N through wheat cut straw to *kharif* sorghum during first and second year, respectively (Table 25). This could be attributed to application of optimum fertilizer along with the organic sources viz., FYM, wheat cut straw and gliricidia to previous crop and optimum dose of fertilizer to wheat reflected in increase in leaf area per plant of wheat. Same results were also reported by Jadhav (1989), Awasti and Surajbhan (1993) and Ashokkumar *et al.* (1994).

The optimum levels of fertilizers produced significantly higher number of tillers than those produced by lower levels of fertilizer at all the growth phases. The maximum i.e. 3.05 and 3.02 tillers per plant at 60 DAS in both the years, respectively produced with the application of 100 per cent RDF to wheat preceded with 50 per cent RDF + 50 per cent N through FYM to sorghum and same trend was noticed at the another stages of crop growth (Table 26). The mortality of tillers started thereafter. This might be due to suppressing effect of main shoots right from beginning to harvest and due to the shy tillering habit of the cultivar under study. These findings are in the line with the earlier results of Singh *et al.* (1993), Mishra *et al.* (1994), Singh *et al.* (1995) and Auti (1996).

The total dry matter accumulated per plant was increased with an advancement in age. The dry matter per plant of wheat at harvest was 5.30 and 5.50 g due to 100 per cent RDF to wheat preceded by 50 per cent RDF + 50 per cent N substituted through FYM for sorghum during first and second year of experimentation, respectively (Table 27). In general, optimum and suboptimum levels of fertilizers applied to *rabi* crop preceded with N substitution through organic sources viz., gliricidia, wheat cut straw and FYM to *kharif* crop are responsible for an increment in dry matter production. Nitrogen application strategy showed remarkably higher dry matter production as compared to the control. At early part of crop growth almost comparable dry matter production was observed among optimum and suboptimum levels of RDF indicating the sufficiency of lower N dose as the crop take time for re-establishment before being able to utilize the applied N. In the next three stages, application of N along with organic sources to previous crop recorded considerably the higher DMP. Such improvement in DMP could be attributed to optimum availability of N at the delayed crop growth. The similar results were also reported by Singh *et al.* (1993), Wadile (1995), Auti (1996) and Raundal *et al.* (1999).

The yield attributes viz., productive tillers, length of panicle, spikelets per panicle, number of grains per panicle, grain weight per panicle and test weight were at the higher magnitude when wheat was preceded by application of organic sources viz., FYM, wheat cut straw and gliricidia in combination with inorganic fertilizers to previous crop and optimum and suboptimum levels of fertilizers to succeeding crop. The values of these characters increased significantly with every successive increased level of nitrogen and were maximum due to application of hundred per cent recommended dose of nitrogen applied to wheat crop and 50 per cent RDF + 50 per cent N through FYM to preceding crop of sorghum. The respective values of these parameters under the above treatment were 0.97 and 0.98 for productive tillers, 8.65 cm and 9.88 cm for length of panicle, 16.0 and 18.1 for number of spikelets per panicle, 41.75 and 46.70 for number of grains per panicle, 1.96 g and 1.79 g for grain weight per panicle and 4.35 g and 4.10 g for hundred grain weight during first and second year of experimentation, respectively (Table 28). This might be due to better availability of N from organic and inorganic sources at different critical physiological stages which favoured better growth of wheat as evidenced by increased tiller numbers, LAI and consequently higher dry matter production. These findings also confirmed the earlier report of Patel (1999). The low availability of N in control plot resulted in poor growth performance of crop, which was ultimately reflected in the lowest yield attributes among all the N management methods.

The maximum and significantly higher grain yield was obtained by the 100 per cent RDF to wheat and preceded with 50 per cent RDF + 50 per cent

N through FYM to sorghum (44.49 and 42.64 q ha^{-1}) for first and second year, respectively. The other sources like wheat cut straw and gliricidia leaves when applied during to sorghum, residual effect was observed on the increase of grain yield of wheat (39.52 and 39.67 q ha^{-1} over years) with application of 100 per cent RDF to wheat (Table 29). It was noticed that wheat when fertilized with optimum or suboptimum levels of fertilizers preceded either by FYM, wheat cut straw or gliricidia leaves in lower proportion were affected drastically, indicating superiority of higher quantity of FYM, gliricidia or wheat cut straw during both the years. Among the N substitution through organic manures like FYM, wheat cut straw and gliricidia, FYM ranked the first followed by gliricidia leaves and wheat cut straw over years. Ensuring adequate availability of N during the crop growth is a pre-requisite for higher grain yield. In the present study, the strategy of applying the recommended dose of N in optimum or suboptimum levels of fertilizers preceded with N substitution through organic sources during *kharif* season matched the crop demands at different physiological stages and reduced the losses through denitrification and volatilization as reflected in recording the highest grain yield. Thus the increased availability of nutrient at distinct physiological phases would have been supported for better assimilation of photosynthates towards grain. Increase in grain yield can also be attributed to favourable effect of accelerating the growth and yield characters. Thus, in the long run, the dose of NPK fertilizers could be reduced to some extent by substitution of N through these organic manures. Similar findings have also been reported by many workers (Sonar and Zende, 1984; Bhat *et al.*, 1991; Maskina, 1993; Hegde, 1996; Patil, 1997; Patil *et al.*, 1999 and Singh *et al.*, 1999) under integrated nutrient management in cereal-cereal sequence. The control treatment recorded minimum grain yield during both the seasons. As discussed earlier, the poor growth and yield components in control treatment may be the reason for decrease in yield and invariably resulted in drastic yield loss as compared to the best treatment. The straw yield followed the similar trend as that of grain yield in the two seasons. Nitrogen management methods had pronounced effect in straw yield. The effective N management under two splits along with organic manuring during *kharif* and two splits with only N fertilizers during *rabi* (i.e. at basal application and top dressing at grand growth stage i.e. tillering stage) had enhanced the leaves, tillers and dry matter production of the crop. Such a positive influence on the growth parameter resulted in higher straw yield (62.98 q ha^{-1}) over all the other N management practices. This was in agreement with the earlier findings of Patil (1997). The higher expression of growth characters due to addition of organic and inorganic sources of nutrients across the season might have been resulted in more straw yield compared to no fertilizers (control). The per hectare total biomass production obtained with recommended dose of fertilizer of 120+60+ 60 kg N, P_2O_5 and K_2O ha^{-1} for *rabi* and preceded with 50 per cent RDF + 50 per cent N through FYM was the highest (102.27 and 110.81 q ha^{-1}) and was significantly more than that recorded in reduced level of fertilizers during both the years followed by 100 per cent RDF and 50 per cent RDF + 50 per cent N through wheat cut straw or gliricidia for both the crop during both the years. The residual nutrient status might be responsible for improving the yield of total biomass of succeeding crop of wheat in sorghum-wheat cropping system. While studying the effect of nitrogen, potassium and zinc on growth and yield of wheat, Patel *et al.* (1995) reported that grain and straw yield increased only upto the application of 120 kg N ha^{-1}. Further increase in N level was not found beneficial. The improvement in yield under 120 kg N ha^{-1} might be due to improvement in growth and yield attributing characters and higher photosynthetic activities at higher level of N. Grain and straw yields of wheat with 60 kg K_2O ha^{-1} were significantly higher than no K application which directly played a role in cellular metabolism and reflected in improved growth and yield attributing characters, which ultimately resulted into higher yield. Similar results have been reported by Singh *et al.* (1995), Wadile (1995) and Auti (1996). Among the different treatments tried, maximum mean straw to grain ratio was obtained through use of 100 and 75 per cent RDF for the first and second year, respectively. In general, 100 per cent RDF during *rabi* along with use of organic sources to preceding crop might be responsible for improvement in straw to grain ratio of wheat. The carry over effect of fertility levels applied through organic manures + fertilizers in sorghum revealed that 75 and 100 per cent RDF significantly differed the harvest index values over control during each year of investigation. However, the harvest index was at par with the treatment comprising of 100 and 75 per cent RDF during *rabi* preceded with 50 per cent RDF + 50 per cent N through wheat cut straw and 75 per cent RDF only during *kharif* season. As far as integrated nutrient management was concerned, the harvest index in almost all the N management methods was comparable during each year of investigation. These findings are in conformity with the earlier report of Singh *et al.* (1995), Wadile (1995), Auti (1996); Patil (1997) and Patil (1999).

The maximum grain equivalence in terms of sorghum grains was recorded in treatment involving use of 50 per cent N substitution through FYM plus 50 per cent RDF (122.29 q ha^{-1}) followed by 100 per cent RDF and 50 per cent RDF + 50 per cent N through gliricidia leaves (108.90 q ha^{-1}). The lowest grain equivalence of 12.11 q ha^{-1} was obtained in absolute control plot. Same trend was noticed in second year of experimentation (Table 30).

In general, the study on sorghum grain equivalence revealed that the treatments involving use of organic manures for substitution of N along with balance dose of fertilizers recorded the highest grain equivalence as compared to the sub-optimum levels of fertilizers without organic manures.

5.3 Effect of integrated nutrient management on sorghum-wheat sequence

The sustainability of cropping sequence was also judged by the total productivity in terms of total biological main produce of crops which remain stable or increased it's stability in a crop sequence. The SYI over 17 years of the crop cycle viz., sorghum and wheat as influenced by addition of organic sources viz., FYM, wheat cut straw and gliricidia leaves clearly indicated that the treatments involving application of different organic manures, recorded the highest crop productivity and SYI with increased trend in fertilizer use efficiency of N. The average productivity of sorghum 50.63 and wheat 37.31 q ha^{-1} yr^{-1}, respectively was recorded in the treatment consisting of 50 per cent RDF + 50 per cent N through FYM and 100 per cent RDF to sorghum and wheat, respectively followed by 100 per cent RDF for sorghum (48.17 q ha^{-1} yr^{-1}), 50 per cent N through wheat cut straw + 50 per cent NPK to sorghum and 100 per cent RDF to wheat (35.49 q ha^{-1} yr^{-1}) (Table 31). Similar observations were registered by Raghwanshi and Umat (1994); Patil *et al.* (1995); Hegde (1996) and Patidar (2000) under integrated nutrient management in cereal-cereal sequence. The data on sustainability yield index (SYI) indicated reduction in its values in the treatments involving the use of chemical fertilizers alone. However, SYI was improved or maintained in the treatments involving use of either FYM or wheat cut straw or gliricidia leaves in combination with fertilizers every year to *kharif* season. Maximum SYI for sorghum (0.66) and wheat (0.75) was observed in treatment consisting of 50 per cent NPK dose + 50 per cent N through FYM for sorghum and 100 per cent RDF to wheat and this was in agreement with the findings of Sidhu *et al.* (1993); Patil *et al.*(1995) and Patil (1997).

5.4 Effect of integrated nutrient management on nutrient availability and soil properties

The NPK uptake by sorghum grain and fodder in the inorganic and organic sources of fertilizers were significantly superior to control. On pooled mean basis, the highest (200.74, 30.73 and 176.09 kg ha^{-1}) uptake of N, P and K was observed in the treatment involving 50 per cent NPK plus 50 per cent N substituted through FYM (Table 32 to 34). As expected, 100 per cent NPK application and 50 per cent N substitution through FYM, wheat cut straw and gliricidia leaves significantly enhanced the NPK content and uptake by *kharif* sorghum over control and reduced levels of fertilizers. Significant influence of organic manures viz., FYM, wheat cut straw and gliricidia leaves on nutrient content and uptake values have also been reported by Narkhede and Ghugare (1987) and Raghuwanshi and Umat (1994) under integrated nutrient management in cereal-cereal rotational experiments. In the present study the highest uptake of N was recorded with the addition of N in two splits at basal and 30 DAS in combination with organic sources. This higher uptake of N could be attributed to better availability of nutrient as a result of adequate supply of N after the establishment of the crop. Higher dose of N added to the soil along with organic manures and proper irrigation practices might have reduced the N losses and enhanced the N uptake. Considerable enhancement in P and K uptake at maturity was recorded in all the N management techniques over control. Nutrient uptake being function of both dry matter production and the nutrient concentration of the dry matter, higher values of dry matter production recorded in these treatments have resulted in more uptake of nutrients.

Regular application of NPK fertilizers either alone or in combination with FYM, wheat cut straw and gliricidia leaves with proper irrigation management significantly increased available N content over no fertilizer treatments. Substitution of N by 25 per cent or 50 per cent through organic manures along with balanced application of P and K through chemical fertilizers proved to be superior to treatments involving chemical fertilizers alone. However, the available N in control plots had markedly lowered down due to continuous cropping. The integration of organic (FYM) and inorganic fertilizers on N basis in proportion of 1:1 was found significantly superior (236.8 and 240.5 kg N ha^{-1} for both the years, respectively) to build up the nitrogen status in the soil after harvest of sorghum during years of experimentation (Table 35). Data also indicated build up of available N with the use of organic manures in conjunction with NPK fertilizers as could be seen from the available N status of soil before and after harvest of crops in sequence. Next to FYM, wheat cut straw treatment was found to be better followed by gliricidia leaves, where cumulative influence of organic manures has manifested. The improvement in N status of soil by addition of organic and inorganic N was in line with the earlier findings of Patil *et al.* (1993), Thind *et al.* (1993); Patil (1997) and Patidar (2000).

Application of optimum level of chemical fertilizers alone or in combination with organic manures for 50 per cent N substitution invariably showed improvement in available P status over sub-optimum levels of fertilizers and control treatments during both the seasons. The available P status after harvest of sorghum ranged from 8.36 to 18.96 kg ha^{-1}. The available P status in control plot had appreciably gone down with continuous cropping but regular addition of optimum dose of NPK alone or in combination with FYM, wheat cut straw and gliricidia leaves supplementation coupled with proper irrigation management techniques indicated its favourable influence in maintaining P status of soil. Similar trend of available P status was noticed during second year also except wheat cut straw application found superior. However, there was no consistent relationship in the rest of the treatments. Yaduwanshi and Tripathi (1983), Acharya and Bishnoi (1988), Udaisoorian (1990), Thind *et al.* (1993) and Patil (1997) also explained the significant positive role of different organic manures along with fertilizers on build up of available P status of soil in cereal-cereal rotations under long term experiment. The use of FYM for the substitution of 50 per cent N along with 50 per cent N through inorganic fertilizers was found significantly superior as they have produced 630.0 and 645.1 kg ha^{-1} during both the years of experimentation, respectively over the rest of the treatments in respect of K status of soil after sorghum whereas, there was no specific trend for building the residual fertility of potassium in soil due to the integration of different sources of organics in combination with an inorganic fertilizers. This might be due to the application of FYM firstly mineralize the nutrients and slowly releasing them upon the action of microorganism with lapse of time. Secondly because of mineralization process, the losses of nutrients either through leaching or volatilization might have been restricted. Verma *et al.* (1987), Bhardwaj and Omanwar (1994) and Patil (1997) have also reported similar results.

The nitrogen uptake through grain (119.70 kg ha^{-1}), straw (68.33 kg ha^{-1}) and total uptake (188.05 kg ha^{-1}) by wheat crop in sorghum-wheat crop sequence was found significantly higher due to 100 per cent fertilizer dose applied to wheat and 50 per cent RDF + 50 per cent N substitution through FYM to preceding crop of sorghum during both the years. This might be due to the higher residual fertility of nitrogen after harvest of previous crop. The fertility was built up due to use of FYM as a source of organic manure for substitution of 50 per cent N (Table 36). It also helped to improve the soil physical conditions. This has made the soil condition congenial for microbial activity as a result there was increased N use efficiency of added fertilizers. The similar trend was observed in case of phosphorus and potassium uptake by wheat crop. In general, application of organic manures viz., FYM, wheat cut straw and gliricidia leaves enhanced the uptake of nutrients remarkably. It can be expected due to beneficial effect of organic manures on the soil physical properties which favoured availability of nutrients. These results are in conformity with the results of More and Ghonsikar (1984), Gaur (1992), Raghuwanshi and Umat (1994) and Patil (1997) in sorghum-wheat cropping system under integrated nutrient management and reported that application of organic manures improved water holding capacity and soil structure which provides better environment for root development and aeration.

The nutrient status viz., N, P and K in soil after completion of sorghum wheat cropping sequence as influenced by integrated nutrient management for sorghum during *kharif* season and optimum and sub-optimum levels of inorganic fertilizers for wheat crop during *rabi* season indicated that the residual fertility of soil was significantly influenced except for phosphorus during 1999 year of experimentation. The conjoint use of organic manure as FYM and inorganic fertilizer on N basis in 1:1 proportion to fulfill the requirement of RDF was very much useful to maintain the soil fertility in respect of N, P and K after harvest of two crops in the sorghum-wheat cropping sequence. The magnitude of sustaining the soil fertility in respect of N, P and K pooled over after harvest of two crops in sorghum-wheat crop sequence was the highest in 50 per cent substitution of N through FYM (233.60, 17.18 and 674.40 kg ha^{-1}) followed by 25 per cent substitution of N through FYM and 50 per cent substitution of N through wheat cut straw and gliricidia leaves, respectively coupled with inorganic fertilizer levels (Table 39). There was no consistency for potassium fertility due to integration of nutrient through organic and inorganic fertilizers. The results are similar to those obtained by other investigators (Bhakare *et al.*, 1991; Thind *et al.*, 1993; Bharadwaj and Omanwar, 1994 and Patil, 1997).

In general, sustainability of nutrient fertility of soil after completion of sorghum-wheat cropping sequence was possible by using the different sources of organic manures irrespective of inorganic sources. The trend in sustaining the residual fertility due to organic manures was in the order of FYM > gliricidia leaf manure > wheat cut straw. However, in second crop of sorghum-wheat sequence with 100 per cent recommended dose of fertilizers was found beneficial to sustain the reduced soil fertility followed by 75 per cent recommended dose of fertilizers. Patil *et al.* (1999) and Patidar (2000) have also reported similar results.

The nutrient balance after harvest of sorghum and wheat crop determined in sorghum-wheat crop sequence and was assessed to check the gain or deficit observed due to use of organic and inorganic fertilizers. The added and inherent soil nutrient utilized by sorghum crop in sorghum-wheat sequence was significantly influenced by the integrated nutrient management for sorhgum crop. The data indicated that the application of 50 per cent RDF in combination with 50 per cent nitrogen through FYM (39.2 kg N ha^{-1}), 100 per cent recommended dose of fertilizers (13.4 kg N ha^{-1}) and 50 per cent RDF along with 50 per cent N through wheat cut straw (5.9 kg N ha^{-1}) were found beneficial to provide the nutrients to sorghum crop during its growth period (Table 40). This might be due to the addition of organic manures as a 50 per cent substitute for nitrogen governing the phenomenon of mineralization of nutrients. The nutrient mineralization is an important phenomenon in soil to avoid the nutrient loss and also for nutrient supply to crop plants during their growth period. Similar results were reported by Bhakare *et al.* (1991).

Addition of organic manures also provides an energy to soil organisms as a result it helped to improve the efficiency of soil microorganism which increase the use efficiency of added nutrients and also increased the availability of inherent soil nutrients. However, the influence of fertility levels on N balance indicated that the use of 50 per cent and 75 per cent recommended dose of fertilizers the sorghum crop showed the negative value of N status in soil. These results showed that 50 or 25 per cent reduction in nitrogen to sorghum crop severely suffered for its growth and development. The other sources of organic manures viz., wheat cut straw and gliricidia leaves coupled with 75 per cent RDF were not found beneficial for supply of balanced nutrient to sorghum crop (Table 40). In general, the use of FYM for substitution of nitrogen in combination with 50 and 75 per cent RDF and 50 per cent RDF along with 50 per cent N substitution through wheat cut straw were beneficial for balance nutrient supply to sorghum crop. In general, the use of FYM for substitution of nitrogen in combination with 50 and 75 per cent recommended dose and 50 per cent RDF along with 50 per cent nitrogen substitution through wheat straw were beneficial for balanced nutrient supply to sorghum crop.

However, use of inorganic fertilizers alone and use of gliricidia and wheat straw for 25 per cent nitrogen substitution adversely affected the balanced nutrient supply for sorghum crop in respect of nitrogen.

The nutrient balance of nitrogen to wheat crop was influenced by the use of 100 per cent RDF each of both crops and 50 per cent RDF + 50 per cent N substitution through FYM applied to previous sorghum crop and 100 per cent RDF to wheat, respectively were found to deficient in supply of nutrient to crop in the tune of -14.9, -14.6 and -5.5, -4.7 kg ha^{-1} during 1999 and 2000 years of experimentation, respectively (Table 41). The negative value of nitrogen indicated that the wheat crop fulfill its need of nitrogen apart from added and inherent nutrient status. This might be due to the previous sorghum crop was fertilized with organic manures along with recommended dose of fertilizers that helped in sustaining the microbial population and their activities during crop growth period of wheat which fulfilled the requirement of nitrogen of wheat crop. Secondly, since at the harvest of sorghum crop, the nitrogen status of soil was less probably because of added quantity of organic manures mineralized nitrogen content. The mineralized nitrogen content might become available to succeeding crop. Therefore, there were negative values in respect of nitrogen nutrient balance to wheat crop.

The phosphorus nutrient balance to sorghum crop in sorghum-wheat cropping sequence was influenced by the conjoint use of organic and inorganic fertilizers as well as inorganic fertilizers only but they did not show consistent relationship in respect of phosphorus nutrient balance to sorghum crop. However, the highest P nutrient apparent loss was noticed in the treatment 50 per cent RDF + 50 per cent N substituted through FYM (-63.0 and –78.2 kg ha^{-1}) followed by 75 per cent RDF + 25 per cent N through FYM (-52.0 and -54.19 kg ha^{-1}) during the year 1999 and 2000, respectively (Table 42).

The phosphorus nutrient balance to wheat crop in sorghum-wheat crop sequence as influenced by the use of optimum and sub-optimum levels of fertilizers to wheat preceded by conjoint use of organic and inorganic fertilizers to *kharif* sorghum but did not show consistent relationship in respect of phosphorus nutrient balance to wheat crop. However, significant phosphorus balance was not available in soil after harvest of wheat in sorghum-wheat crop sequence during study period (Table 43). Similar results were reported by Bhakare *et al.* (1991).

The effect of inorganic fertilizers alone and in combination with organic fertilizers on nutrient availbility of potassium to sorghum crop revealed that the supply of potassium either through organic manures or an inorganic fertilizers get fixed in soil as a results unavailable to crop and hence all the values of potassium nutrient balance of sorghum crop were negative. The fixation of potassium is a natural phenomenon occurred in soil to maintain the equilibrium of potassium. However, it was more pronounced in 50 per cent RDF + 50 per cent N substituted through wheat cut straw (-117.6 kg ha^{-1}) followed by 75 per cent RDF + 25 per cent N through wheat cut straw (-98.0 kg ha^{-1}) and 50 per cent RDF + 50 per cent N through gliricidia leaves (-81.2 kg ha^{-1}) applied to *kharif* sorghum during first year of experimentation. Whereas, it was more pronounced during second year of experimentation in 50 per cent RDF + 50 per cent N through gliricidia leaves (-72.6 kg ha^{-1}) followed by 75 per cent RDF + 25 per cent N through gliricidia (-48.3 kg ha^{-1}) applied during *kharif* season (Table 44).

The potassium nutrient status for wheat crop in *rabi* season due to application of either 75 per cent RDF or 100 per cent RDF to wheat was found beneficial to maintain the nutrient balance in respect of potassium. It was in the range from 2.8 to 89.6 kg ha^{-1} and 1.1 to 42.0 kg ha^{-1} during first and second year of experimentation, respectively. This might be due to potassium applied to previous crop (sorghum) was fixed in soil to maintain the equilibrium. However, during succeeding crop (wheat) there was again addition of potassium through 75 per cent and 100 per cent RDF that increased the equilibrium level of potassium in soil as a result potassium availability increased to the wheat crop. The highest mean positive K balance of 89.6 kg ha^{-1} was recorded at 100 per cent RDF to wheat preceded by 50 per cent RDF + 50 per cent N through gliricidia leaves applied to sorghum in first season during first year followed by 42.0 kg ha^{-1} under same treatment during second season (Table 45).

The conjoint use of organic and inorganic fertilizers to sorghum and inorganic fertilizers to wheat crop did not exhibited significant effect on soil reaction (pH) during both the years of experimentation. This might be due to buffering capacity of soil. Similar results were also reported by Chaudhary *et al.* (1981). Khiani and More (1984) and Patil (1997).

The electrical conductivity of the soil before and after experimentation did not indicate appreciable change due to continuous application of chemical fertilizers and organic manures over years. This might be due balanced application of fertilizers in combination with organic manures which did not affect the EC by accumulation of salts. Khiani and More (1984). Bhrigwanshi (1988) and Patil (1997) have also reported similar results.

The organic carbon content of soil after harvest of sorghum as well as wheat crop was significantly influenced by conjoint use of organic and inorganic fertilizers to sorghum and also by the graded levels of recommended dose of fertilizers to wheat crop. The use of organic sources viz., FYM, wheat cut straw and gliricidia leaves etc. as the substitute for nitrogen along with an inorganic fertilizers were found beneficial to increase the organic carbon content of soil. Organic carbon content varied from 0.38 to 0.73 per cent before sowing of sorghum and was slightly increased at harvest of crop (Table 48). This might be due to the use of organic manures adding the more amount of organic matter in the soil resulted in rise of organic carbon content in soil. Build up of organic carbon due to continuous application of organic manures and fertilizers, which could be ascribed to addition of organic matter and also proliferation of roots as evidenced by higher biomass production. These results corroborate the findings of More (1994) and Patil (1997) for FYM, Bhat *et al.* (1991) and Patil (1997) for green manuring and Varvel (1994) and Patil (1997) for increased rates of fertilizers added continuously over long period in cereal-cereal rotations.

The bulk density had increased slightly with increased levels of inorganic fertilizers, whereas, application of FYM, wheat cut straw and gliricidia leaves in conjunction with chemical fertilizers reduced the bulk density. The bulk density had increased with increased dose of NPK fertilizers from 50, 75 and 100 per cent RDF to both the crops (ranged from 1.29 to 1.31 Mg m^{-3}). However, the bulk density reduced to 1.25, 1.22 and 1.26 Mg m^{-3} in respect of 50 per cent N substituted through FYM, wheat cut straw and gliricidia green manuring (94.7, 92.4 and 95.5 per cent over control) respectively to sorghum as against 1.32 Mg m^{-3} under control (untreated plot).

The increase in bulk density was mainly due to deterioration of the structure of soil by continuous use of chemical fertilizers. The decrease in bulk density may be due to improvement in structural status of soil by judicious application of organic manure in combination with chemical fertilizers. Bangar (1991); Lomte *et al.* (1993), Bellakki and Badanur (1994) and Patil (1997) also reported similar results indicating the changes in bulk density due to application of chemical fertilizers individually or along with different organic manures for a long period.

The treatments receiving FYM, wheat cut straw and gliricidia leaves manure in conjunction with inorganic fertilizers judiciously every year to sorghum, the infiltration rate of soil remarkably increased as compared to other treatments and it was registered higher infiltration rate with the range from 0.88 to 0.92 cm hr^{-1}. On other hand, there was short change in infiltration rate due to continuous use of chemical fertilizers observed in the range from 0.76 to 0.78 cm hr^{-1} (Table 49). The findings are in conformity with the results obtained by various workers under long term experiments (Magar *et al.*, 1983; Bangar, 1991; Ghuman *et al.*, 1997 and Patil, 1997).

The hydraulic conductivity of the soil was significantly affected due to addition of organic manures viz., wheat cut straw, FYM and gliricidia leaves. The hydraulic conductivity of soil was higher (1.94 cm hr^{-1}) in treatment involving 50 per cent RDF + 50 per cent N through wheat cut straw to sorghum and 100 per cent RDF to wheat and was significantly more than rest of the treatments followed by use of FYM and gliricidia leaves for substitution of nitrogen coupled with 50 per cent RDF to sorghum and 100 per cent RDF to wheat (1.86 and 1.76 cm hr^{-1}, respectively). Use of inorganic fertilizers with varying levels during both the season reduced the hydraulic conductivity of soil. It was ranged from 1.40 to 1.42 cm hr-1 in optimum and sub-optimum levels of fertilizer alone. The similar results are reported by Bangar (1991) and Lomte *et al.* (1993)

Increased fertilizer levels from 50 to 100 per cent to both the crops, the size of water stable aggregates ranged from 0.72 to 0.75 mm which indicated that the anti-effects of chemical fertilizers on soil structure, whereas water stable aggregates increased markedly from 0.82 to 0.96 mm due to use of FYM, wheat cut straw and gliricidia manure along with chemical fertilizers showing significant impact of organic manure in improvement in soil structure thereby providing better environment for root development and aeration. These observations corroborate with the findings reported by Kumar Kuldip *et al.* (1993), Bellakki and Badanur (1994), Mishra and Sharma (1997) and Patil (1997).

Incorporation of organic manures viz., FYM, wheat cut straw and gliricidia leaves in soil in combination with balanced dose of chemical fertilizers showed a contrasting and striking feature on organic matter content in soil at the end of experimentation as compared to the effects of chemical fertilizers alone. However, cumulative effect of NPK fertilizers over years maintained the level of organic matter in soil (0.79 to 0.96 per cent) as that of unfertilized plot (0.67 per cent). Supplementation of N either through FYM, wheat cut straw or gliricidia green manuring in conjoint with chemical fertilizers invariably increased the organic matter status of soil (1.10 to 1.27 per cent). These observations are in conformity with the results reported by various investigators (Sinha *et al.*, 1980; Gaur, 1992; Kumar Kuldip *et al.*, 1993; Bellakki and Badanur, 1994; Ghuman *et al.*, 1997 and Patil, 1997).

In general, continuous application of fertilizers in combination with organic manures viz., FYM, wheat cut straw and gliricidia leaves manure in continuous cropping improved the infiltration rate, size of water stable aggregates, organic matter content of soil and decreased bulk density of soil over their initial values. Among the organic manures, FYM application was found to be the most effective followed by incorporation of wheat cut straw and green manuring with gliricidia leaves. The results are in agreement with the findings reported by Patil (1997).

At the end of the experimentation soils were examined for DTPA extractable Fe, Mn, Zn and Cu content and found that Fe content was significantly higher in 100 per cent RDF applied to each of the crop during experimentation. However, when compared among the organic sources, use of gliricidia leaf manure for substitution of N in 50 or 25 per cent level coupled with 50 or 75 per cent RDF to sorghum and optimum or sub-optimum level of fertilizer to wheat was significantly superior in respect of Fe content (5.49 mg kg^{-1}) in soil whereas, the treatment comprising of 50 per cent RDF + 50 per cent N through FYM applied to sorghum and 100 per cent RDF applied to wheat in inorganic form was significantly superior in respect of Mn and Zn (24.89 and 0.84 mg kg^{-1}) content in soil. The maximum value of Cu content (2.38 mg kg^{-1}) was observed in treatment where 50 per cent RDF + 50 per cent N through FYM for sorghum and 100 per cent RDF applied for wheat crop. In general, Fe and Cu content in soil were higher in 100 and 75 per cent RDF applied to each of crop in a year through inorganic fertilizers alone. Whereas the micronutrient contents (viz., Mn and Zn) in soil were higher in integrated nutrient management involving 50 per cent N substitution through either FYM or wheat cut straw or gliricidia leaves as green manure over reduced dose of fertilizers. It might be due to fertilizers carrying thee nutrients as impurities and organic manures supporting enhanced microbial activity and consequently release of organic complexing substances (chelating agents) which would make micronutrient cations in soluble forms. The results are in agreement with the findings reported by Biswas and Benbi (1989), Thind *et al.* (1993) and Patil (1997).

The microbial status of the soil as measured at the end of present investigation indicated that the total microbial biomass in soil obtained was significantly more due to application of FYM for the substitution of 50 per cent N along with 50 per cent RDF to sorghum and 100 per cent RDF to wheat (53.46 $\mu g\ g^{-1}$ soil) in sorghum-wheat crop sequence followed by use of gliricidia leaves for substitution of N (51.67 $\mu g\ g^{-1}$ soil). However, the use of only inorganic fertilizers without organic manures reduced the microbial biomass significantly (Table 51). The reduced microbial biomass in soil by the use of only fertilizers might be due to the fact that an inorganic fertilizers could not supply the sufficient energy to microorganisms, while carbon supplied sufficient energy through organic fertilizers.

The bacterial population was significantly increased (31.7 CFU $10^4\ g^{-1}$ soil) by the use of 50 per cent RDF + 50 per cent N through gliricidia leaves for sorghum and 100 per cent RDF for wheat crop. The combined use of 50 per cent RDF and 50 per cent N substitution through wheat cut straw was found beneficial for fungi population in soil (47.5 CFU $10^3\ g^{-1}$ soil). However, the population of actinomycetes, azotobacter and phosphorus solubilizing bacteria were significantly higher due to use of 50 per cent RDF and 50 per cent nitrogen through FYM to sorghum and 100 per cent RDF to wheat crop in sorghum-wheat cropping sequence. The respective values were 68.1, 17.3 and

24.8 CFU $\times 10^{5}$ g^{-1} soil, respectively (Table 51). In general, the conjoint use of organic and inorganic fertilizers as a source of nutrients in sorghum-wheat cropping sequence were beneficial for improving and sustaining the microbial biomass as well as population in soil. The use of inorganic fertilizers alone to sorghum-wheat cropping sequence had an adverse effect on microbial biomass and population in soil. The results are in agreement with the findings reported by Albequrque and Patel (1955), Kamat (1978) and Nambiar (1994).

An integrated nutrient management for sorghum-wheat cropping sequence was significantly influenced the protein content in sorghum as well as in wheat grains during the year of experimentation. However, there was no consistent relationship in the values of protein content of sorghum and wheat by the use of organic and inorganic fertilizers but they were higher in conjoint use of organic and inorganic fertilizers as compared to inorganic fertilizers alone. On pooled mean basis, the protein yield was higher (7.26 q ha^{-1} for sorghum and 6.82 q ha^{-1} for wheat) due to application of 50 per cent RDF + 50 per cent N substituted through FYM to sorghum and 100 per cent RDF to wheat (Table 53). Similar results have also been reported by Wadile (1995), Thakur *et al.* (1999) and Kehar Singh and Balyan (2000).

5.5 Effect of integrated nutrient management on economic evaluation

The evaluation of sorghum-wheat crop sequence under integrated nutrient management technique was assessed on the basis of gross and net monetary returns and B:C ratio of different crops under study and cropping sequence as a whole at the end of present investigation and it was clearly brought out that the maximum net monetary returns were fetched due to 100 per cent recommended dose of fertilizers during first (Rs. 9665 ha^{-1}) and second (Rs. 5871 ha^{-1}) year, which were closely followed by the treatment comprising of 50 per cent RDF + 50 per cent N through FYM applied to sorghum. Among the organic sources, wheat cut straw has showed very poor performance in respect of net monetary returns (Table 54). It might be due to the poor decomposing ability at initial stage resultantly, which might have increased the C:N ratio and reduced the nutrient availability to the current crop led to low yield. Similarly, reduced levels of inorganic fertilizers showed the reducing trend in respect of net monetary returns during both the years of experimentation.

The B:C ratio obtained from application of 100 per cent RDF for both the years was significantly superior (1.55 and 1.34) and was followed by 50 per cent RDF + 50 per cent N through FYM (1.41 and 1.24) applied during first year and 50 or 75 per cent RDF + 50 or 25 per cent N through gliricidia leaves applied during second year of study The wheat cut straw application seemed to be not beneficial in respect of B:C ratio as compared to other sources applied to *kharif* sorghum. This has not given immediate effect to current crop. Similar trend was also noticed due to use of sub-optimum levels of fertilizers applied to sorghum.

In case of wheat crop, the highest gross (Rs. 29576) and net monetary returns (Rs. 14295) per hectare were obtained by the treatment consisting of 100 per cent RDF during *rabi* and preceded by 50 per cent RDF coupled with 50 per cent N through FYM during *kharif* and found significantly superior over rest of all the treatments during both the years of study.

Rest of treatments were not affected significantly in respect of gross and net monetary returns ha^{-1} to wheat crop. Residual effect of organic sources in 1:1 proportion enhanced the gross and net returns ha^{-1} of wheat over reduced level of fertilizer and control. Reduced levels of fertilizers showed reducing trend and absolute control resulted in loss in net profit ha^{-1} during both the years. The significant B:C ratio(1.94) was recorded by the treatment consisting of 50 per cent RDF + 50 per cent N through FYM during *kharif* succeeded with 100 per cent RDF to *rabi* crop. The reducing levels of inorganic fertilizers during *kharif* and *rabi* season reduced the B:C ratio. However, when compared to other sources with reduced level of RDF B:C ratio was increased to some extent but not reached the level of significance.

The profitability of the sorghum-wheat cropping sequence under integrated nutrient management system the organic source viz., FYM applied to sorghum in combination with 50per cent RDF and to wheat, 100 per cent RDF brought out significant increase in mean net returns (Rs. 20540 ha^{-1}) followed by 100 per cent RDF to both the crops during both the years of experimentation (Rs.18960 ha^{-1}). Among the organic sources, FYM ranked the first and gliricidia was the second one while wheat cut straw has influenced in reducing the net monetary returns ha^{-1} from sequence. Use of sub-optimum levels of fertilizers reduced the level of net profit of sequence whereas, absolute control had registered the loss in net returns. The findings are in conformity with the results obtained by Patidar (2000).

The higher benefit:cost ratio (1.66 and 1.53) was recorded due to use of 50 per cent RDF + 50 per cent N through FYM to sorghum and 100 per cent RDF applied to wheat and was significantly higher than rest of all the treatments except 100 per cent RDF applied for both the crops during both the years of study which were on par with each other only in the second year.

Among the organic sources, of wheat cut straw and gliricidia, gliricidia use was significantly superior over wheat cut straw. Reduced levels of fertilizers decreased the values of B:C ratio of the sequence. Such an outcome can be expected as the grain yield obtained was found to be the lowest. This has clearly brought out that integration of organic and inorganic fertilizers in the sequence with reducing the level of inorganic fertilizers for both the crops has an added advantages to enhancing the overall net monetary returns from the cereal-cereal crop sequence though this rotation is less feasible for soil fertility point of view but acceptable for economic and total productivity point of view which is being adopted widely in command areas. The similar beneficial effects of N management practices by applying organic and inorganic fertilizers to the crops considered in the cropping sequences were reported by many workers in respect of increased monetary returns from the cropping sequences. The notable amongst them are Kurlekar *et al.* (1993); Dubey *et al.* (1997) and Patidar (2000).

5.6 Effect of integrated nutrient management on energy studies

Under integrated nutrient management system followed for sorghum crop during *kharif* season, the energy balance and energy use efficiency were assessed and the energy balance registered by sorghum crop supplied with 50 per cent RDF + substitution of 50 per cent N through FYM was the highest (241166 MJ ha^{-1} and 185320 MJ ha^{-1} during first and second year of experimentation, respectively). The significantly higher energy use efficiency was noticed from the treatment involving 50 per cent RDF coupled with 50 per cent N through FYM during first season of sorghum (14.59) whereas during second season it was highest (10.52) and at par with the treatments applied 100 per cent RDF and 50 or 75 per cent RDF coupled with 50 or 25 per cent N through FYM. Though higher energy input was invested in the treatment, the corresponding increase in energy output due to more economic yield might be the reason for increase in EUE. The use of gliricidia leaf manure in combination with 50 or 75 per cent RDF decreased the energy use efficiency during both the years. This might be due to higher values of energy input (MJ ha^{-1}) obtained due to gliricidia leaves. The lowest energy use efficiency was observed in control plot.

The average mean maximum energy balance per unit input for both the years was 11.16 MJ ha^{-1} obtained from the treatment involving 50 per cent RDF + 50 per cent N through FYM and was higher and superior over all other treatments. The energy balance per unit input was decreased and was in the range from 4.00 to 6.60 MJ ha^{-1} in the treatment where gliricidia leave manure was incorporated with the soil during both the years (Table 57). Absolute control registered the least values of energy balance per unit input during both the years. These results are in conformity with those reported by Jadhav (1986) and Patil (1997).

The energy consumed, energy output, energy balance, energy balance per unit input and energy use efficiency of wheat crop when preceded by integrated nutrient management system were of the higher order during both the seasons of experimentation and was closely followed by 100 per cent RDF during *kharif* as well as *rabi* season indicating that these treatments were equally efficient in energy utilization.

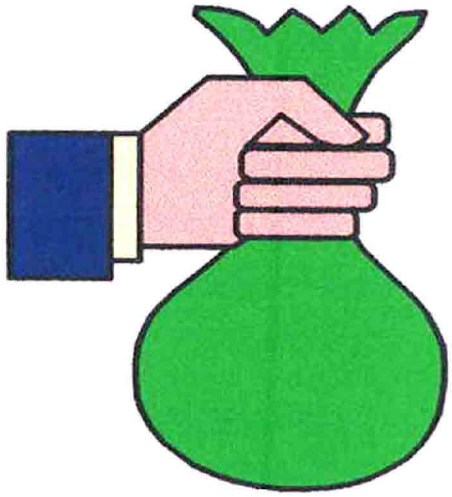
The maximum mean energy balance obtained was 115459 MJ ha^{-1} and 125102 MJ ha^{-1} during first and second year study in the treatment of application of 100 per cent RDF to *rabi* wheat preceded by the 50 per cent RDF + 50 per cent N through FYM applied to *kharif* sorghum. The energy balance recorded by the treatment having applied 100 per cent RDF for wheat preceded by 100 per cent RDF, 50 per cent RDF + 50 per cent N through wheat cut straw or gliricidia leaves to *kharif* sorghum were at par to each other during both the years of study (Table 58).

The energy balance and energy use efficiency of wheat increased with every successive increased level of RDF applied to wheat crop and the values registered with 100 per cent recommended dose of fertilizer were maximum. Similar trend in respect of energy balance per unit input and energy use efficiency of wheat crop preceded by different integrated nutrient management treatments followed during *kharif*. Though higher energy input was invested in this treatment the corresponding increase in energy output due to more economic yield might be the reason for increase in EUE. Similar trend in respect of energy balance per unit input and energy use efficiency of wheat crop preceded by different cropping systems also reported by Jadhav (1986) and Patil (1997).

The energy balance studies and energy use efficiency of sorghum wheat crop sequence indicated the superiority of the treatment comprising of 50 per cent RDF + 50 per cent N through FYM applied during *kharif* season to sorghum and 100 per cent RDF applied during *rabi* season to wheat crop. It was 357603 MJ ha^{-1} and 310471 MJ ha^{-1} during 1999 and 2000, respectively.

The energy balance of the crop sequence obtained by other organic sources viz., wheat cut straw and gliricidia leaves used for N substitution ranged from 267025 to 297131 and from 261649 to 263062 MJ ha^{-1} during first and second year, respectively. In other treatments having no use of organic sources and the fertilizers were used only in a reduced proportion to RDF exhibited decreasing trend in energy balance of the sequence during both the years. The absence of fertilizer and manure showed minimum energy balance of crops or crop sequence. The values of energy use efficiency and energy balance per unit input were also in higher order in sorghum-wheat crop sequence in different treatments comprising of use of organic and inorganic fertilizers and 100 per cent recommended dose of inorganic fertilizers only to both the crops during both the years of experimentation. This could be attributed to higher biomass production in the cropping sequence, where there was integration with the organic and inorganic fertilizers to *kharif* sorghum and optimum and sub-optimum levels of inorganic fertilizers applied to *rabi* wheat.

The yearwise mean maximum energy balance per unit input and energy use efficiency was 8.14 and 7.06 MJ ha^{-1} and 9.14 and 8.06 MJ ha^{-1}, respectively registered due to the application of 50 per cent RDF coupled with 50 per cent N through FYM to *kharif* sorghum and 100 per cent RDF to wheat (Table 59). Though higher energy input was invested in this treatment, the corresponding increase in energy output due to more economic yield might be the reason for increase in EUE and energy balance per unit input. Use of gliricidia leaves manure in combination with 50 or 75 per cent RDF to sorghum and 100 or 75 per cent RDF to wheat decreased the energy balance per unit input and energy use efficiency during both the years of study. This might be due to the higher energy input values of gliricidia reflected in reduction in these values. Decreasing trend in energy balance per unit input and energy use efficiency of the crop sequence was also noticed where decreasing levels of inorganic fertilizers were used in experiment during both the years. The energy balance per unit input and energy use efficiency was very low in absolute control treatment. The results are in conformity with the results obtained by Billore *et al.* (1994), Swaminathan *et al.* (1994), Bhatia (1995), Patil (1997) and Pawar (2000).



SUMMARY AND CONCLUSION

6. SUMMARY AND CONCLUSIONS

6.1 Summary

The present investigation was carried out at the Main Centre for Cropping System Research Project (AICARP), Mahatma Phule Krishi Vidyapeeth, Rahuri (Maharashtra) on medium black soil during the year 1999-2000 and 2000-2001 to assess the effect of integrated nutrient management system in sorghum-wheat crop sequence on growth and yield of crops along with nutrient economics and energy budgeting. An experiment was conducted with ten treatments involving use of chemical fertilizers alone and in conjunction with different organic manures viz., farm yard manure, wheat cut straw and gliricidia leaves in sorghum-wheat crop sequence. An attempt was made to develop appropriate integrated nutrient management system involving balanced proportion of chemical fertilizers and organic manures as the main components for sustaining crop productivity after 17 years of crop cycle.

The soil of experimental field was clay in texture, low in available nitrogen (153 kg ha^{-1}), medium in available phosphorus (14 kg ha^{-1}) and rich in available potassium (496 kg ha^{-1}) content and slightly alkaline in reaction (pH 8.2). The treatments consisted of three organic sources viz., FYM, wheat cut straw and gliricidia leaves used for substitution of N at 50 and 25 per cent coupled with 50 and 75 per cent recommended dose of fertilizers to *kharif* sorghum and only chemical fertilizers applied at different levels viz., 50, 75 and 100 per cent recommended dose of *kharif* crop while during *rabi* season only optimum (100 per cent RDF) and sub-optimum (75 per cent RDF) dose of inorganic fertilizers was applied to wheat. The control treatment where no organic and inorganic fertilizers were applied to both the crops during both the years of experimentation. The design adopted was randomized block with four replications. The experiment was conducted on fixed site without changing the randomization of the treatments for the successive period of two years, to assess the residual effect. The most important findings emerging from this investigation are summarized below.

6.1.1 Effect of integrated nutrient management system on sorghum

Important growth attributes of sorghum viz., plant height, number of leaves, leaf area and dry matter accumulation per plant were influenced significantly by integrated nutrient management system. It has been observed that sorghum put on more height at harvest with application of inorganic fertilizers in conjunction with organic manures at 25 and 50 per cent N substitution through FYM (173.03 cm) and gliricidia leaf manure (173.88 cm) whereas, the substitution of N through wheat cut straw had an adverse effect on height of sorghum during its growth period.

All the N management techniques recorded substantially higher number of leaves (11.88) and its LAI (8.95) compared to control (4.33 and 1.15, respectively) in the two seasons of investigations. Amongst the organic sources used for substitution of nitrogen the source viz., FYM (7.03 and 11.88) and gliricidia (6.68 and 11.78) performed better than wheat cut straw at 30 and 60 DAS during both the years of experimentation. Maximum leaf area (48.29 dm^2) was due to 100 per cent recommended dose of fertilizers to sorghum at 60 DAS which might be due to immediate availability and maximum utilization of all nutrients applied through inorganic fertilizers. Same trend in LAI was observed during both the years of experimentation. Hence adequate nutrient supply from inorganic and organic sources of N resulted in better performance of the LAI. Early flowering of sorghum started due to 50 per cent RDF + 50 per cent N through FYM followed by gliricidia use with 75 per cent RDF during both the years whereas wheat cut straw application alongwith inorganic fertilizers and varying levels of inorganic fertilizers prolongs the flowering by 5 to 10 and 2 to 3 days, respectively and in case of control the 50 per cent flowering was delayed by about 15 to 17 days.

Amongst the organic sources viz., FYM, wheat cut straw and gliricidia used for N substitution along with inorganic fertilizers, the higher dry matter weight per plant of sorghum (211.98 g) was attained by the source of farm yard manure during all the intervals of the crop growth. However, when compared with different levels (50, 75 and 100 per cent RDF) of inorganic fertilizers applied to the crop higher dry matter production was observed with the treatment 75 per cent RDF at 30 and 60 DAS while it was higher from 100 per cent RDF at 90 DAS (223.34 g) and at harvest (230.42 g). During crop growth period in the next three stages (except first stage), application of N either in inorganic form or coupled with organic sources recorded considerably the highest dry matter production.

The performance of sorghum as assessed by important yield attributes viz., length and girth of earhead, weight of earhead, grain weight per earhead, number of grains per earhead and test weight of sorghum grains at harvest indicated that the values of these parameters like length (29.65 cm) and girth (16.73 cm) of earhead were significantly more in treatment comprising of 50 per cent RDF + 50 per cent N through FYM applied to the crop during both the years of experimentation followed by 50 per cent RDF + 50 per cent N through wheat cut straw during 1st and 2nd year study, respectively. The weight of earhead (103.20 g) was registered maximum by the treatment 50 per cent RDF + 50 per cent N through gliricidia whereas mean grain weight per earhead was at higher magnitude (84.78 g) due to 100 per cent RDF to sorghum. The use of either inorganic or organic sources along with inorganic fertilizers did not affect the number of grains per earhead of sorghum. It was noted that maximum (2.53 and 2.76 g) and significantly higher hundred grain weight of sorghum was registered by the treatment consisting of only 100 and 75 per cent RDF applied during first and second year of experimentation. The minimum availability of N in control plot resulted in poor growth performance of the crop which was ultimately reflected in the expression of the lowest values of the yield attributes among all the N management methods.

The mean grain (51.64 q ha^{-1}) and fodder (88.52 q ha^{-1}) yield of sorghum pooled over seasons was significantly more with the application of 50 per cent RDF coupled with 50 per cent N through FYM whereas treatment comprising of 50 or 25 per cent N substituted through gliricidia manure combined with 50 or 75 per cent RDF ranked second to superior treatment (47.55 amd 77.35 q ha^{-1} grain and fodder yield, respectively). However, 100 per cent RDF (50 .06 and 84.30 q ha^{-1} grain and fodder yield, respectively) was at par with superior treatment for both the years. It could be clearly inferred that there exists a scope for reduction of fertilizer dose at certain level when combined with organic sources. The mean maximum biological yield produced was 140.15 q ha^{-1} obtained due to 50 per cent RDF + 50 per cent N through FYM followed by 100 per cent RDF. The fodder to grain ratio obtained from organic sources viz., FYM, wheat cut straw and gliricidia leaves applied to sorghum crop alone with 50 per cent RDF was in the range from 1.62 to 1.84. However, for varying levels of inorganic fertilizers viz., 50, 75 and 100 per cent RDF, the mean corresponding values of fodder to grain ratio pooled over seasons were 1.75, 1.77 and 1.69, respectively. Similar trend was noticed in respect of harvest indices.

6.1.2 Effect of integrated nutrient management system on wheat

The plant height of wheat was significantly higher due to levels of fertilizers applied for both the crops included in sequence. The mean plant height at harvest was maximum (84.12 cm) due to application of 120+60+60 kg N, P_2O_5 and K_2O ha^{-1} (RDF) than the control but at par with rest of the treatments. The number of functional leaves at 60 DAS (7.82) increased due to application of 50 per cent RDF + 50 per cent N substitution to FYM for sorghum and 100 per cent RDF applied to wheat and reducing trend was noticed due to wheat cut straw application and varying levels of inorganic fertilizers (50, 75 and 100 per cent RDF) to previous crop of sorghum. This could be attributed to the significant residual effect of organic sources applied in sequence. The leaf area per plant was increased rapidly upto 60 DAS (3.34 dm^{-2}) and then decreased subsequently due to 100 per cent RDF applied to wheat crop during first and second year, respectively and could be attributed to the application of organic sources viz., FYM, wheat cut straw and gliricidia to previous crop and optimum dose of fertilizer to wheat reflected in increase in leaf area per plant of wheat. Optimum and sub-optimum levels of fertilizers applied to *rabi* crop presided with N substitution through organic sources viz., gliricidia leaves, wheat cut straw and FYM to sorghum are responsible for increment in dry matter production. Nitrogen application strategy showed remarkably higher dry matter production compared to control.

The optimum levels of fertilizers applied to *rabi* crop when preceded with 50 per cent RDF + 50 per cent N through FYM to *kharif* crop produced significantly higher number of tillers (3.04) than those produced by lower levels of fertilizers at all the growth phases. The yield attributes viz., productive tillers, length of panicle, spikelets per panicle, number of grains per panicle, grain weight per panicle and test weight were at higher magnitude when wheat was fertilized with 100 per cent RDF preceded by application of 50 per cent N through FYM and optimum and sub-optimum levels of fertilizers to succeeding crop during both the years. This was followed by 50 per cent RDF + 50 per cent N through gliricida applied to sorghum and 100 per cent RDF applied to wheat. The low availability of N in control plot resulted in poor growth performance of the crop. The maximum and significantly higher (44.49 and 42.64 q ha^{-1}) grain yield was obtained by the 100 per cent RDF to wheat and preceded with 50 per cent RDF + 50 per cent N through FYM during *kharif* season for first and second year respectively. The other sources like wheat cut straw and gliricidia leaves when applied during *kharif* season to sorghum, residual effect was observed on increase of grain yield of wheat with application of 100 per cent RDF during *rabi*. It was also noticed that wheat when fertilized with optimum or sub-optimum levels of fertilizers preceded either by FYM, wheat cut straw or gliricidia leaves in lower proportion were affected drastically, indicating superiority of higher quantity of such organic sources during both the years. Thus, in the long run, the dose of NPK fertilizers could be reduced to 50 per cent by substitution of N through these organic manures. The straw yield followed the similar trend as that of grain yield in the two seasons. The per hectare total biomass production obtained with recommended dose of fertilizer for wheat and preceded with 50 per cent RDF + 50 per cent N through FYM was the highest (106.54 q ha^{-1}) and was significantly more than that recorded in reduced level of fertilizers during both the years on pooled mean basis and was differed significantly due to preceding of 50 per cent RDF + 50 per cent N through wheat cut straw and gliricidia.

Maximum mean straw to grain ratio was obtained through use of 100 per cent RDF (1.42) for both the seasons (i.e. *kharif* and *rabi*) during first year and 75 per cent RDF + 25 per cent N through FYM at *kharif* and 75 per cent RDF at *rabi* season during second year (1.75) and was significantly higher than rest of all the treatments. The mean maximum harvest index of wheat was 45.09 and 40.84 per cent during first and second year, respectively obtained due to 75 per cent RDF to wheat preceded with application of FYM and gliricidia in combination with 75 per cent RDF to *kharif* crop. The sorghum grain equivalence revealed that the treatment involving use of organic manures for substitution of N along with balanced dose of fertilizers recorded the highest grain equivalence (118.27 q ha^{-1}) as compared to the sub-optimum levels of fertilizers without organic manures.

The sustainability of cropping sequence judged by the total productivity of crops indicated that application of different organic sources, registered the highest crop productivity and SYI values with increased trend in N use efficiency. The sustainability yield index (SYI) indicated the reduction in its values in the treatments involving the use of chemical fertilizers alone. On the contrary, the SYI was improved or maintained in the treatments involving use of either FYM or wheat cut straw or gliricidia leaves in combination with fertilizers every year to *kharif* season. Maximum SYI of sorghum (0.66) and wheat (0.75) was observed due to application of 50 per cent RDF + 50 per cent N substituted through FYM for *kharif* and 100 per cent RDF to *rabi* crop involved in sequence.

6.1.3 Effect of integrated nutrient management on nutrient status and soil properties

The N, P, K uptake by sorghum grain and fodder in the fertilizer and organic manure was significantly superior to control. The highest uptake of N (200.74 kg ha^{-1}), P (30.73 kg ha^{-1}) and K (176.09 kg ha^{-1}) was observed in the treatment involving 50 per cent NPK plus 50 per cent N substituted through FYM when pooled over 2 years. As expected 100 per cent NPK application and 50 per cent N substitution through FYM, wheat cut straw and gliricidia leaves significantly enhanced the NPK content and uptake by *kharif* sorghum over control and reduced with levels of fertilizers. Similar pattern of total uptake of NPK nutrients by wheat during *rabi* including the treatment of 100 per cent dose of fertilizers alone was registered due to residual effect of FYM, wheat cut straw and gliricidia (GM) applied during *kharif*, which improved soil environment positively as compared to use of sub-optimum levels of recommended dose of fertilizers treatments and control. Application of optimum level of chemical fertilizers alone or in combination with organic manures for 50 per cent N substitution through FYM invariably showed improvement in available N (238.70 kg ha^{-1}), available P (18.00 kg ha^{-1}) and available K (637.60 kg ha^{-1}) status of soil after harvest of sorghum over sub-optimum levels of fertilizers and control treatments during both the seasons. The conjoint use of FYM as a substitute for 50 per cent nitrogen along with the 50 per cent recommended dose of fertilizers was found beneficial for building and sustaining the residual fertility of soil in respect of nitrogen, phosphorus and potassium after sorghum in sorghum-wheat crop sequence.

The conjoint use of organic manure as FYM and inorganic fertilizers in the 1:1 proportion to fulfill the requirement of recommended dose of fertilizers was very much useful to maintain the soil fertility in respect of N, P and K after harvest of two crops in the sorghum-wheat crop sequence. The trend in sustaining the residual fertility due to organic manures was in order of FYM > gliricidia leaf manure > wheat straw. However, in second crop of sorghum-wheat crop sequence with 100 per cent RDF was found beneficial to sustain the residual fertility followed by sub-optimum level of fertilizers.

Application of 50 per cent RDF in combination with 50 per cent N through FYM (39.2 kg ha^{-1}), 100 per cent RDF (13.4 kg ha^{-1}) and 50 per cent RDF plus 50 per cent N through wheat cut straw (5.9 kg ha^{-1}) were found beneficial to provide the nutrient viz., nitrogen to sorghum crop. In general, use of FYM for substitution of nitrogen in combination with 50 or 75 per cent RDF and 50 per cent RDF along with 50 per cent N through wheat cut straw were beneficial for balance nutrient supply to sorghum crop. The use of 100 per cent RDF to wheat crop where 100 per cent RDF to both the crops and 50 per cent RDF + 50 per cent N through FYM to first and 100 per cent RDF to second crop were found deficient in supply of nutrient to wheat crop. However, the negative values of nitrogen indicated that the wheat crop fulfill its need of nitrogen apart from added and inherent nutrient status of the soil.

The phosphorus nutrient balance to sorghum and wheat crop in sorghum-wheat crop sequence was influenced by the conjoint use of organic and inorganic fertilizers as well as inorganic fertilizers alone but they did not show consistent relationship in respect of phosphorus balance. The supply of potassium either through organic manures or on inorganic fertilizers to the sorghum crop got fixed in soil as a result all the values of potassium nutrient balance was negative because the fixation of K is a natural phenomenon occurred in soil to maintain the equilibrium of K. It was observed from the application either 75 or 100 per cent RDF to wheat crop in sorghum-wheat crop sequence were found beneficial to maintain the nutrient i.e. K balance. The soil reaction (pH) and electrical conductivity (EC) of the soil at the initial and post harvest had shown no appreciable change due to continuous application of chemical fertilizers and organic manures over years. The integrated nutrient management system affected the organic carbon content in soil. Use of organic sources for N substitution along with inorganic fertilizers to sorghum crop were found beneficial to increase the organic carbon content in soil and it was maintained after harvest of wheat. The bulk density was increased significantly due to increased dose of inorganic fertilizers (1.30 Mg m^{-3}) whereas it was reduced due to application of organic sources viz., FYM (1.25 Mg m^{-3}), wheat cut straw (1.22 Mg m^{-3}) and gliricidia (1.26 Mg m^{-3}) in conjunction with chemical fertilizers. The infiltration rate of soil remarkably increased due to addition of organic manure in combination with inorganic fertilizers judiciously every year. The hydraulic conductivity of soil was significantly affected due to addition of organic sources viz., wheat cut straw (1.94 cm hr^{-1}), FYM (1.86 cm hr^{-1}) and gliricidia leaves (1.76 cm hr^{-1}). Highest H.C. was recorded in the treatment involving 50 per cent RDF + 50 per cent N through wheat cut straw during *kharif* and 100 per cent RDF during *rabi* followed by use of FYM and gliricidia leaf manure. The adverse effect of chemical fertilizers on size of water stable aggregates was noticed whereas it was improved due to use of FYM, wheat straw and gliricidia leaves along with chemical fertilizers showing significant impact of organic manure in improvement in soil structure. Incorporation of organic manures viz., FYM (1.27%), wheat cut straw (1.20%) and gliricidia (1.17%) in soil in combination with proportionate dose of chemical fertilizers showed a contrasting and striking feature on organic matter content in soil after the end of experimentation as compared to the effect of chemical fertilizers alone.

The micronutrient contents (viz., Fe, Mn, Zn and Cu) in soil improved due to integrated nutrient management system involving 50 per cent N substitution through either FYM or wheat cut straw or gliricidia leaves as green manuring over reduced dose of fertilizers. However, continuous cropping with reduced RDF brought their level below the initial soil test in soil. The total microbial biomass in soil obtained was significantly more due to application of FYM for the substitution of 50 per cent N along with 50 per cent RDF for sorghum and 100 per cent RDF for wheat crop in sorghum-wheat crop sequence (53.46 µg g^{-1} soil) followed by use of gliricidia leaves for substitution of nitrogen (51.67 µg g^{-1} soil). However, use of only inorganic fertilizers without organic manures reduced the microbial biomass and their population in soil significantly.

There was no consistent relationship in the values of protein content in sorghum and wheat grains though they were higher in conjoint use of organic and inorganic fertilizers as compared to chemical fertilizers alone.

6.1.4 Effect of integrated nutrient management on economic evaluation

The higher net monetary returns (Rs. 7768) per hectare were fetched due to 100 per cent RDF closely followed by treatment comprising of 50 per cent RDF + 50 per cent N through FYM (Rs. 6242) applied to sorghum. Similar trend observed in respect of B:C ratio (1.55 and 1.41, respectively) during both the years of experimentation. Reducing trend in net monetary returns and B:C ratio was noticed due to use of sub-optimum levels of fertilizers applied to sorghum crop. In case of wheat crop, the highest gross

(Rs. 29576) and net monetary returns (Rs.13798) per hectare were obtained by treatment consisting of 100 per cent RDF during *rabi* and preceded by 50 per cent RDF + 50 per cent N through FYM applied during *kharif* and found significantly superior over rest of all other treatments during both the years of study. Same trend was noticed in B:C ratio (1.94).

The profitability of sorghum-wheat cropping sequence under integrated nutrient management system, the organic source viz., FYM applied to *kharif* season to sorghum in combination with 50 per cent RDF and during *rabi* season, 100 per cent RDF to wheat brought out significant increase in mean net returns (Rs. 20540) followed by 100 per cent RDF (Rs. 18960) to both the crops during both the years of experimentation. Among the organic sources viz., FYM ranked the first and gliricidia was the second one while wheat straw has influenced in reducing the net monetary returns ha^{-1} from sequence. Similar trend was noticed in respect of B:C ratio of the sequence. Reduced levels of fertilizers reduced net profit as well as reduced the values of B:C ratio of the sequence.

6.1.5 Effect of integrated nutrient management on energy studies

The energy balance registered by sorghum crop from the treatment involving application of 50 per cent RDF + 50 per cent N through FYM was the highest during first (241166 MJ ha^{-1}) and second (185320 MJ ha^{-1}) year of experimentation and significantly higher energy use efficiency was noticed from the same treatment during first year and it was at par with varying levels of fertilizers and reduced levels of other organic sources viz., wheat cut straw or FYM during second year. The energy balance per unit input was higher in treatment consisting of 50 per cent RDF + 50 per cent N through FYM (11.16

MJ ha^{-1}) and superior over all other treatments. The energy consumed, energy output, energy balance, energy balance per unit input and energy use efficiency of wheat crop when preceded by integrated nutrient management system were of the higher order during both the seasons of experimentation and closely followed by 100 per cent RDF during *kharif* as well as *rabi* season indicating equally efficient in energy utilization. The energy balance studies (334037 MJ ha^{-1}) and energy use efficiency (8.60) of sorghum-wheat crop sequence indicated the superiority of the treatment comprising of 50 per cent RDF + 50 per cent N through FYM applied during *kharif* season to sorghum and 100 per cent RDF applied during *rabi* season to wheat crop. The energy balance of the crop sequence obtained by other organic sources viz., wheat cut straw (275114 MJ ha^{-1}) and gliricidia leaves (278168 MJ ha^{-1}) used for N substitution showed lower range compared to superior treatment. In other treatments having no use of organic sources and the fertilizers used only in reduced proportion to RDF exhibited decreasing trend in energy balance of the sequence during both the years. The absence of fertilizers and manure i.e. control showed minimum energy balance (36708 MJ ha^{-1}) of crops or crop sequence.

6.2 Conclusions

1. The growth and yield attributing characters, grain and fodder yield of sorghum and sorghum grain equivalence were at higher magnitude due to integrated use of 50 percent recommended dose of fertilizers alongwith 50 per cent N substituted through FYM which was at par with 100 per cent recommended dose of fertilizers i.e. 120:60:60 kg NPK ha^{-1}. Among the organic sources FYM performed better followed by glaricidia and wheat straw in respect of yield potential of sorghum.

Growth and yield contributing characters and yield potential of succeding crop of wheat were substantially higher due to 100 per cent recommended dose of fertilizer to wheat preceded by 50 per cent RDF + 50 per cent N through FYM to *kharif* sorghum.

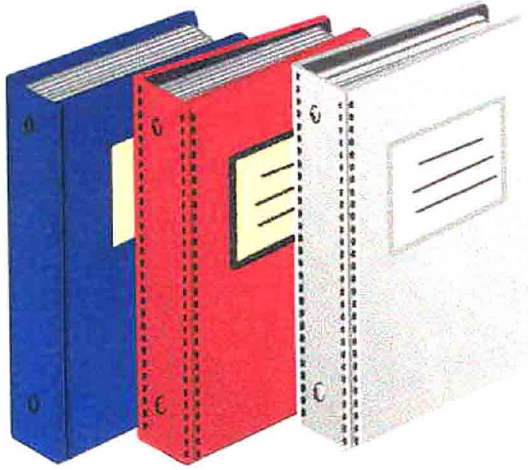
2. The highest uptake of NPK by plant available NPK and micronutrient status and nutrient balance in soil was influenced by conjoint use of organic and inorganic fertilizers as well as inorganic fertilizers alone. The trend in sustaining the residual fertility due to organic sources was in order of FYM > gliricidia leaf manure > wheat straw.

3. Incorporation of FYM, wheat straw and gli ricidia leaves for 25 to 50 per cent N substitution in conjunction with balanced dose of NPK fertilizers increased the infiltration rate, water stable aggregate and organic matter content of soil and decreased the bulk density because of this INM system and strengthened the chemical, biological and physical properties of soil.

4. The synergistic effect of organic source viz., FYM coupled with 50 per cent RDF applied to sorghum and 100 per cent RDF applied to succeeding crop of wheat showed significant increase in total productivity and sustainability yield index (SYI), net monetary returns (Rs. ha^{-1}), benefit:cost ratio, energy balance and energy use efficiency which closely followed by 100 per cent RDF to both the crops in sorghum-wheat crop sequence without any adverse effect on soil health.

RECOMMENDATION

Application of 50 per cent recommended dose of fertilizer + 50 per centN through FYM to *kharif* sorghum and 100 per cent RDF to wheat enhanced the total grain productivity, grain equivalent, energy use efficiency and monetary returns of sorghum-wheat crop sequence without any adverse effect on soil health, microflora and micronutrient assessed after 17 years of crop cycle.



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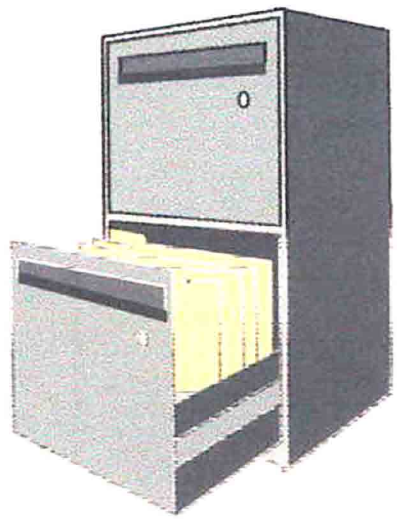

APPENDICES

8. APPENDICES

APPENDIX-I

Details of prices used for calculation of economics

Sr. No.	Particulars		Rates (1999)	Rates (2000)
1.	Labour charges	: Male	Rs.41 day^{-1} $head^{-1}$	Rs.41 day^{-1} $head^{-1}$
		: Female	Rs.41 day^{-1} $head^{-1}$	Rs.41 day^{-1} $head^{-1}$
2.	Ploughing		Rs. 75 hr^{-1}	Rs. 75 hr^{-1}
3.	Harrowing		Rs. 17 hr^{-1}	Rs. 17 hr^{-1}
4.	Cost of seed			
	(i) Sorghum		Rs.30 kg^{-1}	Rs.30 kg^{-1}
	(ii) Wheat		Rs. 12 kg^{-1}	Rs. 12 kg^{-1}
5.	Cost of fertilizers			
	(i) Urea		Rs. 3.60 kg^{-1}	Rs. 3.60 kg^{-1}
	(ii) Single super phosphate		Rs.2.80 kg^{-1}	Rs.2.80 kg^{-1}
	(iii) Muriate of potash		Rs.4.80 kg^{-1}	Rs.4.80 kg^{-1}
6.	Cost of manures			
	(i) FYM		Rs.250 mt^{-1}	Rs.250 mt^{-1}
	(ii) Wheat straw		Rs. 200 mt^{-1}	Rs. 200 mt^{-1}
	(iii) Glaricidia leaves		Rs.200 mt^{-1}	Rs.200 mt^{-1}
7.	Irrigation charges		Rs.800 ha^{-1}	Rs.800 $^{ha-1}$
8.	Insecticide and pesticides			
	(i) Endosulphan		Rs.280 lit^{-1}	Rs.280 lit^{-1}
	(ii) BHC 5%		Rs. 6 kg^{-1}	Rs. 6 kg^{-1}
	(iii) Neucron		Rs.550 lit^{-1}	Rs.550 lit^{-1}
	(iv) Dithane M-45		Rs.120 kg^{-1}	Rs.120 kg^{-1}
9.	Bullock pair		Rs.100 day^{-1} $pair^{-1}$	Rs.100 day^{-1} $pair^{-1}$
10.	Threshing and winnowing		Rs.15 q^{-1}	Rs.15 q^{-1}
11.	Main produce			
	(i) Sorghum		Rs.425 q^{-1}	Rs.425 q^{-1}
	(ii) Wheat		Rs.650 q^{-1}	Rs.650 q^{-1}
12.	By produce			
	(i) Sorghum		Rs.40 q^{-1}	Rs.40 q^{-1}
	(ii) Wheat		Rs.20 q^{-1}	Rs.20 q^{-1}

APPENDIX-II

Energy norms of different input and output

Sr. No.	Input	Unit	Energy norms (MJ)
1.	Human labour		
	Adult man	Man-h	1.96
	Adult women	Woman-h	1.57
	Children	Child-h	0.98
2.	Animal labour Bullock medium	Pair-h	10.10
3.	Machinery		
	Electric motor	Kg	64.80
	Self propelled machine	Kg	68.40
4.	Farm machinery		
	Steel	Kg	62.70
	Wood	Kg	30.80
5.	Chemical fertilizers		
	Nitrogen	Kg	60.00
	P_2O_5	Kg	11.10
	K_2O	Kg	6.70
	Chemical	Kg	120.00
6.	Farm yard manure (dry)	Kg	0.30
7.	Diesel	Lit.	56.31
8.	Electricity (1.7630 kwh)	Kwh	11.93
9.	Seed/Output		
	Cereals	(dry) kg	14.7
	Pulses	(dry) kg	14.4
	Oilseed	(dry) kg	25.0
	Sugarcane	(dry) kg	5.3
	Cotton	(dry) kg	11.8
	Cotton seed	(dry) kg	25.0
	Onion	(dry) kg	1.6
	Bye products		
	Fodder	(dry) kg	18.0
	Straw	(dry) kg	12.5
	Stalk	(dry) kg	18.0
	Sugarcane tops	(dry) kg	6.10
10.	Dung	(dry) kg	18.0
11.	Fuel wood		
	Hard	(dry) kg	20.70
	Soft	(dry) kg	18.90
	Agro waste	As per values of by products	
	Kerosene	Litre	41.30

Source : Panesar B.S. and A. B. Bhatnagar (1994). "Energy norms for inputs and outputs of agricultural sector". USG Pub., Ludhiana.

VITA

9. VITA

MADHUKAR BHIMRAJ DHONDE

A candidate for the degree

of

DOCTOR OF PHILOSOPHY (AGRICULTURE)

in

AGRONOMY

Title of thesis	:	**Integrated nutrient management system for productivity potential of sorghum-wheat sequence under irrigated condition.**
Major field	:	Agronomy

Biographical information

- Personal	:	Born at Sade, Tal. Rahuri. Dist. Ahmednagar on 1st June, 1956 in a farmer's family. Son of Shri. Bhimraj Nana Dhonde. Married with Sharadadevi, daughter of Late Shri. Laxmanrao Patil Sonawane, At. Nandgaon, Tal. Nagar, Dist. Ahmednagar on 3rd February, 1982. Having one son Mr. Satish studying D. Pharmacy course and one daughter Kum. Sonali studying in XIIth std.
- Educational	:	Passed S.S.C. Examination from Shri Shahu Vidya Mandir, Khadambe Kd., Tal. Rahuri, Dist. Ahmednagar. Received Bachelor of Science (Agri.) degree from College of Agriculture, Dhule (MPKV, Rahuri) in first class in 1979. Received Master of Science (Agri.) degree in the discipline Agronomy with First class from Mahatma Phule Krishi Vidyapeeth ,Rahuri in 1981.

Attended two refresher course, 4 short interstate training courses and one summer school.
Completed 21 years service in research, extension and management in the university.

- Professional : Selected as Jr. Research Assistant on 20.4.1981 and worked upto 30.4.1984 and then selected as Sr. Research Assistant on 1.5.1984 and worked as a Farm Manager, Agril. Research Station, Niphad (Nasik) upto 6.6.1985.

Selected as Asstt. Professor of Agronomy on 7.6.1985 and posted as Jr. Agronomist at DLA, Solapur, then transferred at Central Campus, Rahuri as Farm Manager, Cattle Project, Rahuri on 18.8.1987. Then worked as Jr. Agronomist in the Cropping System Research Project for 4 years and in Water Management Project, MPKV, Rahuri for 9½ years w.e.f. 15.10.1992 to till date.

Recognized University Teacher and Research Guide for M.Sc. (Agri.) degree published and presented totally 46 research papers, popular articles and proceedings/ abstracts in the journals of university as well as national reputed and state/national level seminars/symposia.

Published two books/bulletins on farm water management research in different commands of Maharashtra state.

Prepared and submitted eight ad-hoc project proposals to different authorities of State as well as national level for its approval. Out of which one ad-hoc project is already implemented and completed.

Having the life membership of three professional societies/organizations of the state and national level.

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