

DYNAMICS OF NITROGEN AND PHOSPHORUS IN SOIL UNDER WHEAT-MUNGBEAN-MAIZE CROPPING SEQUENCE

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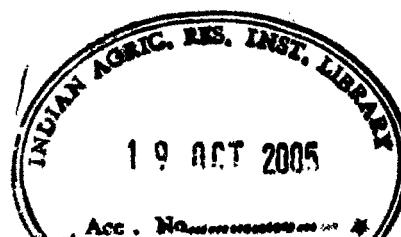


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DYNAMICS OF NITROGEN AND PHOSPHORUS IN SOIL UNDER WHEAT-MUNGBEAN-MAIZE CROPPING SEQUENCE

A Thesis

By

MAMATA BEGUM

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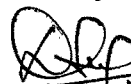
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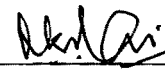
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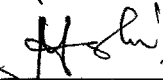

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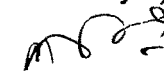
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CERTIFICATE

This is to certify that the thesis entitled, "**DYNAMICS OF NITROGEN AND PHOSPHORUS IN SOIL UNDER WHEAT-MUNGBEAN-MAIZE CROPPING SEQUENCE**", submitted to the Faculty of the Post-Graduate School, Indian Agricultural Research Institute, New Delhi, in partial fulfillment of the requirements for the award of the degree of **Doctor of Philosophy in Soil Science and Agricultural Chemistry**, by **Ms. Mamata Begum** embodies the results of *bonafide* research work carried out by her under my guidance and supervision. No part of the thesis has been submitted by her for any other degree or diploma.

I further certify that such help or information, as have been availed of in this thesis, have been duly acknowledged by her.

Date: 31/05/04

Place: New Delhi


(G. Narayanasamy)
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1. INTRODUCTION

Intensification of Indian agriculture has witnessed a lot of changes in the cropping patterns of different agro-ecological regions. With the changeover of the cropping pattern and the adoption of high production technology, modern farming achieved a breakthrough in the age-old yield barrier giving new dimensions to agricultural production. More and more areas were brought under cultivation, and single crops have given way to multiple cropping systems using high yielding and nutrient-responsive crop varieties. Use of inputs, particularly fertilizers increased, horizontally as well as vertically, in few cases even in an indiscriminate and injudicious manner. This can be seen from a wide disparity among the States and Union Territories in the amounts of fertilizers applied, which is to a very large extent governed by the existing socio-economic conditions. For example, the total NPK consumption in Nagaland (2002-03) was 1.9 kg ha⁻¹ as against 794 kg ha⁻¹ in Pondichery and 175 kg ha⁻¹ in Punjab (FAI, 2003). The proportion in which the three primary nutrients are added also appear to be imbalanced (6.5:2.5:1). Less attention is also paid towards the soil test based recommended values for different crops and cropping systems.

General deterioration of soil health and decline in productivity in the intensively cultivated areas have emerged as major challenges in the closing decade of the last millennium. It therefore becomes imperative to examine the sustainability of modern intensive farming. As per the inferences drawn from many long-term experiments, complementary use of organic/biological sources of plant nutrients with mineral fertilizers has either maintained or enhanced soil quality and improved the performance of crops and cropping systems. The organics not only serve as sources of plant nutrients, but also aid in improving the physical, chemical and biological health of soil (Sommerfeldt and Chang, 1985; Stevenson, 1986; Campbell *et al.*, 1986; Acharya *et al.*, 1988; Chouksey *et al.*, 1995). Numerous studies have been carried out on the advantage of the conjunctive use of organics with inorganics on different soil types and climatic



conditions. Investigations have also been directed towards the study of nutrient dynamics in soil as affected by the application of chemical fertilizers with or without organic manures.

The present study, primarily focused on the influence of integrated nutrient management on a wheat-based cropping system, revolves around two major plant nutrients, nitrogen (N) and phosphorus (P). Nitrogen occupies a unique position among the essential elements because of its high requirement by most of the crops. Although a major share of research has been carried out on nitrogen, its behaviour in soil is still enigmatic in many respects. The mineralization-immobilization processes in soils primarily dictate the forms, *viz.* organic (Stevenson, 1982) and inorganic (Young and Aldag, 1982), in which N occurs in soils. Most of the nitrogen in the plough layer of arable soils is present in a continuum of complex organic forms, which can be divided conceptually into a number of pools (Paul and Juma, 1981). Over 90% of N in most of the surface soils occurs in organic form (Kelley and Stevenson, 1995). Organic soil N plays a key role in terms of plant nutrition through direct and indirect effects on microbial activity and nutrient availability. A widely used approach for characterizing organic N in soil or humic substances is by acid hydrolysis (Stevenson, 1982). Several studies have compared the distribution of organic N in different soils, or among soils under different management practices (Porter *et al.*, 1964; Smith and Young, 1975; Osborne, 1977).

On an average, one-third of the fertilizer N applied remains behind in organic forms after the first growing season, the remainder having been taken up by plants and lost through leaching and denitrification (Allen *et al.*, 1973). During the initial years, N gets distributed in the easily mineralizable fractions such as amino acids and amino sugars, while in the later years, it gets locked in the more recalcitrant forms. Knowledge on the amount of the easily mineralizable fraction and the identification of the dominant fraction contributing to the bioavailable N (especially NO_3^- -N), and its dynamics would be helpful in N-fertilizer scheduling (Mulvaney *et al.*, 2001) for different crops and cropping systems.

Nitrogen is usually the most limiting nutrient in ecosystem (Epstein, 1970). However, phosphorus can be a limiting nutrient, particularly in highly weathered soils

(Vitousek and Sanford, 1986), where plant available forms have been depleted. When P availability is decreased, less carbon and nitrogen can be retained by the ecosystem (Cole and Heil, 1981) suggesting that long-term soil fertility can be improved by conserving P. The chemistry of P in soil offers an interesting study, particularly because of the fact that, although it is not easily lost from the soil, its availability to the plants cannot be assured. Crop utilization of inorganic fertilizer P is often very low and varies from 8 to 33% depending on the nature of crops and soils (Mattingly, 1975). It is therefore possible to accumulate large amounts of P by applying it through fertilizer to crops or cropping systems (Alessi and Power, 1980; Halvorson and Black, 1985).

Long-term transformations of residual P govern the availability of P to crops. Such transformations depend upon the inherent soil properties, particularly texture (O'Halloran *et al.*, 1987), and on P sources (More and Agale, 1993), crop species, management and fertilizer history, and climate (Aulakh and Pasricha, 1991). To evaluate the fate of fertilizer P in soil, several methods have been used (Olsen and Sommers, 1982). These methods include plant P uptake, A value, Olsen P, exchangeable ^{32}P , equilibrium solubility products and quantity/intensity analysis. However, most of the techniques quantify either soil labile P or available P pools only. The sequential extraction techniques proposed by various workers (Chang and Jackson, 1957; Peterson and Corey, 1966; Williams *et al.*, 1971; Hedley *et al.*, 1982) help in understanding the transformation of P to the labile, semi-labile and stable inorganic and organic pools. A knowledge of such transformations could be utilized in deciding the rate and time of fertilizer P application so as to maximize crop response and P use efficiency.

The productivity of summer legumes in Indian conditions is very low. Inclusion of a summer legume such as mungbean in an exhaustive cropping system would not only improve the productivity of the crop by addition of minimal amount of fertilizers but also improve the nitrogen status of soil and be beneficial to the subsequent crop.

Studies on the temporal variation in different forms and fractions of N and P as affected by integrated nutrient management on wheat based cropping systems with the

inclusion of a summer legume are limited. Hence, the present investigation was carried out with goals of identifying the fractions contributing to the N and P nutrition of each of the component crops of the wheat-mungbean-maize cropping system. The specific objectives of the study are:

1. To assess the direct and residual effect of different fertilizer and manurial treatments on crop yield and nutrient uptake.
2. To monitor the changes in different N and P pools in the soil and relate these to the performance of crops.

2. REVIEW OF LITERATURE

A comprehensive review of literature pertaining to the present investigation is presented hereunder.

2.1. Effect of long-term application of fertilizers and manures on crop yield and nutrient uptake

The single most important factor responsible for low yield of different crops is the inadequate supply of mineral nutrients. Pasricha and Brar (1999) observed in a permanent research trial conducted at Punjab Agricultural University that inspite of the best use of all other factors such as high yielding varieties, irrigation facilities, control of insect pests and diseases, the productivity of wheat remained low, which increased upon addition of fertilizer. Use of 120 kg N ha⁻¹ resulted in increase in dry matter yield and N uptake by maize (Pal *et al.*, 1987). The grain N content and the crop N uptake by wheat and maize increased with increasing levels of N from 60 to 180 kg N ha⁻¹ (Balasubramanian and Singh, 1982). Similar results were obtained with wheat by several workers (Swarup and Ghosh, 1984; Kumar *et al.*, 1995; Riley *et al.*, 1996). Increasing amounts of fertilizer N have shown to increase both the amount and concentration of N in wheat straw and stubble (Powlson *et al.*, 1986). Crop uptake of mineralized N studied in Broadbalk wheat experiment in Rothamsted, England was found to be 12-30 kg N ha⁻¹ greater with 96 and 144 kg N ha⁻¹ applications than uptake from plots never receiving fertilizer N (Glendining *et al.*, 1996).

Phosphorus application is also a key component of crop production technology. Application of 60 kg P₂O₅ ha⁻¹ to wheat resulted in an extra yield of 12 to 18 quintals per hectare over N alone (Tandon, 1980). The yield of wheat and P uptake increased in comparison to control with the application of different phosphatic fertilizers to a P deficient sandy loam soil (Chaudhary and Batra, 1992). There are several other reports on increase in crop yield and P uptake by the application of phosphatic fertilizers (Sharma and De, 1974; Shekhawat *et al.*, 1975; Jaggi and Minhas, 1990; Maliwal, 1990; Negi *et al.*, 1992).

Singh *et al.* (1986) recorded the highest wheat grain yield by applying optimum dose of NPK, i.e. $N_{120}P_{60}K_{60}$. At this fertilizer dose, Pawar *et al.* (1988) could obtain higher yield for both wheat grain and straw. In another long-term field trial, Brar *et al.* (1989) reported that the highest grain yields for both maize and wheat were obtained when 200 kg N and 44 kg P ha⁻¹ were added. Gill *et al.* (1994) recorded significant increase in maize yield with the application of 150% of recommended dose of fertilizers. They concluded that for attaining maximum productivity in maize-wheat system, the high yielding varieties require 150% of the recommended NPK, i.e. 180 kg N + 90 kg P₂O₅ + 45 kg K₂O per hectare where water is not limiting, and 80 kg N + 40 kg P₂O₅ + 20 kg K₂O per hectare where water is a limiting factor.

However, the results generated from long-term fertilizer experiments have shown that under high intensity, continuous wheat-maize cropping system, even optimum level of NPK failed to maintain the desired yield level. This, along with the high cost of chemical fertilizers and scarcity during peak season has made researchers to look for alternate sources which could partially or wholly substitute the chemical fertilizers. The same was also reported for other cropping systems. Reporting on the results generated from a series of long-term fertilizer experiments, Virmani (1994) concluded that continuous use of high analysis chemical fertilizers increased the crop yield in the initial years but adversely affected the sustainability at later stages.

The decline in soil fertility and the resultant productivity are the consequences of nutrient imbalance which can be recognized as one of the most important factors limiting crop yields (Nambiar and Ghosh, 1984), as intensive use of high analysis chemical fertilizer results in the deficiency of nutrients other than those applied and decrease the organic carbon content (Singh *et al.*, 1999b). However, when organic manure is applied in conjunction with chemical fertilizers, the gap between potential yield and the actual yield gets bridged up to a large extent. A review of the results of long-term fertilizer experiments conducted in India from 1971 to 1984 by Singh and Nambiar (1986) has revealed that balanced use of 100% NPK dose based on the initial soil test values

produced an average yield of 6.0-10.2 t ha⁻¹ in maize-wheat, soybean-wheat, rice-rice and rice-wheat cropping systems. Incorporation of FYM @ 10-15 t ha⁻¹ (along with optimal dose of NPK), enhanced the grain yield by 0.8-1.2 t ha⁻¹ over the optimal nutrient inputs, while the average grain loss without P and K amounted to 39-45% in light alluvial sandy (Ludhiana), 37-76% in medium black (Jabalpur and Coimbatore) and 62-91% in acidic submontane (Palampur) soils. Yield gain in wheat-maize cropping sequence with the combined use of recommended NPK and FYM has been reported by many researchers. (Suri *et al.*, 1995; Kumar and Singh, 1997; Ram *et al.*, 1998; Rameshwar and Singh, 1997, 1998; Vats *et al.*, 2001).

Singh and Dubey (1987) reported that grain yield of wheat under direct, residual and cumulative effect of NPK increased significantly with an increase in NPK dose from 90-45-45 to 120-60-60 kg ha⁻¹, and also with increase in FYM dose to supply 25, 50 and 100% of the N dose applied through fertilizers. It was also reported that direct, residual and cumulative effects of NPK application were significant on N uptake by grain.

Application of lime or farmyard manure along with the fertilizers on an Alfisol cropped with maize and wheat caused significant improvement in the yield attributes, quality of grains and uptake of nutrients by both the crops (Lal and Mathur, 1989).

Working on a Vertic Ustochrept with finger millet-maize-cowpea sequence, Muthuswamy *et al.* (1990) reported that soil test based balanced NPK fertilizer application in conjunction with FYM produced the highest yield of all the three crops. Further, increasing the optimum dose to 150% NPK significantly increased maize yield.

Prasad and Rokima (1991a) reported significant increase in grain and straw yield of rice and wheat with increasing levels of NPK from 50 to 100% of the soil test based dose and the highest grain and straw yield of rice and wheat were recorded in the treatment NPK (100%) + FYM + Blue green algae (BGA). Sharma *et al.* (1995a) observed that the application of FYM or Biogas slurry (BGS) alone significantly increased the grain yield of wheat in a wheat-maize cropping sequence in comparison to control.

However, compared to no-fertilizer or application of FYM only, supply of 120 kg N, 60 kg P_2O_5 + 50 kg K_2O increased maize grain yield by 1.54 and 0.88 t ha⁻¹, respectively, in a sandy loam soil, low in organic carbon as well as total N, and medium in available P and K (Pal *et al.*, 1993). Zheng (1999) observed that reliance on FYM alone brought about yield reduction. Dressel *et al.* (1992) also found that the N uptake by wheat in FYM treated plots was lower than that under the NPK treated plots.

Sarkadi (1995) pointed out that the efficiencies of FYM and chemical fertilizers were similar in increasing the P content of maize. Negi *et al.* (1992) observed that in acid soils of Himachal Pradesh, where the utilization of applied P by crops seldom exceed 10%, crop yields and P use efficiency increased significantly over control when FYM @ 10 t ha⁻¹ was applied to the wheat crop of wheat-maize sequence.

It has also been found that crop residues like sugarcane trash and mustard straw, which find no alternate economic use can be recycled for improved crop yield (Dev and Bhardwaj, 1995). Reporting the results of a 21-year long experiment with maize-wheat-cowpea (fodder) sequence at Punjab Agricultural University, Ludhiana, Biswas and Benbi (1997) pointed out that after eight years of experimentation, the optimal levels of NPK were unable to sustain maize yields due to Zn deficiency, which disappeared once FYM was added to the plots. Hegde and Katyal (1998) also observed a decline in yield due to continuous application of fertilizer alone. Similar results were obtained by Dressel *et al.* (1992) and Gagnon *et al.* (1997).

Field investigations were initiated on an acidic silty clay loam soil (Hapludalf) to study the effect of *Eupatorium adenoforum*, and FYM alone and in combination with four levels of nitrogen fertilizer on the yield of wheat and maize and the extent to which nitrogen could be substituted through organic manures (Minhas and Singh, 1998). Though response to N was significant up to 120 kg N ha⁻¹, application of FYM or *Eupatorium* alone or in combination with N further increased the yields of both the crops during the two years. Per cent N recovery increased when N was applied along with organic manures. Combined application of 10 t FYM ha⁻¹ and 10 t of *Eupatorium*

ha⁻¹ along with N could substitute, on an average 40 and 60 kg N ha⁻¹ in the cases of wheat and maize, respectively.

Studying the status of crop responses to fertilizers in different agroclimatic zones of India, Swarup and Srinivas Rao (1999) observed that the application of N alone had a deleterious effect on soil productivity, the effects being more pronounced in Alfisols. The magnitude of crop responses to P and K addition was much higher in Alfisols and Vertisols than in Inceptisols and Mollisols. Deterioration in productivity was found to be associated with deficiencies of Zn or S. Integrating FYM (@ 10-15 t ha⁻¹) with 100% recommended NPK doses sustained higher productivity while maintaining soil fertility in most of the cropping systems and soil types.

On a Typic Ustochrept at Delhi, Singh *et al.* (1999a) reported that application of 100% optimum recommended dose of NPK to maize-wheat-cowpea sequence resulted in significantly higher grain and stover/straw yields of maize and wheat as well as dry fodder yield of cowpea, whereas yields with application of NP alone were quite low, comparable to 50% NPK dose. Application of 100% NPK+FYM gave as high yield of maize as the super optimal dose of 150% and also resulted in consistently higher yield of wheat. Use of S or Zn showed no yield advantage.

On the basis of various long-term fertilizer experiments in India, one can recommend the integrated application of FYM (@ 10-15 t ha⁻¹) along with soil test based optimal fertilizer doses for maintaining soil fertility and sustaining crop productivity levels.

2.2. Inclusion of legumes in cereal based cropping systems

Short duration legumes such as mungbean, blackgram, *etc.* can be grown in the fallow period after the harvest of *rabi* crops. Legumes often enrich the soil by adding N; the enrichment though depends on the proportion of N fixed by them and its distribution in different plant parts (Eaglesham *et al.*, 1982).

Leguminous green manures can fix large quantity of atmospheric nitrogen. On an average they are reported to contribute about 30-60 kg N ha⁻¹ (Sharma *et al.*, 1987a). This value could be as high as 200 kg N ha⁻¹ in some cases (Singh *et al.*, 1991). They are also credited with supplying a substantial amount of N to the succeeding non-legume crop grown in rotation (Ahlawat *et al.*, 1981; Kolar and Grewal, 1998).

Improvement in performance of cereals following legumes occurs to the tune of 0.5 to 3 t ha⁻¹, which amounts to around 30 to 35% yield increase in comparison to cereal-cereal cropping sequence (Peoples and Craswell, 1992). Kolar and Gill (1994) also observed that inclusion of leguminous crops after wheat proved beneficial to succeeding maize crop than keeping the land fallow.

The yield attributes of wheat, NO₃-N content of soil, N uptake and N use efficiency were found to be higher with leguminous green manure incorporation than when the field was left fallow or with wheat straw incorporation (Badaruddin and Meyer, 1990). Two weeks after pea and oat harvest which were in rotation with winter cereals and oilseeds, the soil N content was about 30 kg N ha⁻¹ greater after peas than after oats (Jensen and Haahr, 1990). Nitrogen accumulation in barley, wheat and oilseed rape not supplied with N fertilizer was found to be 20-47 and 14-24 kg ha⁻¹ after peas and oats, respectively. Inclusion of greengram in a maize-wheat system without the addition of fertilizers depletes the soil of available P and K, but increases available N (Rao and Singh, 1991).

In a rice-wheat cropping system, incorporation of mungbean residues after the picking of pods significantly increased the rice yield and economized 60 kg N ha⁻¹ (Rekhi and Meelu, 1983). A two-year field study carried out at IARI revealed that grain yield, straw yield and N accumulation by winter wheat were significantly influenced by pre-wheat treatments (Sharma *et al.*, 1996b). The incorporation of mungbean or urdbean grown before wheat in sequence, resulted in higher grain and straw yield of wheat as compared to the plots where sorghum was grown before wheat. They attributed higher N uptake in the former case to the lesser removal of soil nitrogen by legumes as compared to sorghum fodder.

2.3. Effect of long-term fertilizer and manure application on soil properties

The influence of applied manures and fertilizers in multiple cropping systems on soil characteristics, as reported in various studies is summarized in the following sections.

2.3.1. Soil physical properties

In order that a soil can support the growth and development of crops, the physical environment needs to be conducive. Bulky organic manures such as FYM and compost help in improving the soil physical properties by causing an increase in aggregation (Sommerfieldt and Chang, 1985) and water holding capacity (Acharya *et al.*, 1988) and a decrease in bulk density and soil strength (Hafez, 1974).

Results of various long-term studies have shown that addition of organic manures along with optimal NPK dose improved soil physical properties like bulk density, aggregate stability, water retention and hydraulic conductivity over other treatments (Nambiar, 1994).

After eight years of study in a black clay soil of Madhya Pradesh, Kesavan *et. al.* (1995) observed that the soil structure deteriorated due to the application of urea alone. There was a gradual increase in the smaller size aggregates in all the treatments except in the FYM treated plots. Dev and Bhardwaj (1993) noted a significant reduction in bulk density and increase in pore space consequent on the addition of sugarcane trash and mustard straw.

Analyses of soil samples after seven years of a long-term trial in an old alluvial soil of Bihar showed that application of organic manures on long-term basis increased pore space, water stable aggregates, water holding capacity and decreased bulk density of soil (Sinha *et al.*, 1997). Superimposition of phosphatic fertilizers over FYM resulted in more water-stable aggregates compared to FYM alone. Similar results were reported by Benbi *et al.* (1998) after 20 annual cycles of maize-wheat-fodder cowpea cropping sequence.

The application of 100% NPK and their combined use with OM, *i.e.* FYM, white *popindc* leaves and black gram stover showed a remarkable increase in water holding capacity and decrease in bulk density (Sharma and Gupta, 1998).

2.3.2 Soil chemical properties

2.3.2.1 Soil reaction

In general, long-term application of nitrogenous fertilizers, particularly urea and ammonium sulphate reduces soil pH, while the addition of nitrate containing fertilizers is associated with an increase in pH (Kirkby and Mengel, 1967; Yousef and Chino, 1988).

Reduction in soil pH by about 1.7 units was noticed in respect of N treatment (applied in the form of ammonium sulphate) from the initial value of 5.5 after a period of 28 years in a permanent manorial experiment on an acid red loam (Paleustalfs) at Ranchi as a result of which the productivity of wheat and maize declined to zero yield level after 18th and 25th year, respectively (Lal and Mathur, 1988). Incorporation of FYM along with NPK fertilizers, as also need based liming however, was found to have a moderating effect on soil acidity and improved productivity.

The influence of FYM addition on soil pH varies with the type of soil. Singh *et al.* (1980) reported that the continuous application of FYM to a sierozem soil (pH 8.2) in the semi-arid region of Haryana resulted in lowering of pH due to release of organic acids. The production of aliphatic and aromatic hydroxy-acids as a result of decomposition of FYM could also result in complexing of free and exchangeable aluminium ions and thus increase the pH (Grewal *et al.*, 1981). In contrast, Chaudhury *et al.* (1981) could not observe any change in pH whether or not the plots received FYM.

Sinha *et al.* (1997) observed a decrease in soil pH as a result of continuous application of nitrogen as urea either alone or in combination with P and K in alluvial soils. From a long-term experiment with maize-wheat cropping sequence at Ranchi,

Sarkar *et al.* (1998) reported that the soil pH reduced from 5.5 to 4 in all the fertilizer treatments except in the plots where either FYM or NPK + lime was applied.

2.3.2.2. Soil organic carbon

The level of soil organic carbon is one of the most important indicators of soil health (Karlen *et al.*, 1997) and its production potential. The performance of any system can be ultimately judged on the basis of amount of organic carbon sequestered into or depleted from the soil.

It has been established that cultivation hastens organic matter decomposition and results in the depletion of soil organic carbon (SOC). A native soil sample (collected in 1910) and another from a cultivated soil (collected in 1990) from a Typic Haploboroll under a long-term wheat-fallow, non-fertilized rotation established in 1910 at Lethbridge, Alberta contained 3.03 and 2.33% soil organic matter, respectively (Schulten *et al.*, 1995). Similarly, Bharadwaj and Omanwar (1994) recorded highest organic matter content in fallow plots as compared to control, where rice, wheat or cowpea was grown without the application of fertilizer or manure.

Although the SOC content drops down with time as a result of bringing the field under plough, the decline can be minimized or even negated by a judicious application of organics. An increase in soil organic carbon was observed as a result of addition of manures to alluvial calcareous soil (Maurya and Ghosh, 1972), and with the application of NPK fertilizer along with FYM in acidic red loam soil (Prasad and Singh, 1980) of Bihar. Increase in SOC content was 24-29% of the initial level over the years (1971-85) at optimal to super optimal NPK doses in Ustochrepts (Ludhiana), which rose to about 76% with NPK + FYM treatment (Nambiar, 1986). However, it declined from its initial level in Eutrochrepts (Barrackpore) due to intensive cropping. The loss amounted to 34-39% at optimal to superoptimal NPK doses, which was minimized to 27% with the incorporation of FYM.

Results obtained by Sinha *et al.* (1997) indicate the possibility of increasing the organic matter and cation exchange capacity of alluvial soils through incorporation of

organic manures. Increase in cation exchange capacity of soil due to the increase in organic carbon and humus content of the soil through the application of FYM and compost was also reported earlier by Campbell *et al.* (1986). However, through analysis of soil samples from the old manurial experiments after 44 years (*i.e.*, 1916 to 1959), Krishnamoorthy and Ravi Kumar (1973) had reported that differences in soil organic carbon content between plots that received cattle manure and those which received inorganic fertilizers were not significant. But, several other reports support the fact that application of organic manures alone or in combination with optimum level of NPK fertilizers increased the organic carbon content of soil (Singh *et al.*, 1980; Singh and Nambiar, 1986; Subramanian and Kumaraswamy, 1989a; Sharma and Gupta, 1998; Bhandari *et al.*, 2000).

Under All India Co-ordinated Research Project (AICRP) on Long Term Fertilizer Experiments (LTFE) with different cropping systems, a decline in soil organic carbon has been reported as a result of continuous application of fertilizer N alone irrespective of cropping systems and soil types (Acharya *et al.*, 2000). On the other hand, balanced use of NPK fertilizers either maintained or slightly enhanced the level over the initial values. Beneficial effect of FYM in improving organic carbon over control, N, NP and NPK fertilizer was more pronounced on Vertic Ustochrept (Coimbatore), Typic Haplustert (Jabalpur) and Haplaquept (Bhubaneswar). The positive influence of FYM on soil organic carbon was also reported earlier by Jenkinson (1991).

2.3.2.3. Available nutrients

On the nutrient front, there still exists, on an average a negative balance of 8-10 Mt per annum in Indian soils. Use of mineral fertilizers is the quickest and surest way of counteracting nutrient depletion and boosting crop production, but cost and other constraints frequently deter farmers from using them in recommended quantities. Thus, 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. The interactive advantages of combining inorganic and organic sources of

nutrients are generally superior to the use of each component separately (Nambiar and Abrol, 1989).

According to Bansal *et al.* (1980) available N content increased due to application of nitrogenous fertilizers to an Aquic Hapludoll. Similar results were obtained on other soils by Jenkinson and Johnston (1977) and El Harris *et al.* (1983). The use of fertilizer N on a long-term basis resulted in large increase in mineralisable N in many experiments reviewed by Glendining and Powlson (1995). The Broadbalk plot (Rothamsted) which received 192 kg N ha⁻¹ for only 13 years mineralized as much N as that in a plot receiving 144 kg N ha⁻¹ for 129 years. Continuous use of phosphatic fertilizers has also resulted in build up of available N (Singh *et al.*, 1980). However, Grewal *et al.* (1981) noticed that long-term application of P and K fertilizers had little effect on available N of soil (Ustochrept) of Punjab.

Results based on six-year data showed that application of N and P to a calcareous chernozem soil increased the available N and P content (Borisov and Nikolov, 1975). A marked decline in the available phosphate level in the plough layer was observed by Biswas (1977), which was rapid when high doses of fertilizer N alone were applied to high yielding crop varieties in light textured soil. This emphasizes the need to apply P along with N. On the basis of their study on P removal and available P balance under intensive cropping and long-term fertilizer use, Singh *et al.* (1998) reported on a build up of available P in phosphate receiving plots and depletion in control and N-treated plots. With regular application of fertilizer P to soybean and wheat in rotation in a Typic Haplustert, the level of Olsen P increased significantly and linearly through the years in both manured and unmanured plots (Reddy *et al.*, 1999).

Long-term application of phosphatic fertilizers results in the accumulation of NaHCO₃ extractable P in the soil, the magnitude of which depends on the rate and the total amount of P added and its removal by crops (Rao and Sharma, 1978; Campbell *et al.*, 1984; Biswas and Benbi, 1989; McCollum, 1991; Benbi and Biswas, 1999). The same is also true in respect of potassium (K) availability, which is enhanced due to the

continuous application of heavy doses of potassic fertilizers (Swarup and Ghosh, 1978; Schwab *et al.*, 1990).

A review of the results of large number of long-term fertilizer experiments has shown that application of 150% of optimum NPK based on initial soil test led to appreciable improvement in available N, P and K content of soil. Depletion of P was highest under 100% N treatment and that of K under 100% NP treatment. With increased use of high analysis fertilizers, deficiencies of sulphur (S) and zinc (Zn) have been observed in most of the Indian soils (Singh and Nambiar, 1986). Sharma *et al.* (1987b) observed an increase in available P and K in a sandy loam (Typic Ustipsamment) soil of Punjab with the application of optimum dose of NPK. Hegde and Katyal (1998) reported on a build up of available N and P in Ustochrepts at Ludhiana and in Chromusterts at Banswara due to NPK fertilization in maize-wheat cropping sequence and a general decline in soil fertility status under unfertilized plots.

Though balanced fertilization through inorganics help to maintain the levels of N, P and K in the soils so as to meet the crop demands, it did very little to improve soil health and therefore puts a question mark on the sustainability of cropping system. Therefore, the use of organics in order to improve the soil fertility was inevitable. But the use of organics alone will not serve the purpose, as indicated by a study conducted by Mathan *et al.* (1978). They observed that application of FYM alone maintained low soil N levels as compared to 100% NPK in a black soil. This calls for the conjunctive use of organics with inorganics, which have yielded good results. On the basis of such an integrated use, Vats *et al.* (2001) observed that not only did the organics improve the use efficiency of chemical fertilizers, but also brought about a significant increase in the availability of limiting nutrients. There was a marked improvement in the fertility status of various soils (alluvial, red loam, medium-black, laterite, submontane and foot hill) on which the study was conducted.

In a long-term fertilizer experiment on an Inceptisol at Coimbatore with finger millet-cowpea-maize cropping sequence, Subramanian and Kumaraswamy (1989a)

observed an increase in total N, and available N in the 100% NPK + FYM as compared to control and 100% NPK alone under continuous cropping. An increase in available N by 4-10% of the initial level in N treated plots, significant build up of P to the extent of 40% due to combined application of inorganic P and FYM, and maximum depletion of K in NP treatment was reported by Muthuswamy *et al.* (1990) in the LTFE on Vertic Ustochrept with finger millet-maize-cowpea cropping sequence over a period of 16 years. The application of 100% NPK and their combined use with organic manures showed remarkable increase in available N and P content in soils (Sharma and Gupta, 1998).

In a study on the effect of continuous use of fertilizers on soil fertility and productivity of a Mollisol under rice-wheat-cowpea sequence for 25 years, Nand Ram (1998) reported decreases in the status of organic carbon, available P, K and Zn from the initial level in the unfertilized plots. However, the integrated use of optimal NPK and FYM not only restored the initial status of organic carbon but also enhanced the availability of P, K and S in soil.

The application of FYM in conjunction with 100% NPK led to significantly greater accumulation of available P as compared to 100% NPK alone despite the higher amount of total P removal in the former treatment as compared to the latter (Benbi and Biswas, 1999). The incorporation of FYM and green manure for four years in the sandy loam soil of PAU, Ludhiana, resulted in a positive flux of available nutrients and organic carbon in the soil (Bhandari *et al.*, 2000).

Application of organic manures is very cost-effective in that it curtails the requirement of chemical fertilizers. From long-term studies on neutral and calcareous chernozem soils, Sarkadi (1993) concluded that regular application of FYM, and to a lesser extent crop residues (wheat straw and maize stover) reduced the requirement of N fertilizer application. Reduction in the application of P and K in wheat crop was suggested by Suri *et al.* (1997) under a rainfed subtropical condition wherein FYM was applied to the previous maize crop.

Based on an experiment conducted at Udaipur, Totawat *et al.* (2000) reported that biogas slurry could substitute 50% of recommended dose of N in a maize-wheat cropping system. Further, inoculation of maize and wheat seeds with *Azotobacter chroococcum* significantly improved the N status of the soil and the yield attributes of both the crops under study, which could be credited to the creation of a congenial environment for better root growth through secretion of growth promoting substances, and fixation and subsequent availability of atmospheric N.

Some studies have even compared the efficiencies of different sources of organic manures. Toor and Bishnoi (1996) observed that poultry manure was more effective than FYM in increasing the availability of N and P. However, both the sources were equally effective in respect of available K. In another experiment, the content of available N, P, K, Fe, Cu, Mn and Zn in soil due to the application of different manure was found to follow the order: vermicompost > poultry manure > biogas slurry > FYM (Reddy and Reddy, 1998).

Although the organic manures do not contain large amounts of available nutrients *per se*, they facilitate the availability of the nutrients to the crops through various biochemical phenomena. The application of organics boosts microbial population and hastens mineralization process, thereby increasing the availability of N and S which predominantly exist in organic forms. Decomposition of organic matter also produces organic acids which enhance P availability. The organic acids act by either replacing P sorbed on the metal hydroxides (Sibanda and Young, 1986), or bring about dissolution of P locked in metal oxides by forming complexes with iron and aluminum (Hue *et al.*, 1986). Over the years, a number of studies have shown that mixing FYM and inorganic P significantly increased extractable P in soil (Meek *et al.*, 1979; Geiger *et al.*, 1992). Plant availability of P from rock phosphate is enhanced when mixed with organic materials probably because of acids produced during composting and biological activity (Mishra *et al.*, 1982). Hue (1992) concluded that the efficiency of P fertilizer would increase significantly when applied along with organic acids or acid producing materials.

Mahajan *et al.* (1997) suggested that the low response of P application on addition of FYM could be due to the organic acids that are released during its decomposition which releases P from native stable phosphate pools. Continuous application of FYM also increases the availability of exchangeable cations like calcium, magnesium, potassium and sodium.

A reduction in DTPA extractable micronutrients was observed in control plots under rice-wheat-cowpea as compared to fallow plots (Kamanee *et al.*, 1982). Application of NPK fertilizers resulted in higher level of extractable micronutrients over unfertilized plots except for the Zn-treated plot. Application of N or K alone had an adverse effect on extractable Zn. Addition of FYM tended to increase the DTPA extractable micronutrient cations in soil. Increased availability of cations, particularly micronutrients in soil by addition of organics is explained by the chelating effects of organic acids produced on their decomposition.

2.3.3. Soil microbiological properties

The concept of soil as a living and dynamic system is justified by the numerous reactions which are primarily mediated by microorganisms. They are therefore the indicators of soil health, and are very sensitive to any soil manipulation. The integrated use of organics and inorganics have been found to have beneficial effect on the biological properties of soil.

In a long-term field experiment with a soybean-wheat-maize fodder rotation, it was noted that the populations of bacteria, actinomycetes, fungi *etc.* in the soil were highest with a combination of NPK + FYM. Biological N fixation by soybean was also more with NPK + FYM (Chouksey *et al.*, 1995).

Decrease in microbial biomass carbon (MBC) in urea treated plots under wheat in an irrigated wheat-maize cropping sequence was observed by Mahmood *et al.* (1997). They obtained a higher MBC value at higher rate of FYM application. During the maize season, higher values were obtained in both urea and FYM treated plots as compared to control.

2.4. Total nitrogen content of soil

The total N content of soils ranges from less than 0.02% in subsoils to more than 2.5% in peats, and is related to climate, vegetation, topography, parent materials and the activity of man (Tisdale *et al.*, 1993). Except for certain subsoils, about 95% of the total N is organic in nature. Soils of India have low total N content (0.02 to 0.1%) due to the tropical and subtropical climate prevailing in the country (Prasad and Thomas, 1982), though relatively high values are encountered in the hilly regions of north-east and north-west.

Rao and Sharma (1978) observed a negative balance of total N in soil at the end of two years of maize-wheat sequence even with N-fertilizer application, except in those cases where greengram was included. The negative balance in total nitrogen content of soil was also observed in a Vertic Ustochrept at the end of six cropping cycles of rice-wheat-greengram under different fertilizer treatments (Patel *et al.*, 1989). However, increase in total N content of soil due to long-term application of manures and fertilizers have been widely reported.

Deforestation and cultivation generally lower the N content in soils (Ghildyal *et al.*, 1962). In a 15-year study on a Typic Agriudoll in Argentina under continuous maize, Palma *et al.* (1998) observed significant loss of organic carbon and total nitrogen in cultivated soil in comparison to undisturbed pasture, the effect being more evident in conventional tillage than in no-tillage.

Continuous use of various N and P fertilizer combinations in a fine sandy loam soil of Pusa (Bihar) markedly increased N content of soils over control (Maurya and Ghosh, 1972). After 12 cropping cycles, Brar and Singh (1984) observed an increase in N content from 0.017 to 0.019 and 0.024% with the application of 100 and 200 kg N ha⁻¹, respectively.

Annual application of inorganic N fertilizer (48, 96 and 144 kg N ha⁻¹) each year increased total soil N content relative to the plot which never received fertilizer N, due

to greater return of organic N to the soil through roots, root exudates, stubble *etc.* in Broadbalk Wheat Experiment at Rothamsted (Glendining *et al.*, 1996). The application of 144 kg N ha⁻¹ for 135 years increased total N content by 570 kg ha⁻¹ in 0-23 cm soil layer. Other plots that received smaller applications of N during the same period showed smaller increases. Further, a plot receiving 192 kg N ha⁻¹ showed a 9% increase in total N over 20 years, in comparison to plots which received 48 kg N ha⁻¹, indicating that application of inorganic N can produce measurable changes in total N within 20 to 30 years (Glendining and Powlson, 1995).

In a long-term experiment with wheat-maize rotation on a non-saline sandy loam soil, application of phosphatic fertilizer with and without organic manures increased the total N content of soil (Sandhu and Meelu, 1974). Regular application of farmyard manure has resulted in a remarkable increase in total N content of soil at Rothamsted long-term field experiments (Jenkinson and Johnston, 1977).

In an incubation study, crop residues, i.e. maize stubble, wheat stubble and organic manures (FYM and *dhaincha*) were found to increase the total nitrogen contents of two alluvial and one sedentary latosolic soils of Bihar (Srivastava *et al.*, 1984). Sidhu and Beri (1989) observed an increase in total N content after four years of wheat-maize rotation by incorporation of chopped wheat straw (4 t ha⁻¹).

Though the N content of soil increases with the application of inorganic fertilizers, the increase is enhanced when organic manures are applied along with them (Kanchikerimath and Singh, 2001). Earlier Subramanian and Kumaraswamy (1989a) reported highest value of total N in plots under 100% NPK + FYM treatment in an Inceptisol of Tamil Nadu. Udayasoorian *et al.* (1989) had found that continuous addition of organic manures for seven years under an intensive cropping system on an Alfisol of Andhra Pradesh significantly increased its total N content.

Soil samples from 0-30 cm layer of a cinnamonic-podzolic soil were collected from a long-term field experiment with maize and wheat grown in a 27-year rotation. The treatments included control, PK, NPK and NPK + FYM. The total nitrogen content

of the soil increased from 0.06 to 0.09% in the NPK + FYM treatment in comparison to unfertilized soil (Ikononova *et al.*, 1999).

2.5. Distribution of various forms of N in soil

2.5.1. Inorganic nitrogen fractions

Inorganic N compounds detected in soils are nitrate (NO_3^-), nitrite (NO_2^-), exchangeable ammonium (NH_4^+), non-exchangeable (fixed) NH_4^+ , dinitrogen gas (N_2) and nitrous oxide (N_2O). Other chemical or biological intermediates, such as nitric oxide (NO), nitrogen dioxide (NO_2), hydroxylamine (NH_2OH), hyponitrous acid ($\text{H}_2\text{N}_2\text{O}_2$), azide (N_3^-) and even some cyano-compounds which are yet to be identified (Young and Aldag, 1982). Although available forms of soil N (mainly NO_3^- and NH_4^+) are of great immediate interest to crop production, other inorganic forms merit consideration.

Ammonium-nitrogen may be present in exchangeable or fixed form. Though exchangeable $\text{NH}_4\text{-N}$ is one of the major initial sources of plant available N, non-exchangeable $\text{NH}_4\text{-N}$ is considered as a potential source of the same (Baethgen and Alley, 1987). Plants are usually thought to take up N in the form of NH_4^+ and NO_3^- , with the latter being favoured when it is available in abundance (Streeter and Batra, 1988).

A review on inorganic forms of N in Indian soils (Prasad and Thomas, 1982) indicated that exchangeable ammonium varies from 10 to 50 ppm. Singh and Singh (1969) had found higher ammonium-N under legumes than under other crops. Higher rates of fertilizer N application results in higher concentration of ammonium in soils (Rajput *et al.*, 1984; Sagwal and Rahul, 1984).

Nitrate-N content of soils was found to vary from 17 to 50 ppm in alluvial, 3.3 to 27.7 ppm in black and 1.21 to 31 ppm in red soils, while it was about 1.5 to 13.5 ppm in hill and forest soils as estimated by a colorimetric method using crystal violet, which was found to give similar results as that obtained by Deverda's alloy reduction method (Shukla and Singh, 1968). Significantly higher nitrate-N content in plots treated with FYM was reported in colluvial soil of New Delhi (Havanagi and Mann, 1970) and in

Ustochrept of Haryana (Sagwal and Rahul, 1984). Rajput *et al.* (1984) noted increased $\text{NO}_3\text{-N}$ content of Aquic Hapludoll with increase in the levels of nitrogenous fertilizer applied to the soil.

Mineral N at 0-60 cm layer of soil increased with increasing N levels. The increase was to the tune of 48, 89 and 104% at low, moderate and high rates of N application, respectively (Panayatova and Karev, 1998). Earlier, Benbi *et al.* (1991) studied the $\text{NO}_3\text{-N}$ distribution in an Ustochrept profile under a long-term fertilizer experiment at Ludhiana (Punjab) and had found that after 16 years of cropping (maize-wheat-fodder cowpea) the application of nitrogenous fertilizers alone or in combination with P resulted in higher $\text{NO}_3\text{-N}$ concentration in soil profile than the application of N with both P and K. Brar and Brar (2002) observed highest $\text{NO}_3\text{-N}$ content throughout the soil profile under 100% NPK treatment applied to the major crops grown in Punjab, indicating better utilization of N by crops under balanced fertilizer application.

Continuous addition of FYM over seven years in an intensive cropping system on an Alfisol significantly increased its ammoniacal and nitrate nitrogen contents, whereas addition of green leaf manures did not have any profound effect (Udayasoorian *et al.*, 1989). However, a decrease in $\text{NO}_3\text{-N}$ content of the soil by the application of FYM was observed by Puranik *et al.* (1978) and Prasad and Rokima (1991a). The $\text{NH}_4\text{-N}$, $\text{NO}_3\text{-N}$ and $\text{NO}_2\text{-N}$ contents of the soil increased gradually with time following the 16 years of NPK fertilizers application to a soybean-wheat-maize fodder rotation on a Typic Chromustert in Madhya Pradesh (Thakur *et al.*, 1992). However, the highest N content was observed with the application of NPK together with FYM.

In an incubation study carried out in an Inceptisol by Khankhane and Yadav (2000), it was observed that the amount of $\text{NH}_4\text{-N}$ decreased and those of $\text{NO}_3\text{-N}$ and $\text{NO}_2\text{-N}$ increased significantly with the increase in incubation period from 1 to 16 weeks, when FYM, biogas slurry and sewage sludge were applied with or without NP fertilizers.

A long-term fertilizer experiment initiated at Coimbatore with fixed rotation of finger millet-maize-cowpea revealed that incremental addition of N and FYM had a positive effect on the build up of mineral N in soil (Santhy *et al.*, 2001a).

2.5.2. Organic nitrogen fractions

More than 90% of the N in the surface layer of most soils occurs in the form of organic compounds, more than half of which remain to be identified (Kelley and Stevenson, 1996). The main identifiable organic N components in soils are amino acids and amino sugars released upon acid hydrolysis. They are also the predominant sources of mineralization leading to the availability of N to plants (Mengel, 1996). Hydrolysable amino acids account for 30-50% of the soil organic N pool (Stevenson, 1982), although values as high as 53 to 56% have been reported (Jorgensen, 1967). Amino acids also account for a considerable part of organic N in the humic and fulvic acid fractions.

Stevenson (1982) proposed that hydrolysable organic N, in the form of amino acids, peptides or proteins, is attached to a central humic core by H-bonding or covalent linkages. He also suggested that the unknown organic N that resists hydrolysis occurs as free amino ($-\text{NH}_2$) groups, open-chain ($-\text{N}-$, $=\text{N}-$) groups, parts of heterocyclic ring structures, amino acids attached to aromatic rings, and bridge constituents linking quinone rings. Recently, ^{15}N CPMAS nuclear magnetic resonance (NMR) spectroscopy showed that at least a part of the organic N that resisted treatment with 6 M HCl consisted of amide or peptide structures and free amino groups (Knicker and Ludemann, 1995).

Wide variations in N distribution pattern in soils have been reported, the reasons for which have been attributed to the differences in properties of soils examined. Khan and Sowden (1971) concluded that the main difference between the forms of N in some saline and non-saline soils of Alberta, Canada was that a higher proportion of N in the latter occurred in acid-insoluble forms. According to Ramamoorthy and Velayutham (1976), about 18-30% of the total N in most surface soils is present in the form of bound amino acids, 3-7% as amino sugars and 18-43% as non-hydrolysable N. Results of Sowden (1977) for the distribution of N in surface layers of 92 Canadian soils show that a higher percentage of N in overlying organic layers occurred as amino acid N than in mineral layers.

Sowden *et al.* (1977) determined the distribution of major N compounds in samples taken from soils formed under widely different climatic and geological conditions on earth's surface. While the total N content of the samples analyzed ranged from 0.01 to 1.61%, the proportion of total N that could be hydrolysed by hot 6 M HCl were quite similar, ranging from 84.2 to 88.9%, amino acid N varied from 33.1 to 41.7%, amino sugar N from 4.5 to 7.4%, and ammonia N from 18.0 to 32.0%. Proportions of unidentified hydrolysable N ranged from 16.5 to 17.8%, whereas those of non-hydrolysable N ranged from 11.1 to 15.8%. They added that higher percentages of N in soils from warmer climates occurred as amino acid and amino sugar N while lower percentage occurred as hydrolysable ammonia ($\text{NH}_3\text{-N}$). Further, the ratio of amino acid N to amino sugar N was lower in tropical and subtropical soils.

On studying the N distribution patterns in volcanic and non-volcanic tropical soils, Dalal (1978 a,b) reported that higher percentages of N in the latter soils occur as acid-insoluble N, $\text{NH}_3\text{-N}$, and amino sugar N. Stevenson (1982) summarized the distribution of the forms of N in representative surface soils of the world. Amino acids accounted for 1.3-52.0% and amino sugars, 0.8-13.8% of N. The percentage of N in acid insoluble forms ranged from 6.9 to 41.3; the range for hydrolysable unknown fraction was from 2.4 to 40.2%.

Catroux and Schnitzer (1987) analyzed a hydromorphic humic soil for the nitrogen fractions. About 30% of total soil N in the upper soil layer was amino acid-N. The amount of amino sugars was relatively low, whereas the $\text{NH}_3\text{-N}$ represented a substantial proportion. The order of magnitude of the three nitrogen fractions agrees well with that found in arable soils (Schnitzer and Spiteller, 1986). About 50% of the total soil N could not be identified.

In a study on distribution of N fractions in Aridisols of Rajasthan, Aggarwal *et al.* (1990) reported that amongst organic-N hydrolysable fractions, the order of distribution in different depths of profiles was: amino acid-N (14.3-47.6%) > unidentified N (3.9-45.4%) > amino sugar-N (3.7-20.3%) > hydrolysable ammoniacal-N (1.0-10.1%).

On the basis of their data, Schulten and Schnitzer (1998) proposed the following distribution of total N in soils and humic substances: proteinaceous materials (proteins, peptides, amino acids), 40%; amino sugars, 5-6%; heterocyclic N (including purines and pyrimidines), 35%; $\text{NH}_3\text{-N}$, 19%. According to them, approximately one-fourth of the hydrolysable- NH_3 is fixed as NH_4^+ .

It is a well known fact that the N content of most soils declines when land is subjected to intensive cultivation (Stevenson, 1982). This loss of N is not spread uniformly over all N fractions, although neither long-term cropping nor the addition of organic amendments to soil greatly affect the relative distribution of the forms of N. All forms of N including acid-insoluble N appear to be biodegradable (Keeney and Bremner, 1964; Ivarson and Schnitzer, 1979).

Studies by Rendig (1951) and Ferguson and Gorby (1971) revealed that hydrolysable components of soil organic nitrogen, namely amino acid, hydrolysable NH_3 , hexosamine and unidentified form are more susceptible to mineralization and subsequent losses under cultivation as compared to the non-hydrolysable fraction. Among the hydrolysable ones, the amino acid suffers greater depletion than other forms of soil N (Porter *et al.*, 1964; Smith and Young, 1975). According to Keeney and Bremner (1964) and Meints and Peterson (1977), cultivation results in a marked decrease in all forms of N, except non-exchangeable ammonium N, but on an average, has little effect on the percentage distribution of N.

Growing of cereals alone results in greater proportion of hydrolysable ammonium and hexosamine accumulating in the soil while legumes in rotation tend to accumulate more of N in amino acid form (Stevenson, 1956). Results for two cropping systems (Breton plots of Alberta, Canada) obtained by Khan (1971) show that the proportion of the soil N as amino acid and amino sugar was significantly greater for a 5-year rotation of grasses and legumes than for a wheat-fallow sequence.

Changes in different forms of N in soil take place due to application of manures and fertilizers. Khan (1971) pointed out that while manure application resulted in

increased percentage of soil N as amino sugars, long-term application of mineral fertilizers had no significant effect on N distribution pattern.

The influence of soil test based fertilizer use on the organic fractions in the plough layer of a Typic Ustochrept of Delhi under a pearl millet-wheat-cowpea rotation was studied by Subba Rao and Ghosh (1981). Seven years of multiple cropping without manuring caused marked depletion in all the hydrolysable N fractions (except unidentified hydrolysable N) namely, hexosamine (48.8%), hydrolysable NH_3 (23.9%) and amino acid (7.3%) as compared to adjacent fallow. Fertilizer nitrogen application maintained the levels of various forms of N as in the fallow plots and nitrogen in conjunction with phosphorus raised the status of amino acid. Phosphate led to improved contents of hydrolysable NH_3 and total hydrolysable N whereas farmyard manure enhanced the latter only. Intensive cropping system coupled with appreciably high doses of fertilizers favoured greater immobilization of N in hydrolysable ammonium and total hydrolysable fractions.

The application of FYM and N-fertilizers to a Vertisol increased the amino acid-N content considerably over control (Kamat *et al.*, 1982) and a fair increase in hydrolysable NH_3 -N and amino-sugar content was observed when fertilizers were used in combination with FYM. Pal *et al.* (1987) found that irrespective of cropping and N-fertilization, the amount of available N significantly decreased and the fixed NH_4^+ -N increased with increase in the period of investigation from 0 to 90 days. A substantial decrease in the amount of total hydrolysable N due to cropping was noted and the extent of decrease was less in the N-fertilized than in the corresponding unfertilized soil. Among the constituent forms of hydrolysable organic-N estimated, the maximum decrease was observed in amino acid-N fraction. Hydrolysable NH_3 -N content, in general showed an increase under all the treatments. Amount of hexosamine, however, showed no significant change while the amount of unidentified form registered an increase.

In another study relating to nitrogen fractions and their availability to plants in a calcareous soil (Calciorthent), Prasad and Rokima (1991a) reported that all the fractions

of N except $\text{NO}_3\text{-N}$ and hexosamine-N increased with increasing doses of NPK with or without manures.

From a study on the effect of long-term fertilizer use and cropping on distribution of macronutrient fractions in a Vertic Ustochrept, Santhy *et al.* (1998) reported on a considerable build up of all the organic N-fractions in NPK+FYM and 150% NPK treated plots. Similar results were obtained earlier on an acid Alfisol by Kher and Minhas (1992)

Working on the transformation of soil organic nitrogen with manuring under rice-wheat cropping system in a silt loam soil at IARI, New Delhi, Pathak and Sarkar (1995) observed that the application of N irrespective of sources and levels increased the content of total hydrolysable N (THN), amino acid-N (AAN), amino sugar-N (ASN), hydrolysable unidentified N (HUN) and non-hydrolysable N (NHN) after rice. There was not much change in the status of hydrolysable ammonia N (HAN) while the content of inorganic N sharply decreased due to rice cropping. In the unmanured soil, the status of all these N fractions declined except those of NHN and HUN. After harvest of wheat, the contents of THN, HAN, AAN and HUN decreased whereas NHN and ASN content increased in comparison to their corresponding status at rice harvest stage.

Recently, Johnsson *et al.* (1999) have reported that long-term fertilizer use @ about 73 kg N ha^{-1} per annum, during a period of 24 years resulted in an enrichment of three major organic fractions, *viz.* amino acids, amino sugar and non-amino acids plus non-amino sugars by 31%, 33% and 27%, respectively.

Based on data obtained from a long-term fertilizer experiment on a Typic Haplustert with soybean-wheat cropping system, Singh *et al.* (1999b, 2001) reported that conjunctive use of organic manure and urea N increased the total hydrolysable N and its fractions. All the N fractions showed a decline in control and in plots receiving low doses of N and FYM alone. Integrated use of organic and urea N not only increased the active pools but also enhanced the most reserve pools, *viz.* non-hydrolysable and fixed ammoniacal (non-exchangeable) N in soil.

2.6. Relationship of various nitrogen fractions in soil with crop yields, N availability and uptake of nitrogen by crops

Utilization of fertilizer N by crop plants seldom exceeds 60%, due to the removal of the soluble N ions through various means. One-third of the applied fertilizer N is held back by the soil in organic forms, and only a portion of this is available to the next crop (Kelley and Stevenson, 1995). The phenomenon of mineralization of soil organic matter is the dominant process through which bioavailable N is released for crop growth (Scarsbrook, 1965). Only in some cases where the rate of mineralization is too slow, the soluble forms of organic N is taken up by different crops (Chapin *et al.*, 1993). The organic N fraction which forms a major share of total N, has been separated into various components, and each component may play an important role in the availability of N.

The different forms of N, *viz.* total N, mineral N, organic N *etc.* affect the crop yield and N uptake. These forms of N are also found to be interrelated. The possibility of a particular fraction or fractions of the total N extracted from soil by acid (6 M HCl) hydrolysis being a useful index of N availability has been examined by many workers (Keeney and Bremner, 1964; Cornforth, 1968; Freeney and Simpson, 1969; Kadirgamathoiyah and Mackenzie, 1970; Osborne, 1977).

Cornforth (1968) observed that N uptake by corn correlated with hydrolysable and non-hydrolyzable N fractions of uncropped soils. The correlations were as follows: total hydrolysable N ($r = 0.85$), $\text{NH}_3\text{-N}$ ($r = 0.84$), amino acid N ($r = 0.85$), hydroxy amino acid N ($r = 0.90$) and non-hydrolyzable N ($r = 0.73$). Although relationships with N uptake were similar for total hydrolysable N and the fractions comprising it, the correlations were not better than those occurring between N uptake and total soil organic N ($r = 0.88$). However, Osborne (1977) found that none of the organic fractions showed significant relationship with the dry matter production of ryegrass and concluded that chemical fractionation of soil nitrogen following acid hydrolysis had no practical value in predicting the plant yield. But according to Dalal (1978b), significant correlations of hexosamine, hydroxyamino acid and alpha-amino acid N with mineral N (exchangeable

$\text{NH}_4 + \text{NO}_3$) showed that these organic forms may contribute to the potentially available N in soil. It was observed that organic N fractions *viz.* amino acid-N, hexosamine-N and hydrolysable NH_3 -N were found to bear a highly significant and positive relationship with both yield and per cent N content of pearl millet, wheat and cowpea (Subba Rao and Ghosh, 1981).

Kamat *et al.* (1982) reported that available N content of soil correlated positively and significantly with hydrolyzable NH_3 -N + amino sugar-N ($r = 0.953$), amino acid N ($r = 0.926$) and acid insoluble humin-N ($r = 0.901$). Subba Rao *et al.* (1984) observed significant positive relationship among different fractions of organic N and available (alkaline permanganate) N. It was also noted that non-distillable and distillable acid soluble fractions accounted for 69 and 29% variations in available N, respectively.

A significant positive relationship of amino acid-N and amino sugar-N with NO_3 -N was observed by Aggarwal *et al.* (1990), indicating the contribution of these fractions to the available N pool in Aridisols. Amino acid-N was significantly correlated with mineralisable N. Correlation coefficients between different fractions of N at rice harvest and the following wheat yield (Pathak and Sarkar, 1995) showed that total hydrolysable N, hydrolysable ammonia N, amino acid N and amino sugar N significantly contributed towards plant available N, grain yield and N uptake by wheat.

Multiple regression equations indicate that exchangeable NH_4^+ -N and available N can predict N uptake by rice and wheat (Prasad and Rokima, 1991a). Further, all the fractions of N (except hexoseamine, unidentified and non-hydrolyzable N) correlated significantly among one another. However, the path analysis indicated that exchangeable NH_4^+ was the dominant form of N that contributed directly or indirectly to nitrogen nutrition of crops.

According to Singh and Takkar (1997), total hydrolysable N, amino sugar-N, hydrolysable ammonia-N and amino acid-N are the active components of available pool of nitrogen in Typic Haplustert under rice-wheat system.

In a study on the bio-availability of organic N form in a podzol, Johnsson *et al.* (1999) reported that the most important net source of nitrogen for plants and microorganisms seemed to be included in the pool of acid (6 M HCl) hydrolysable amino acids and amino sugars.

Singh *et al.* (1999b) reported significant positive correlations among all the N fractions, except amino sugar-N, after harvest of both crops in soybean-wheat system on a Typic Haplustert. They also noted significant influences of hydrolysable $\text{NH}_3\text{-N}$ ($r = 0.91$), amino acid N ($r = 0.65$) and amino sugar N ($r = 0.78$) with grain yield of wheat.

In different soil types with various crop rotation and N management practices, Mulvaney *et al.* (2001) observed that amino sugar content of the soil was highly correlated with crop yield, but the content of total hydrolysable N, hydrolysable $\text{NH}_3\text{-N}$ and amino acid N did not give any consistent reading.

The foregoing paragraphs have mostly shown that amino acid, amino sugar and hydrolysable ammonia fractions of organic N to be positively and significantly correlated with crop yield and N uptake. However, attempts need to be made to ascertain the extent and rate of contribution of each of the fractions to yield and N uptake by a particular crop.

2.7. Total phosphorus content of soil

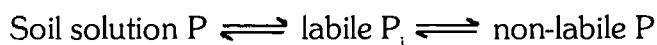
Phosphorus is the eleventh most abundant element in the earth's crust. The total P content of surface soil mostly varies between 0.02 and 0.1% (Tisdale *et al.*, 1993). While Paramasivan and Udayasoorian (1991) reported total P values of tropical surface soils to range between 682 and 1100 mg kg^{-1} soil, Fisher *et al.* (1998) observed that the total P content of top soil sampled from a grazed pasture averaged at 1264 mg kg^{-1} soil. The total P content of the soil is higher in soils of basaltic origin (Spain, 1990; Saker *et al.*, 1999).

Total P content decreases with depth of the soil (Paramasivan and Udayasoorian, 1991). It also decreases with the age of the soil (Lajtha and Schlesinger, 1988), an

example being the higher content of Entisols compared to Alfisols (Patiram *et al.*, 1993). Decline in soil organic carbon could explain both the above phenomena, which is also why the cultivated soils exhibit lesser total P content as compared to the virgin soil (Thomson *et al.*, 1954; Bharadwaj *et al.*, 1994). The application of phosphatic fertilizers (Sharma *et al.*, 1987b; Turner *et al.*, 2002), balanced fertilization and application of FYM along with chemical fertilizers (Santhy *et al.*, 2001b) have shown to improve the total P content of soil.

2.8. Distribution of phosphorus in soil

The part of the P cycle of most immediate importance to plants, and soil organisms, can be summarized by the following equilibria:



Rapid dissolution of labile P_i fraction is small and the P cycle is tightly closed, most of the P entering plants is supplied from the slow recycling of plant residue P through microbial processes in the soils. However, in agricultural systems, which are more open, P is removed either through the crop produce or lost by surface runoff and erosion. Consequently, fertilizer P is added to compensate for these losses and to take care of the immediate crop needs. But, the crop utilization of inorganic P is often very low and varies from 8 to 33%, depending on the nature of crops and soils (Mattingly, 1975). A redeeming fact, however, is that the residual P is not lost, but is accumulated in the soil (Alessi and Power, 1980; Halvorson and Black, 1985) and gets distributed among the pools of P shown in the above equilibria. The three pools have been further compartmentalized by various workers (Peterson and Corey, 1966; Syers *et al.*, 1972; Hedley *et al.*, 1982) depending on the reagents used in the process of sequential P extraction from soils. The allocation of the residual P among the various pools depends on the inherent soil properties, crop species, management and fertilizer history, and climate.

After eight years of cropping with peanut-wheat rotation in a Typic Ustipsamment, where fertilizer P was added to either one (alternate) or both the crops (cumulative),

Aulakh and Pasricha (1991) observed that higher amount of the applied P was converted to the labile (resin, NaHCO_3 and microbial P) and semi- labile (NaOH and sonicated NaOH P) pools when P was applied alternately. This suggests that increased rates and frequency of P application tend to enhance the conversion of residual-P to more stable pools, which take a long time to release P to the crops.

Another broad way of grouping the different P forms in the soils is based on the process through which P is released into the soil solution. As per this, P is classified into two pools, *viz.* organic (P released into solution through microbially mediated mineralization processes) and inorganic (P released through the interplay of dissolution-precipitation and adsorption-desorption processes). These two forms of P are interrelated in that the increase in one form brings about a decrease in the other (Thompson *et al.*, 1954; Van Diest and Black, 1959).

The above two forms are discussed in some detail in the following sections.

2.8.1. Organic Phosphorus

Organic P represents on an average 50% of the total P in soils and typically varies between 15 and 80% in most soils (Stevenson, 1986). Under Indian conditions, values as low as 16.6% in acid hill soils (Sharma and Tripathi, 1992) to as high as 39.2% in slightly alkaline soils (Paramasivan and Udayasoorian, 1991) have been reported. The quantity of organic phosphorus is mainly dependent on the organic matter content in soil and is found to follow the same trend of variation as that of the total P.

Organic phosphorus generally occurs in soil as esters of orthophosphoric acid (Anderson, 1980). Inositol hexakis- and pentakis-phosphates, primarily of plant origin, comprise up to 60% of soil organic P along with smaller amounts of phospholipids and nucleotides, and traces of sugar phosphates, phosphoproteins, glycerophosphate and phosphonates (Tate, 1984). A large proportion of organic P still remains to be identified.

The decrease in the organic P is brought about by a decrease in organic carbon content of soil (Paramasivan and Udayasoorian, 1991), which is true for a cultivated

soil as compared to an uncultivated one (Rossel *et al.*, 2000). Presence of plants also decreases the organic P content of soil near the roots as was observed earlier by Sekhon and Black (1969) which may be due to the release of readily assimilable organic substances excreted by roots and subsequent mineralization. Moreover, plant roots produce phosphatase enzyme, capable of dephosphorylating organic phosphorus. The ways of improving the organic P status of a soil are by the addition of P fertilizers (Aulakh and Pasricha, 1991; Sood and Bhardwaj, 1992; Zhang *et al.*, 1998) and organic manures (Reddy *et al.*, 2000).

The maintenance of organic P assumes significance considering the fact that most of the P fixed in the inorganic forms are very sparingly available for plant uptake (Tate, 1984). Soil organic phosphorus plays a significant role in P nutrition of crops in high P-fixing soils of the tropics (Appiah and Thomas, 1982; Reddy *et al.*, 2000) and under semi-arid ecosystems (Cole *et al.*, 1977; Cross and Schlesinger, 2001), but it is not found to play an important role in soils already receiving high levels of inorganic P (Guo *et al.*, 2000). Appiah and Thomas (1982) observed a low activity of phosphatase with the application of P fertilizers.

The importance of organic P in releasing phosphate to the soil solution can be realized from the study conducted by Hedley *et al.* (1982). On a wheat-wheat-fallow system, continuous cropping reduced total P content of soil by 29% of its initial value, of which 74% was organic and residual P. Out of the total P lost, 22% came from extractable organic P and 52% from stable forms, indicating that considerable microbially-mediated mineralization had occurred. This study was also supported by Charter and Mattingly (1980) and Tiessen *et al.* (1982). However, Perrott *et al.* (1992) observed in a soil of hill country site of New Zealand under pasture, that no net utilization of soil organic phosphorus occurred when application of phosphatic fertilizer was withheld, although, there was a decline in pasture production. On the contrary, accumulation of organic phosphorus was found in both fertilized and unfertilized plots. Immobilization of inorganic P into organic forms resulted in significant decline of the available soil P

status of unfertilized plots. This shows that the organic P content does not play an important role in soils of cool temperate regions.

2.8.2. Inorganic Phosphorus Fractions

Inorganic P usually constitutes the dominant part of total P in Indian soils. It accounts for about 52-95, 54-65 and 50-94% of total P in lateritic soils of Maharashtra, rice growing soils of West Bengal and Hapludalfs of Himachal Pradesh, respectively (Tandon, 1987).

Inorganic P can be broadly grouped into calcium phosphate (Ca-P), iron phosphate (Fe-P), aluminium phosphate (Al-P) and reductant soluble phosphate (RS-P) (Chang and Jackson, 1957). These phosphate fractions occur in all soils, but differ in proportion according to soil properties (Kanwar *et al.*, 1983; Chakravorthy and Barua, 1987; Dwivedi *et al.*, 1987; Paramasivan and Udayasoorian, 1991). Earlier Lindsay and Moreno (1960) had observed that the solubility of Ca-P decreases whereas that of Al and Fe-P increases with the increase in pH. However, the order of abundance of different P fractions is nearly constant for a class of soil. In rice growing soils of West Bengal, Ca-P, Fe-P, Al-P, RS-P and occluded P constituted about 47, 28, 16, 7 and 2% of total inorganically bound P (Khan and Mandal, 1973). Singh and Sinha (1977) reported that in the acid soils of Bihar, 50% of total P was in occluded form. Among the different fractions of inorganic P, Ca-P formed the dominant fraction followed by reductant-soluble-P, Fe-P and Al-P in Alfisol, Inceptisol and Entisol of Uttar Pradesh (Tandon, 1987). In major soil series of Madurai district of Tamil Nadu having near neutral pH, Paramasivan and Udayasoorian (1991) observed that the most dominant P fraction was Ca-P followed by Fe-P and Al-P.

In tea growing soils of Assam, the contribution of different fractions towards inorganic P was in the decreasing order of Al-P, Fe-P, RS-P and Ca-P (Khara and Balloli, 1994). And in calcareous soils, the usual trend is that Ca-P is the most dominant P fraction followed by RS-P, Fe-P and Al-P (Dakshinamurthy and Murugappan, 1996).

A knowledge of the various forms of P present in soil and the conditions under which these become available to plants is helpful in assessing the availability of P to the crops. The relative solubility of inorganic P fractions governs the replenishment of the labile pool from which plant absorbs P (Singhanhia and Goswami, 1979).

Through several studies, it is now well established that a dynamic equilibrium tends to exist among the different fractions of P in soil. Inter-conversion is a distinct possibility under natural soil conditions. Additionally, the type of plants grown on a site also influences the transformation of P in soil. Jain and Sarkar (1979) found that Ca-P and Fe-P got converted to saloid-P and Al-P after wheat harvest. They were of the opinion that it was due to the exudation of HCO_3^- and H^+ by wheat roots which helped in the conversion. Similarly Dhillon and Dev (1988) reported that in a calcareous soil the saloid-P improved on cropping in low P soils and declined in high P soils. The status of saloid P was lowered after the *kharif* crops i.e. rice, maize and pearl millet and improved on growing *rabi* crop i.e. wheat. Iron-P was depleted due to rice but improved after maize and pearl millet. Calcium-P continued to decrease due to growing of these crops and the decline was more in rice-wheat rotation.

It has been observed that application of phosphatic fertilizers to soil brings about an increase in different P fractions (Brar *et al.*, 1987; McKenzie *et al.*, 1992; Kumar *et al.*, 2000; Bhardwaj *et al.*, 2000). Bharadwaj *et al.* (1994) had obtained higher values of different inorganic P fractions in fallow plots in comparison to the control plot as cropping without fertilization depleted the soil P due to crop uptake. Similar results were obtained by Tiessen *et al.* (1982). Subramanian and Kumaraswamy (1989b) had found that omission of phosphatic fertilization for many years increased the phosphorus fixing capacity of the soil and phosphorus fertilization, particularly in combination with organic manure reduced it. A large part of fertilizer P applied to the soil not supplied with P for a long time gets fixed and becomes non-available. The amount of P fixed increased with increasing level of P, but the percentage of fixation decreased. Zhang and McKenzie (1997) also observed that addition of manures decreased the fixation of inorganic phosphates and increased the availability of P to plants.

Soil phosphorus fractionation studies in laboratory under aerobic regime have revealed that a major portion of the applied P is retained as Al-P, Fe-P, and Ca-P (Singh and Bahaman, 1976), but the transformation of applied P is likely to be greatly altered in the presence of actively growing plant roots which give out acidic exudates (Singhania and Goswami, 1978; Jain and Sarkar, 1979), so also with the type of fertilizer applied (Tripathi and Minhas, 1991; More and Agale, 1993).

In greenhouse experiments, Bhujbal (1989) observed that most of the added ammonium nitrate phosphate and monoammonium phosphate got transformed into Ca-P in Vertisol, whereas, in the Aridisol, Mollisol, Alfisol and Ultisol, Al-P and Fe-P were predominant. The reductant soluble P was marginally increased and the saloid-P which is considered to be non-specific and loosely-bound, recorded the lowest value among all the fractions. Calcareous soils are reported to retain large amount of P as Ca-P irrespective of the nature and kind of added fertilizer due to the more stabilized nature of calcium system under high pH (Subramanian and Kumaraswamy, 1989b; Jaggi, 1991). In an acid soil, Krishnappa (1991) obtained higher Fe-P followed by Al-P with fertilizer P application.

It was observed, in P deficient sandy loam soil (Ustochrept) of Hisar to which different phosphatic fertilizers were applied, that with the passage of time, the saloid P content of the soil decreased, whereas the Al-P, Fe-P and Ca-P increased (Chaudhary and Batra, 1992).

Linguist *et al.* (1997) recovered most part of the fertilizer P in either the moderately labile (54%) or recalcitrant P (37%) pools. Only 6 to 10% of fertilizer P was recovered in the labile P pool in an Ultisol after three months of fertilizer application.

According to Bahl and Singh (1997) applied P gets transformed more into saloid P and Ca-P in alkaline soils and, Al-P and saloid-P in acid soils. In a sandy loam alkaline soil (Typic Ustochrept), Jain and Sarkar (1980) registered an increase in Al-P and Fe-P in the initial stages of crop growth and decrease in Ca-P. The magnitude of

transformation of Ca-P into Al-P and Fe-P fractions was less in unfertilized plots than in fertilized plots. The distribution of applied P among different fractions and their availability to crops also depends on the type of soil to which it is applied (Wagar *et al.*, 1986; Guo and Yost, 1998).

In different soils with varying weathering intensity, i.e. Vertisol, Mollisol, Ultisol, Oxisol *etc.*, Guo *et al.* (2000) observed that the Fe-impregnated strip-P and inorganic $\text{NaHCO}_3\text{-P}$ ($\text{NaHCO}_3\text{-Pi}$) decreased the most in response to plant P withdrawal followed by NaOH-P (NaOH-Pi). The HCl-P and residual P seemed to act as a buffer for strip-P and $\text{NaHCO}_3\text{-Pi}$ in slightly weathered soils, whereas NaOH-Pi seemed to act as buffering pool in the highly weathered soils. Residual P in the slightly weathered soils was available to plants for a short time. In contrast, residual P in the highly weathered soils accumulate in the presence of intensive plant uptake indicating that it was unavailable to the plants.

The relative distributions of inorganic P fractions after application of phosphatic fertilizers to a P responsive calcareous montane soil followed the order $\text{HCl-P} > \text{NaOH-P} > \text{Resin-P} > \text{bicarbonate-P} > \text{water soluble-P}$, with NaOH-P and HCl-P representing 75% of the total inorganic P fractions (Yang *et al.*, 2002)

Iyamuremye *et al.* (1996) studied the effects of organic amendments (manure, lucerne and wheat straw) on P fractions after 28-day incubation on five acid soils of high P-fixing capacity. Manures and lucerne residues increased resin-Pi and $\text{NaHCO}_3\text{-Pi}$ (biologically available), $\text{NaHCO}_3\text{-Po}$ (readily mineralizable) and NaOH-Pi (chemisorbed) in all soils. Wheat straw had little effect due to its low P content. It was observed that the different P fractions increased when crop residues were allowed to decompose on the soil surface rather than being incorporated (Weil *et al.*, 1988). However, Huffman *et al.* (1996) noted that soil texture had greater effect on P transformation than did residue placement.

Addition of FYM increased saloid-P in all the soils under study, Al-P in Ustochrept, Fe-P and Al-P in Haplustalf and Ca-P in Calcifluent (Singh and Sarkar, 1986). Bahl and Singh (1997) observed that by the application of green manures, the saloid-P

content increased at the expense of other P fractions. But with the increase in period of incubation in an Inceptisol to which organic manures were added with or without inorganic fertilizers, Khankhane and Yadav (2000) observed a decrease in saloid-P while Al-P, Fe-P and Ca-P increased significantly. However, Bharadwaj *et al.* (2000) did not observe any accumulation of different P fractions by the application of only FYM to an acid soil in comparison to control.

In a study on the transformation of added P to a calcareous soil in combination with organic manure and BGA, Prasad and Rokima (1991b) found that most of the added P was transformed into organic P and Ca-P (40-45% of total) and very little to water soluble P (0.23 to 0.34%), saloid-P (0.64 to 1.69%), Al-P (0.94 to 1.40%) and Fe-P (0.49 to 1.34%).

Reddy *et al.* (1999) observed a significant increase in NaHCO_3 -Pi and -Po (labile P), and NaOH-P, and Po (moderately labile P) fractions of a Typic Ustochrept under soybean-wheat rotation as a consequence of the integrated application of inorganic P fertilizer along with organic manures.

2.9. Relationship of various phosphorus fractions in soil with crop yield, phosphorus availability and uptake of phosphorus by crops

The availability of P to a growing plant is influenced by various soil P fractions. Taking the help of statistical procedures like correlation, multiple regression, path analysis, *etc.*, researchers have quantified the contribution of various P fractions towards available P.

Using path analysis, Tiessen *et al.* (1984) found that labile P in Mollisols is associated with inorganic bicarbonate and hydroxide extractable P, but in Ultisols, they found that labile P was largely from organic P.

The uptake by wheat was significantly correlated with saloid bound P ($r = 0.78$ to 0.94), Al-P ($r = 0.76$ to 0.90) and Fe-P ($r = 0.67$ to 0.90) in different soils (Singh and Sarkar, 1986). The importance of Al-P as a source of available P for crop uptake had

earlier been reported by many workers (Martens *et al.*, 1969; Khara and Datta, 1969; Jain and Sarkar, 1980; Sharma *et al.*, 1985).

Olsen P, crop yield and P uptake by different crops correlated significantly with saloid P, Al-P and Ca-P of soil belonging to Typic Ustochrept (Dhillon and Dev, 1990). In pot experiment, taking soils of varying pH and nutrient status, Jaggi *et al.* (1990) observed that all the inorganic phosphate fractions, except Ca-P, were significantly correlated with all the yield parameters. Correlation coefficient was the highest with Al-P, followed by saloid-P or Fe-P fraction. Al-P fraction alone contributed 70 and 68% towards grain yield and P uptake by grains respectively, and the contribution of saloid-P for the per cent grain yield was estimated to be 62.

Multiple regression equation depicting the relationship among available P and different P fractions has been worked out in several studies (Jaggi *et al.*, 1990; Tomar and Tek Chand, 1992).

Prasad and Rokima (1991b) observed that all the P fractions were correlated with yield ($r = 0.77^{**}$ to 0.99^{**}), P content in grain ($r = 0.50^{*}$ to 0.82^{**}) and uptake ($r = 0.73^{**}$ to 0.98^{**}) of rice and wheat. Regression and path coefficient analyses indicated that Al-P, Fe-P and saloid P were dominant forms that contributed most towards available P and its subsequent utilization by rice and wheat.

Stepwise regression analyses show that Al-P and Ca-P are the predominant fractions contributing towards availability of phosphorus in an acid Alfisol of Himachal Pradesh (Rao and Chakrabarty, 1994). A significant correlation between dry matter yield of maize and saloid-P plus Al-P and Fe-P was observed by Bahl and Singh (1997). In a field experiment, Saha *et al.* (2000) observed that Fe-P and Al-P were significantly correlated with both available P in soil and P uptake by wheat in an acid soil. Ca-P also had positive correlation, but was not found to be significant.

In a sandy loam soil, Schmidt *et al.* (1996) observed that P extracted in the resin, inorganic NaHCO_3 and inorganic NaOH-fractions represented sources of soil P

for the crop uptake under the conditions of deficient P fertilization. These fractions are also the P sinks under the conditions of excess P fertilization. Similar observations were also reported by Reddy *et al.* (1999).

Positive correlations were found between labile organic P, moderately labile organic P, available P and P taken up by wheat, indicating that labile and moderately labile organic P were more available (Zhang *et al.*, 1998).

Resin-P, water soluble-P, bicarbonate extractable P, their summation (available P) and Olsen P were significantly correlated with the amount of P added and increased the most following P fertilizer application in a calcareous montane soil. During the 12 weeks of incubation, Olsen P was significantly correlated with Resin-P but not with bicarbonate-P, NaOH-P decreased the most among the three available fractions, yet Olsen P was relatively constant. Results suggest that available P fraction, especially the Resin-P fraction, may be a better indicators than Olsen P for predicting P availability and P response in calcareous soils (Yang *et al.*, 2002).

3. MATERIALS AND METHODS

The present study relates to one year of a field experiment on wheat-mungbean-maize cropping system practised at the Main Block 3B of the IARI farm. The materials used and the methods followed for this investigation are described in this chapter.

3.1 Location

The Indian Agricultural Research Institute is located at 28°38' N latitude and 77°10' E longitude, and is about 228 m above mean sea level. The experimental farm area of about 280 ha forms an integral part of this institute with a total area of nearly 500 ha.

3.2 Soil

The soil of the experimental field, a Typic Haplustept, belongs to the *Mehrauli* series. It is a non-calcareous alkaline sandy clay loam, low in cation exchange capacity (CEC). Characteristics of the soil sampled before sowing of wheat are shown in Table 1.

3.3 Climate and Weather Conditions

Delhi falls under semi-arid, sub-tropical zone characterized by hot summers and cold winters. Mean annual precipitation is about 650 mm, most of which is received during the south-west monsoon period of July to September. The weather conditions, which prevailed during the period of this investigation, are depicted in Figure 1.

3.4 Layout of the Field Experiment

The experiment was laid out in a randomized block design with a plot size of 15 × 3.25 m² for wheat and mungbean. The design followed for maize was split-plot, where the plot size was 5 × 3.25 m². Wheat, mungbean and maize were grown in that sequence. Wheat variety HD-2285 was sown on 4th December, 2000 and harvested on 8th April, 2001. Mungbean variety Pusa Bold-1 was sown after harvest of wheat on 16th April, 2001 and was allowed to grow till maturity. After two pickings, the stover was incorporated into the soil on 1st July, 2001. Maize variety PEMH-1 was sown on 10th

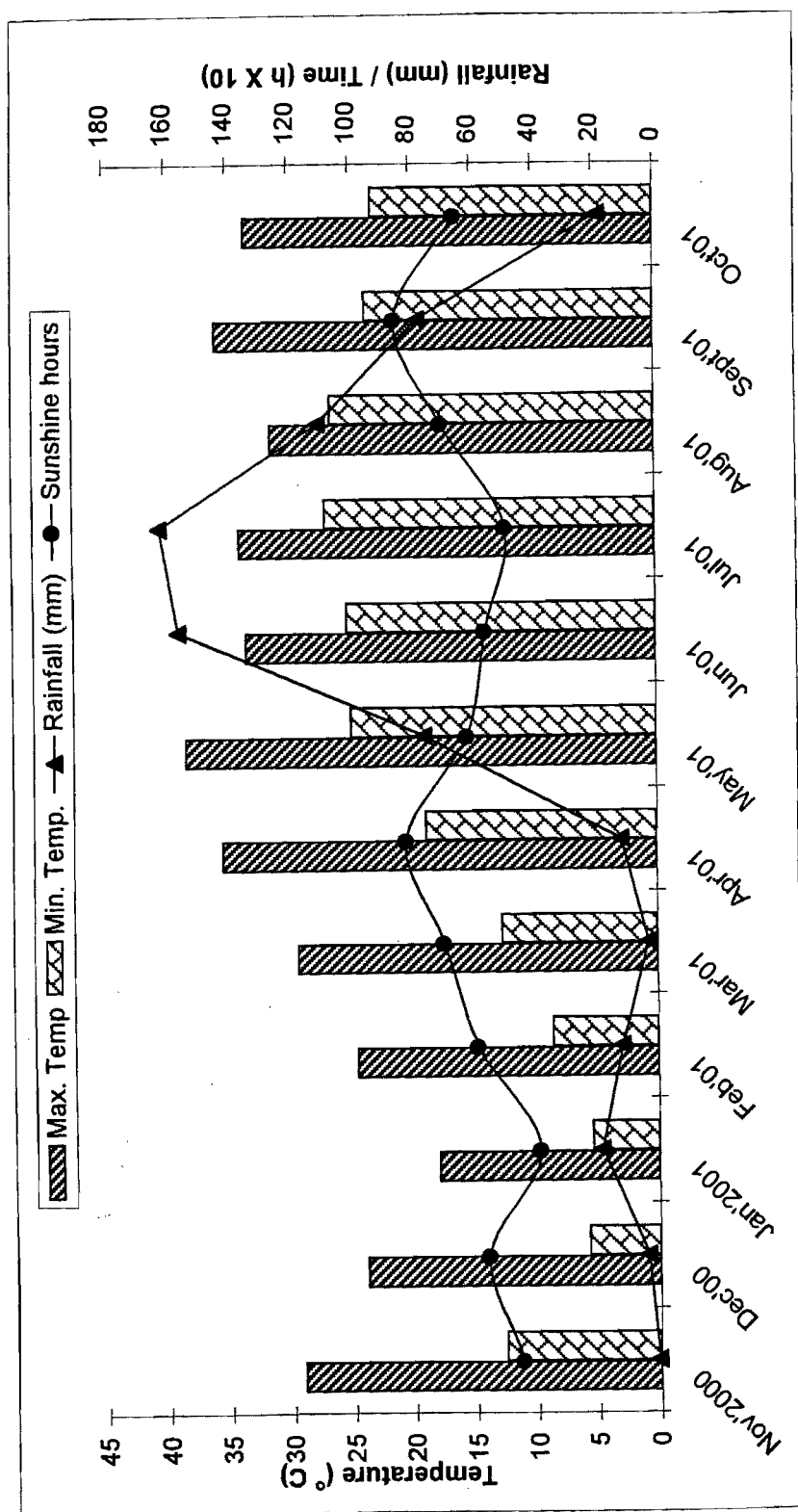


Figure 1. Meteorological observations during the field experiment

July, 2001 and harvested on 20th October, 2001. Standard package of practices were followed for all the three crops.

3.5 Treatments

3.5.1 Wheat

The treatment details for wheat are as follows:

T₁ : Control

T₂ : FYM only @ 5 t ha⁻¹

T₃ : N₁₂₀ only

T₄ : P₆₀ only

T₅ : N₆₀P₃₀K₃₀ (50 % of recommended dose of fertilizers)

T₆ : N₉₀P₄₅K₄₅ (75 % of recommended dose of fertilizers)

T₇ : N₁₂₀P₆₀K₆₀ (100 % of recommended dose of fertilizers)

T₈ : N₉₀P₄₅K₄₅ + FYM @ 5 t ha⁻¹

T₉ : N₆₀P₃₀K₃₀ + FYM @ 5 t ha⁻¹

P and K in the treatments imply P₂O₅ and K₂O respectively.

Replications - Three

Total number of plots - 27

Phosphorus and potassium were applied as basal whereas nitrogen was applied in three splits, viz., before sowing, at tillering and before heading stages. FYM was incorporated before sowing of wheat.

3.5.2 Mungbean

No fertilizer or manure was added to mungbean.

3.5.3 Maize

Maize was taken up in a split-plot design. Each main plot of wheat (and also mungbean) was divided into three sub-plots for raising maize with the following treatments.

M_1 : Control ($N_0P_0K_0$)

M_2 : $N_{60}P_{30}K_{30}$ (50 % of recommended dose of fertilizers)

M_3 : $N_{90}P_{45}K_{45}$ (75 % of recommended dose of fertilizers)

Replications - Three

Total number of plots – 81

Phosphorus and potassium were added as basal where as nitrogen in this case was applied in split before sowing of maize, at knee-high stage and before silking stage.

3.6 Sample Collection

3.6.1 Soil sampling

Surface samples (0-15 cm) were collected before sowing of wheat and thereafter at different physiological stages of wheat (heading, dough and after harvest), mungbean (flowering and before incorporation) and maize (before sowing, silking, dough and after harvest). Samples were dried in shade, ground and passed through 2 mm sieve for carrying out various chemical analyses.

3.6.2 Plant sampling

After the harvest of wheat, mungbean and maize, grain and straw/stover yield were recorded separately for each crop and representative plant samples were collected from all the treatments. Samples were ground in a steel mill, passed through 1 mm sieve and used for estimating N, P and K content.

3.7 Laboratory Analyses

3.7.1 Soil analysis

The analyses of soil samples for different properties was carried out following standard procedures, as listed in Table 2.

The methods employed for analysis of the other soil properties and plant nutrient contents are given below:

Table 1. Some characteristics of the experimental field soil

Property	Value
Particle size distribution	
Sand (%)	53.5
Silt (%)	26.0
Clay (%)	20.5
Texture	Sandy clay loam
pH (1:2.5)	8.4
EC (dS m ⁻¹)	0.56
Organic C (g kg ⁻¹)	4.2
CEC [cmol (p ⁺) kg ⁻¹ soil]	11.9
Total N (mg kg ⁻¹ soil)	581
Available N (mg kg ⁻¹ soil)	82.4
Mineral N	
NH ₄ -N (mg kg ⁻¹ soil)	8.9
NO ₃ -N (mg kg ⁻¹ soil)	15.0
Total P (mg kg ⁻¹ soil)	571
Available P (mg kg ⁻¹ soil)	10.4
Available K (mg kg ⁻¹ soil)	160

Table 2. Analytical procedures used in soil analysis

Soil property	Method / Instrument / Reagent	Reference
Mechanical analysis	Bouyoucos hydrometer method	Day (1965)
pH	In 1:2 soil-water suspension using combined electrode (glass and calomel)	Jackson (1973)
Electrical conductivity	In 1:2 soil-water suspension using conductivity bridge	Jackson (1973)
Cation exchange capacity	1 N NaOAc for leaching cations	Bower (1952)
Organic carbon	Wet digestion method	Walkley and Black (1934)
Available nitrogen	Alkaline permanganate method	Subbiah and Asija (1956)
Available phosphorus	0.5 M NaHCO ₃ (pH 8.5)	Olsen <i>et al.</i> (1954)
Available potassium	1 N NH ₄ OAc (pH 7.0)	Hanway and Heidel, (1952)

3.7.1.1 Mineral nitrogen ($\text{NH}_4^+ + \text{NO}_3^- \text{-N}$)

Portions of ten grams of processed soil samples were extracted with 100 mL of 2 M KCl for 1 h. Extracts were then analysed for $\text{NH}_4\text{-N}$ by steam distillation with MgO in a micro-Kjeldahl system, and for $\text{NO}_3\text{-N}$ after reduction with Devarda's alloy followed by distillation (Bremner and Keeney, 1966). The ammonia (NH_3) evolved was trapped in 2% H_3BO_3 containing mixed indicator (0.099 g bromocresol green and 0.066 g methyl red dissolved in 100 mL of 95% ethanol) and then determined by titrating against 0.003 N H_2SO_4 .

3.7.1.2 Total nitrogen

Total nitrogen was determined by the method outlined by Bremner (1960). Soil was digested for 5 h with concentrated H_2SO_4 using salt-catalyst mixture ($\text{K}_2\text{SO}_4\text{:CuSO}_4\text{:Se}$ in the ratio 100:10:1). Following digestion, the material was diluted, made alkaline with 10 M NaOH and then steam distilled in a micro-Kjeldahl system for 4 minutes. The NH_3 released was absorbed in 2% H_3BO_3 containing mixed indicator, and titrated against 0.01 N H_2SO_4 to obtain the $\text{NH}_4\text{-N}$ content (say N_1). As this method did not account for the $\text{NO}_3\text{-N}$ in the soil, the value of $\text{NO}_3\text{-N}$ (as estimated by the reduction procedure mentioned in the previous section) was added to N_1 to compute the total N.

3.7.1.3 Total organic nitrogen

The value of mineral N obtained from section 3.7.1.1 was subtracted from the total N (as computed in the previous section) to calculate the total organic N.

3.7.1.4 Organic nitrogen fractions

The method proposed by Bremner (1965) was adopted in order to determine the various organic N fractions of soil. Ten grams of finely ground soil (< 100 mesh) was placed in a round bottom flask, to which 2 drops of *n*-octyl alcohol and 20 mL of 6 N HCl were added. The contents were heated for 12 h under reflux. After cooling, the

contents were filtered through Whatman No. 50 filter paper under suction using a Buchner funnel. The volume of the filtrate was made up to 100 mL and stored in a refrigerator. Twenty-five mL of cold aliquot was neutralized to pH 5.0 by using 5 N cold NaOH, and further to pH 6.5 with 0.5 N NaOH. The neutralized aliquot was employed for determination of different organic N fractions as described below:

a) *Total hydrolysable-N*: Ten mL of neutralized hydrolysate was pipetted out into a micro-kjeldahl distillation tube, to which 1 g of K_2SO_4 - $CuSO_4$ mixture and 4 mL of concentrated H_2SO_4 were added. The tubes were then kept in an aluminum block digester whose temperature was raised slowly to 370-390 °C and digestion was carried out for 1 h. After cooling, the digested material was diluted and steam distilled for 4 minutes after addition of 20 mL of 10 M NaOH. The NH_3 evolved was determined as described in section 3.7.1.2. From the value thus obtained, mineral NH_4 -N determined as per the method in section 3.7.1.1 was subtracted to obtain total hydrolysable-N.

b) *Unhydrolysable-N*: This fraction was obtained from the difference between total organic N and total hydrolysable N.

c) *Amino acid-N*: Five mL of neutralized hydrolysate was placed in a micro-kjeldahl distillation tube, to which 1 mL of 0.5 N NaOH was added, and the tube was heated in boiling water until the sample was reduced to 2-3 mL (approximately 20 min). The flask was allowed to cool and 500 mg of citric acid and 100 mg of ninhydrin were added. The tube was placed in a vigorously boiling water bath so as to completely immerse the bottom of the tube in boiling water. After about 1 minute, the tube was swirled for few seconds without removing it from the bath, and was allowed to remain in the bath for an additional 9 minutes. After cooling, 10 mL of phosphate-borate buffer and 1 mL of 5 N NaOH were added to the tube and steam distilled for 4 minutes. The NH_3 released was determined as per the method given in section 3.7.1.1.

d) *Ammonia-N*: Ten mL of hydrolysate was placed in a distillation tube. About 0.08 g of MgO was added and the contents were steam-distilled for 2.5 minutes.

e) *Ammonia + Amino sugar-N*: Ten mL of neutralized hydrolysate was placed in a distillation tube, to which 10 mL of phosphate-borate buffer was added and the contents were steam-distilled for 4 minutes.

In case of the section 3.7.1.4 (d) and (e), the $\text{NH}_4\text{-N}$ content after distillation was measured as per the section 3.7.1.1 and was corrected for the mineral $\text{NH}_4\text{-N}$ content as in the case of total hydrolysable -N .

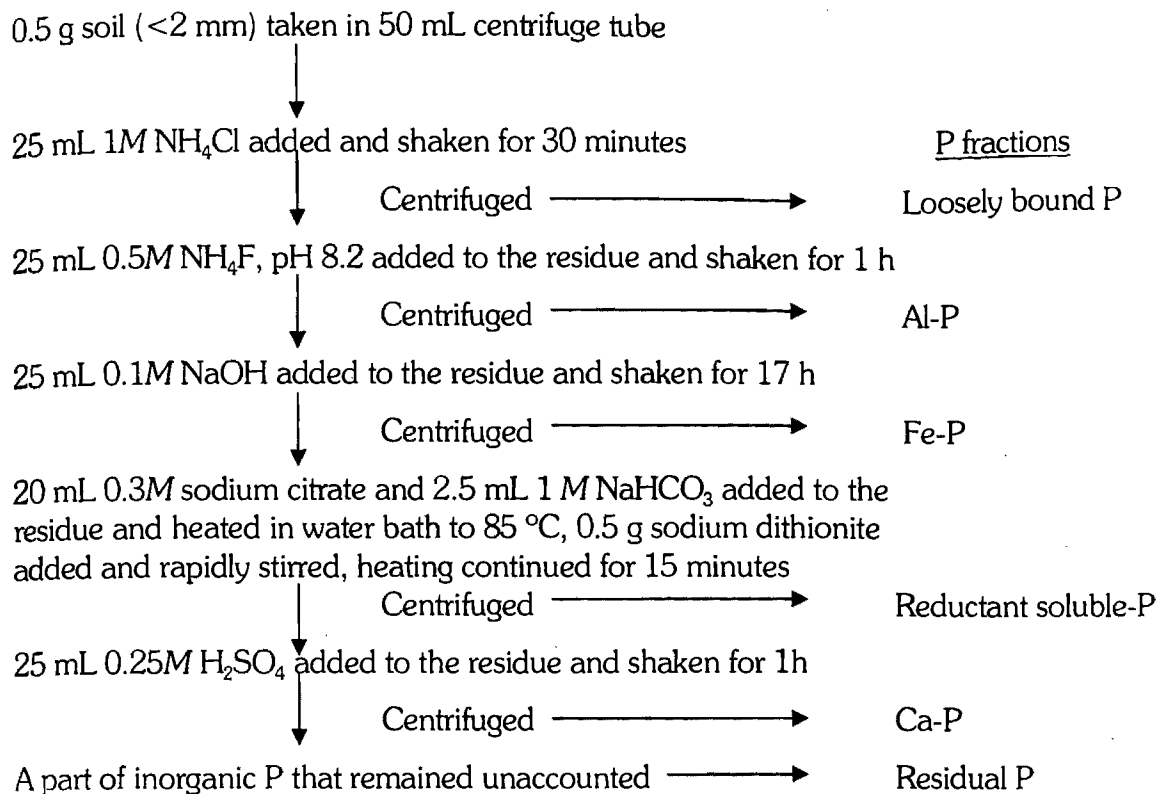
f) *Amino sugar-N*: This form of N was taken as the difference between the amount of N recovered in section 3.7.1.4 (d) and (e).

3.7.1.5 *Total, organic and inorganic phosphorus*

The method outlined by Walker and Adams (1958) was employed for the determination of total phosphorus. Two sets of 0.5 g soil were weighed. One set was taken in porcelain crucibles and placed in a muffle furnace. The temperature of the furnace was slowly increased to 550 °C and was maintained at that temperature for one h. After cooling the crucible, the soils were transferred to 50 mL centrifuge tubes. The second set of soil was also taken in 50 mL centrifuge tubes but without ignition. Twenty-five mL of 0.5 M H_2SO_4 was added to each tube, the tubes were stoppered and shaken for 16 h on a platform shaker, followed by centrifugation at 4500 rpm for 15 minutes. The P content of the filtrates was measured based on the ascorbic acid reduction of the ammonium phospho-molybdate complex, as outlined by Watanabe and Olsen (1965). The colour intensity was measured at a wavelength of 880 nm. The difference in P content between ignited (total P) and unignited samples (inorganic P) was taken as the organic P.

3.7.1.6 *Inorganic phosphorus fractions*

Fractionation of inorganic P was carried out by the method of Williams *et al.* (1971). The procedure is depicted through the following flowchart.



All the inorganic P fractions except reductant soluble-P was determined as per the ascorbic acid method described in the previous section. For determination of reductant soluble-P, 10 mL aliquots were taken in 125 mL separatory funnels to which 10 mL molybdate solution and 10 mL iso-butyl alcohol were added. The contents were shaken for two minutes. After five minutes of standing, the aqueous layer was discarded and the iso-butyl alcohol mixture was washed by shaking it for one minute with 10 mL 1 N H₂SO₄. The aqueous layer was discarded and 10 mL of ascorbic acid reagent was added (Page *et al.*, 1982), and the funnel was shaken for one minute. After discarding the aqueous layer, the blue coloured iso-butyl alcohol layer was transferred to 25 mL volumetric flask and the volume was made up with ethyl alcohol. The maximum colour intensity that developed in 10 minutes was measured at a wavelength of 880 nm.

3.7.2 Plant analysis

3.7.2.1 Nitrogen

Processed grain (0.5 g) and straw samples (1 g) were digested with 8 mL of concentrated H₂SO₄ and 2 g digestion mixture in micro-Kjeldahl tubes in a block digester

at 370-390 °C till the content turned green. The $\text{NH}_4\text{-N}$ was steam-distilled for 3 minutes by using 10 M NaOH, and was absorbed in 4% boric acid containing mixed indicator, followed by titration against 0.1N H_2SO_4 .

3.7.2.2 Phosphorus and potassium

For estimating total P and K contents, 10 mL of di-acid mixture (9:4 :: $\text{HNO}_3\text{:HClO}_4$) was added to 1 g of plant sample, and was digested on a hot plate till the content was colourless. After dilution, the content was filtered and the final volume was made up to 100 mL. Phosphate in the aliquot was determined colorimetrically as vanado-molybdophosphate yellow complex in nitric acid medium (Jackson, 1973). Potassium concentration in the solution was determined after obtaining the required dilution using a flamephotometer.

3.8 Statistical analysis

Statistical treatment of data obtained from the experiment was done according to standard procedures outlined in Gomez and Gomez (1984). Correlation and regression analyses was carried out with the help of Microsta package.

4. RESULTS AND DISCUSSION

The results obtained from the field and the laboratory studies are presented and discussed in this chapter.

4.1 YIELD AND NUTRIENT UPTAKE

4.1.1 Wheat

4.1.1.1 Yield

Grain, straw and total drymatter yield of wheat are depicted in Table 3. The highest grain yield (67.4 q ha^{-1}) was recorded under the treatment T_7 , which is 100% of the recommended dose of fertilizer (Figure 2). It was statistically at par with the treatment T_3 (N_{120} only), T_6 ($N_{90}P_{45}K_{45}$, i.e. 75% of the recommended dose), T_9 (50% of the recommended dose + FYM), T_4 (P_{60} only) and T_8 (75% of the recommended dose + FYM), which registered grain yields of 64.8, 63.4, 62.0, 61.8 and 61.5 q ha^{-1} , respectively. Increase in wheat yield by application of optimum fertilizer dose has been reported by several workers (Singh *et al.*, 1986; Pawar *et al.*, 1988). However, substituting a part of inorganic nitrogen through FYM compared favourably with 100% NPK. This is in concurrence with the findings of Singh and Nambiar (1986), Suri *et al.* (1995), Kumar and Singh (1997) and Vats *et al.* (2001). This could thus be considered as an economically viable option in the case of wheat. The lowest yield of 54.4 q ha^{-1} was obtained under control (T_1), but it was at par with T_2 (FYM only @ 5 t ha^{-1}) and T_5 ($N_{60}P_{30}K_{30}$ i.e. 50% of the recommended dose). The latter two treatments recorded grain yield of 56.7 and 56.3 q ha^{-1} , respectively. Application of FYM alone did not bring about significant improvement in the wheat yield as compared to control, which could be attributed to the slow rate of nutrient supply that failed to meet the immediate demands of the crop. Also, addition of FYM @ 5 t ha^{-1} , which supplied about 25 kg N ha^{-1} , was not sufficient to bring about substantial increase in yield. Similar observations were made by Sharma *et al.* (1995) and Zheng (1995). Significant increase in wheat yield in plots receiving P fertilizers as compared to no-P receiving plots have been reported by Sharma and De (1974) and Negi *et al.* (1992).

Yield of wheat straw was similar under the treatments receiving more than 50% of the recommended dose of N, viz. T₃, T₆, T₇, T₈ and T₉, with values of 128, 130, 138, 143 and 114 q ha⁻¹, respectively. The lowest straw yield of 97 q ha⁻¹ was recorded under control. Increase in straw yield with the application of higher doses of N is a common phenomenon in a soil low in available nitrogen status. The highest dry matter yield was registered under the treatment T₇ (206 q ha⁻¹) followed by T₈ (205 q ha⁻¹), both of which were statistically at par. Straw yield pattern followed almost similar trend as that of grain.

4.1.1.2 Nutrient (N, P, K) content and uptake

Nitrogen: The treatments T₇ (1.78%), T₃ (1.77%), T₄ (1.77%), T₆ (1.76%), T₈ (1.75%) and T₁ (1.74%) were found to be at par in terms of high nitrogen (N) content of wheat grain (Table 4). The lowest value was recorded under the treatment T₅ (1.63%), where only 50% of NPK was applied which was statistically similar to T₂ (1.68%). The nitrogen content of wheat straw followed a trend similar to grain, but was found to be 7-8 times lower than that in grain, indicating thereby translocation of nitrogen from the vegetative to the reproductive parts.

The treatment T₇ (100% NPK) recorded the highest N uptake of 120 kg ha⁻¹ in grain and it was followed by T₃ (100% N), T₆ (75% NPK) and T₄ (100% P), with uptake values of 115, 111 and 109 kg ha⁻¹, respectively. All the four treatments were at par. They were followed by T₈ (75% NPK + FYM, 108 kg ha⁻¹) and T₉ (50% NPK + FYM, 104 kg ha⁻¹), both being at par. The lowest grain N uptake was recorded under the treatment T₅ (50% NPK), with a value of 92 kg ha⁻¹. It was however at par with T₁ (control, 95 kg ha⁻¹) and T₂ (FYM only, 95 kg ha⁻¹). Application of nitrogen at lower level or through only FYM could not match with the other treatments in terms of N uptake by grain as these were unable to supply sufficient nitrogen to the crop in a soil which was low in available N status.

Higher uptake of N by wheat straw occurred under the treatments T₇ (47.5 kg ha⁻¹), T₈ (43.3 kg ha⁻¹), T₆ (38.3 kg ha⁻¹) and T₉ (38.0 kg ha⁻¹), which were not significantly

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Table 3. Effect of fertilizer and manurial treatments on yield (q ha^{-1}) of wheat

Treatments	Grain yield	Straw yield	Total dry matter yield
T ₁	54.4	97	151
T ₂	56.7	120	177
T ₃	64.8	128	193
T ₄	61.8	110	172
T ₅	56.3	102	158
T ₆	63.4	130	194
T ₇	67.4	138	206
T ₈	61.5	143	205
T ₉	62.0	114	176
Mean	60.9	120	181
CD ($P = 0.05$)	6.3	30	30

Table 4. Effect of fertilizer and manurial treatments on N content (%) and N uptake (kg N ha^{-1}) by wheat

Treatments	Grain		Straw		Total N uptake
	N content	N uptake	N content	N uptake	
T ₁	1.74	95	0.22	21.2	116
T ₂	1.68	95	0.19	23.0	118
T ₃	1.77	115	0.27	34.2	149
T ₄	1.77	109	0.31	33.3	143
T ₅	1.63	92	0.24	24.4	116
T ₆	1.76	111	0.29	38.3	150
T ₇	1.78	120	0.34	47.5	168
T ₈	1.75	108	0.31	43.3	151
T ₉	1.67	104	0.33	38.0	142
Mean	1.73	106	0.28	33.7	139
CD ($P = 0.05$)	0.07	12	0.05	10.0	14

T₁: control; T₂: FYM; T₃: N₁₂₀; T₄: P₆₀; T₅: N₆₀P₃₀K₃₀; T₆: N₉₀P₄₅K₄₅; T₇: N₁₂₀P₆₀K₆₀; T₈: T₆ + FYM; T₉: T₅ + FYM

different among themselves. They were followed by T_3 (34.2 kg ha⁻¹), T_4 (33.3 kg ha⁻¹) and T_5 (24.4 kg ha⁻¹), with the lowest value of 21.2 kg ha⁻¹ recorded under control (T_1).

Highest (168 kg ha⁻¹) value of total (grain and straw) N uptake by wheat was due to the treatment receiving 100% NPK (T_7). It was followed by T_8 (151 kg ha⁻¹), T_6 (150 kg ha⁻¹), T_3 (149 kg ha⁻¹), T_4 (143 kg ha⁻¹) and T_9 (142 kg ha⁻¹), all of which were at par. Lower N uptake values of 118, 116 and 116 kg ha⁻¹, respectively were registered under T_2 , T_1 and T_5 . These three treatments were found to be statistically similar. From the results, it is clear that the application of nitrogen at the recommended rate results in higher content and uptake of nitrogen by the wheat crop. This could be explained by the ability of these treatments to provide high amounts of readily available nitrogen to meet the crop demand. Similar results were obtained by Balasubramanian and Singh (1982), Swarup and Ghosh (1984) and Kumar *et al.* (1995). Application of phosphorus along with nitrogen also enhanced the N uptake by the crop through the phenomenon of synergism. Further, substitution of 25% of inorganic nitrogen through FYM was as good as 100% NPK due to the rapid mineralization of FYM in an environment of readily available nutrients.

Phosphorus: The treatment effects on the phosphorus (P) content of wheat grain was found to be variable (Table 5). However the uptake was highest under T_7 (100% recommended fertilizer dose, 23.8 kg ha⁻¹) followed by T_6 (75% recommended fertilizer dose, 23.2 kg ha⁻¹) and T_4 (100% P only, 22.2 kg ha⁻¹), all of which were at par. These were followed by the statistically similar treatments T_8 (75% recommended fertilizer dose + FYM, 21.7 kg ha⁻¹), T_9 (50% recommended fertilizer dose + FYM, 21.3 kg ha⁻¹), T_1 (Control, 20.6 kg ha⁻¹) and T_3 (100% N only, 20.5 kg ha⁻¹). The lowest value of 19.2 kg ha⁻¹ was recorded under T_2 (FYM only) followed by statistically similar treatment, T_5 (50% recommended fertilizer dose) recording a value at 19.5 kg ha⁻¹. The treatments T_7 (5.57 kg ha⁻¹), T_6 (4.78 kg ha⁻¹) and T_8 (4.69 kg ha⁻¹) were at par and superior to the rest of the treatments in influencing the P uptake by wheat straw. Highest total P uptake by wheat occurred where 100 and 75% of the recommended fertilizer dose, i.e. T_7

(29.4 kg ha⁻¹) and T₆ (28.0 kg ha⁻¹) were applied. They were superior to FYM-substitution treatments T₈ (26.4 kg ha⁻¹) and T₉ (24.7 kg ha⁻¹), and the treatment receiving 100% P (T₄, 25.5 kg ha⁻¹). These three treatments were at par among themselves. The lowest total P uptake was recorded under T₅ (21.9 kg ha⁻¹). Low P uptake by application of 50% of recommended NPK dose was also observed in a Typic Ustochrept by Singh *et al.* (1998). The influence of various treatments on the P uptake by wheat grain and straw is shown in Figure 3.

Potassium: Highest potassium (K) content (0.35%) and correspondingly, the highest K uptake (22.4 kg ha⁻¹) by wheat grain were recorded under the treatment T₆ (Table 6, Figure 3). Low K content of 0.29 and 0.30% were registered under T₃ and T₂, respectively, both of which were at par. The rest of the treatments recorded K content from 0.32 to 0.33%. The treatments T₆ (22.4 kg ha⁻¹) and T₈ (20.5 kg ha⁻¹) were at par with T₇ (21.6 kg ha⁻¹) in terms of K uptake by wheat grain. They were followed by T₉ and T₄, each with an uptake value of 19.6 kg ha⁻¹, T₃ (18.6 kg ha⁻¹), T₁ (17.4 kg ha⁻¹) and T₅ (18.2 kg ha⁻¹). The lowest K uptake was recorded under T₂ (16.8 kg ha⁻¹).

There were no significant differences among the treatments when K content of straw was considered. But the uptake values differed as a result of the differences in straw yield. Five treatments, *viz.* T₇ (371 kg ha⁻¹), T₃ (366 kg ha⁻¹), T₈ (358 kg ha⁻¹), T₆ (328 kg ha⁻¹) and T₂ (300 kg ha⁻¹) were at par among themselves and superior to the rest in influencing K uptake by straw. The lowest uptake value of 237 kg ha⁻¹ was registered under control (T₁). The same trend was followed by the treatments with respect to the total K uptake by wheat. The order followed was: T₇ (392 kg ha⁻¹) > T₃ (385 kg ha⁻¹) > T₈ (379 kg ha⁻¹) > T₆ (351 kg ha⁻¹) > T₂ (317 kg ha⁻¹) > T₉ (300 kg ha⁻¹) > T₄ (297 kg ha⁻¹) > T₅ (260 kg ha⁻¹) > T₁ (255 kg ha⁻¹). The results obtained with respect to potassium uptake suggest that there occurred a luxury consumption of this nutrient by the wheat crop. No specific trend could be observed when the different treatments were compared against the background of high available soil K.

Table 5. Effect of fertilizer and manurial treatments on P content (%) and P uptake (kg P ha⁻¹) by wheat

Treatments	Grain		Straw		Total P uptake
	P content	P uptake	P content	P uptake	
T ₁	0.38	20.6	0.03	2.95	23.6
T ₂	0.34	19.2	0.03	3.20	22.4
T ₃	0.32	20.5	0.02	2.56	23.1
T ₄	0.36	22.2	0.03	3.29	25.5
T ₅	0.35	19.5	0.02	2.41	21.9
T ₆	0.37	23.2	0.04	4.78	28.0
T ₇	0.35	23.8	0.04	5.57	29.4
T ₈	0.35	21.7	0.03	4.69	26.4
T ₉	0.34	21.3	0.03	3.41	24.7
Mean	0.35	21.4	0.03	3.65	25.0
CD (<i>P</i> = 0.05)	0.02	2.0	0.01	1.43	2.1

Table 6. Effect of fertilizer and manurial treatments on K content (%) and K uptake (kg K ha⁻¹) by wheat

Treatments	Grain		Straw		Total K uptake
	K content	K uptake	K content	K uptake	
T ₁	0.32	17.4	2.45	237	255
T ₂	0.30	16.8	2.51	300	317
T ₃	0.29	18.6	2.85	366	385
T ₄	0.32	19.6	2.52	277	297
T ₅	0.32	18.2	2.40	242	260
T ₆	0.35	22.4	2.52	328	351
T ₇	0.32	21.6	2.68	371	392
T ₈	0.33	20.5	2.49	358	379
T ₉	0.32	19.6	2.47	280	300
Mean	0.32	19.4	2.54	307	326
CD (<i>P</i> = 0.05)	0.02	2.3	NS	82	82

T₁: control; T₂: FYM; T₃: N₁₂₀; T₄: P₆₀; T₅: N₆₀P₃₀K₃₀; T₆: N₉₀P₄₅K₄₅; T₇: N₁₂₀P₆₀K₆₀; T₈: T₆ + FYM;
T₉: T₅ + FYM

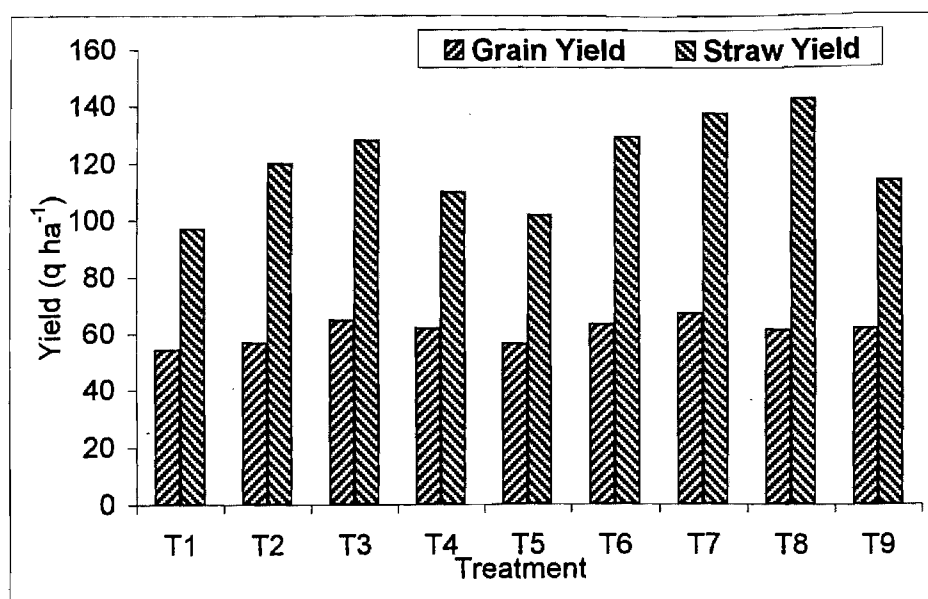


Figure 2. Effect of different treatments on the yield of wheat

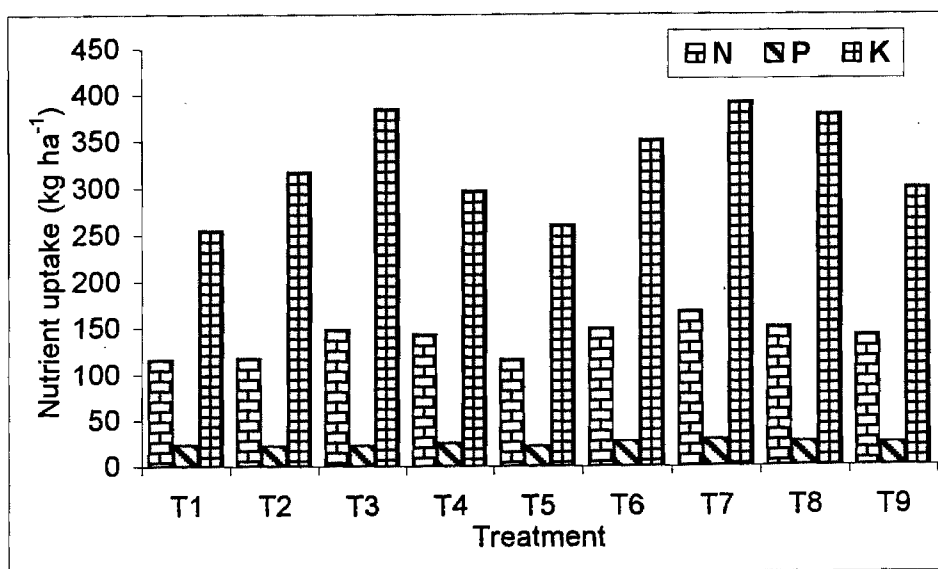


Figure 3. Effect of different treatments on the nutrient uptake by wheat

T₁:Control; T₂:FYM; T₃:N₁₂₀; T₄:P₆₀; T₅:N₆₀P₃₀K₃₀; T₆:N₉₀P₄₅K₄₅; T₇:N₁₂₀P₆₀K₆₀;
T₈:T₆+FYM; T₉:T₅+FYM

4.1.2 Mungbean

4.1.2.1 Yield

Mungbean variety Pusa Bold 1 (Pusa Vishal) was grown after the harvest of wheat without any fertilizer or manurial treatment. It was observed that none of the treatments applied to wheat had any significant effect on the grain and root biomass yield of mungbean, while the stover and total biomass yield was significantly affected (Table 7 and Figure 4). The differences in the grain yield were not evident as a result of incomplete picking of mungbean pods. The highest stover yield was obtained in the treatment T_4 (70.9 q ha^{-1}), where only optimum dose of phosphorus was added to wheat. However, it was found to be at par with T_5 (70.0 q ha^{-1}), T_8 (69.8 q ha^{-1}), T_6 (67.2 q ha^{-1}) and T_9 (67.0 q ha^{-1}). Application of FYM along with inorganics during wheat was found to have a residual effect on mungbean grown in succession. The lowest stover yield of 57.5 q ha^{-1} was recorded under control (T_1). The total biomass yield of mungbean was lowest under T_1 (70.7 q ha^{-1}), followed by T_3 (74.6 q ha^{-1}). Both of them were similar and inferior to rest of the treatments applied to wheat.

4.1.2.2 Nutrient content and uptake

As was observed in case of yield, the content and uptake of N and P by mungbean grain were not found to be significantly affected by any of the treatments applied to wheat (Table 8 and 9, Figure 5). Compared to the plots where only phosphorus was applied to wheat (T_4 , 101 kg ha^{-1}), all the other treatments were found to yield statistically similar and superior N uptake by mungbean stover. However the highest P uptake was registered under T_4 (17.3 kg ha^{-1}). The treatments combining FYM with fertilizer, viz. T_8 (17.0 kg ha^{-1}) and T_9 (17.2 kg ha^{-1}) compared favourably with T_4 with respect to P uptake by mungbean stover. The lowest P uptake was observed under the treatments where no P was applied to wheat, viz. T_1 (11.3 kg ha^{-1}) and T_3 (11.1 kg ha^{-1}). The rest of the treatments, viz. T_2 (13.6 kg ha^{-1}), T_5 (14.7 kg ha^{-1}), T_6 (13.9 kg ha^{-1}) and T_7 (13.6 kg ha^{-1}) were statistically at par and significantly superior to T_1 and T_3 . The total P uptake by mungbean almost followed a similar trend as that by stover. As in the case of yield, INM treatment to wheat resulted in high uptake of N and P in case of mungbean.

Table 7. Effect of fertilizer and manurial treatments on yield (q ha⁻¹) of mungbean

Treatments	Grain yield	Stover yield	Root yield	Total biomass yield
T ₁	6.11	57.5	7.11	70.7
T ₂	7.61	62.0	8.00	77.6
T ₃	7.62	59.6	7.29	74.6
T ₄	8.43	70.9	7.29	86.6
T ₅	8.78	70.0	7.65	86.4
T ₆	8.01	67.2	7.64	82.8
T ₇	8.16	62.7	7.64	78.5
T ₈	7.92	69.8	7.82	85.6
T ₉	8.21	67.0	8.00	83.2
Mean	7.87	65.2	7.61	80.7
CD (<i>P</i> = 0.05)	NS	8.2	NS	10.0

Table 8. Effect of fertilizer and manurial treatments on N content (%) and N uptake (kg N ha⁻¹) by mungbean

Treatments	Grain		Stover		Root		Total uptake
	Content	Uptake	Content	Uptake	Content	Uptake	
T ₁	3.86	23.5	2.12	122	0.83	5.87	152
T ₂	3.76	28.6	2.15	133	0.98	7.85	170
T ₃	3.76	28.7	2.01	120	0.81	5.91	155
T ₄	3.85	32.4	1.43	101	0.78	5.73	140
T ₅	3.79	33.4	1.81	127	0.86	6.54	167
T ₆	3.74	30.0	1.84	123	0.85	6.48	160
T ₇	3.75	30.6	2.05	129	0.93	7.17	167
T ₈	3.77	29.8	1.93	135	1.06	8.28	173
T ₉	3.62	29.8	2.07	139	0.97	7.73	176
Mean	3.76	29.6	1.94	126	0.90	6.84	162
CD (<i>P</i> = 0.05)	NS	NS	0.09	20	0.12	NS	NS

T₁: control; T₂: FYM; T₃: N₁₂₀; T₄: P₆₀; T₅: N₆₀P₃₀K₃₀; T₆: N₉₀P₄₅K₄₅; T₇: N₁₂₀P₆₀K₆₀; T₈: T₆ + FYM;
T₉: T₅ + FYM

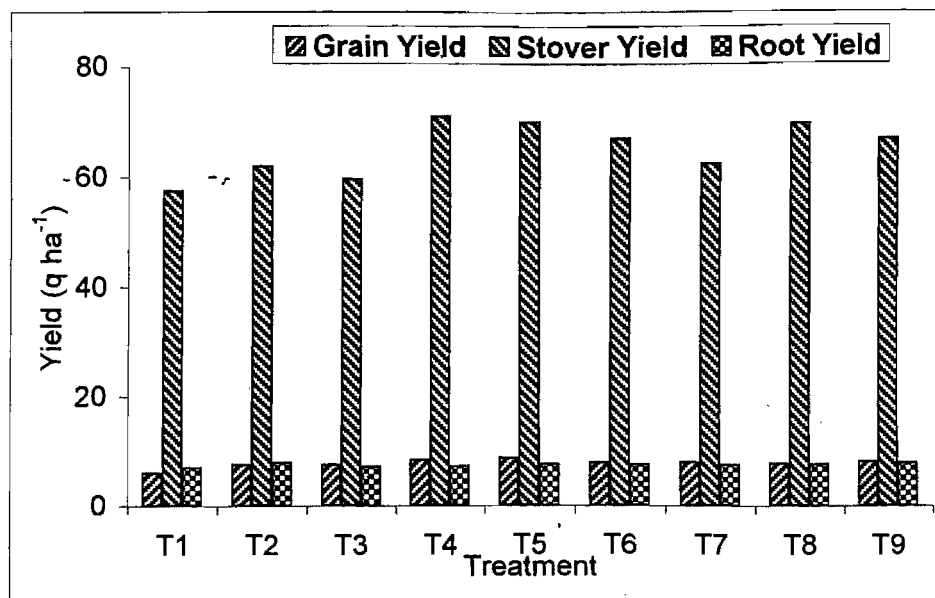


Figure 4. Effect of different treatments on the yield of mungbean

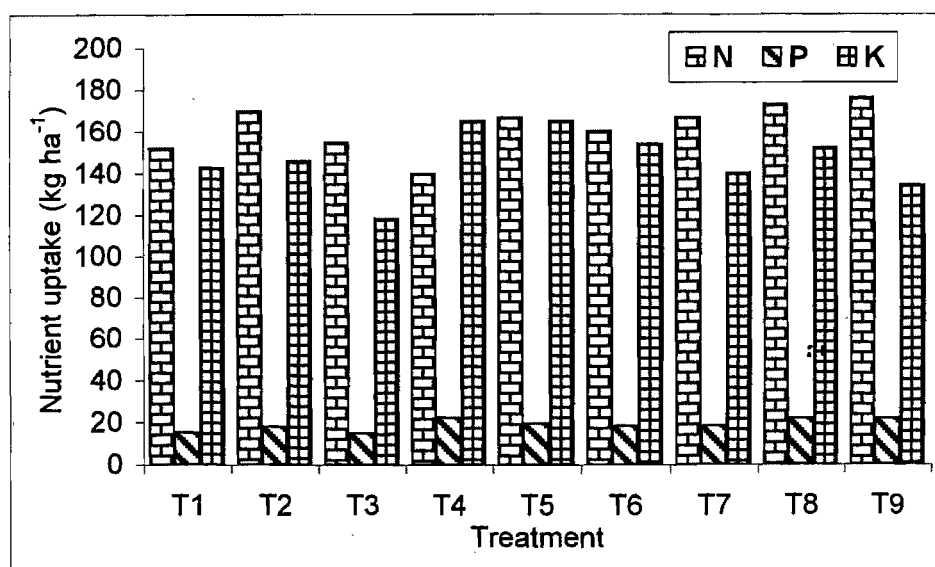


Figure 5. Effect of different treatments on the nutrient uptake by mungbean

T₁:Control; T₂:FYM; T₃:N₁₂₀; T₄:P₆₀; T₅:N₆₀P₃₀K₃₀; T₆:N₉₀P₄₅K₄₅; T₇:N₁₂₀P₆₀K₆₀;
T₈:T₆+FYM; T₉:T₅+FYM

Statistically similar treatments, namely T_1 (9 kg ha⁻¹), T_2 (10 kg ha⁻¹), T_3 (9.7 kg ha⁻¹) were found to be inferior to the rest of the treatments, all of which were found to be at par when the K uptake by mungbean grain was compared. The K content and uptake by mungbean stover were found to be variable. Variability was also observed in respect of total K uptake by mungbean (Table 10).

4.1.3 Maize

4.1.3.1 Yield

The grain and straw yields of maize were enhanced with increased level of application of fertilizer (Table 11). While M_3 (75% of recommended dose for maize) recorded the highest grain yield of 29.6 q ha⁻¹, the lowest yield (24.3 q ha⁻¹) was recorded under M_1 (control). Yield increase in maize is directly associated with the increased application of fertilizers as compared to control in N responsive soils (Muthuswamy *et al.*, 1990; Sharma *et al.*, 1995a; Singh *et al.*, 1999a). Among the treatments applied to wheat, the treatments T_8 and T_9 , where FYM was supplemented along with inorganic fertilizer, resulted in higher grain yields of 32.3 and 30.7 q ha⁻¹ respectively, with the former treatment being superior to the latter (Figure 6). These treatments were followed by T_7 (29.2 q ha⁻¹), which was statistically superior to T_6 (27.5 q ha⁻¹). Increase in maize yield through the residual effect of FYM applied to wheat was also reported by Negi *et al.* (1992). The lowest grain yield of 22.2 q ha⁻¹ was registered under control (T_1). Application of FYM alone (T_2 , 25.9 q ha⁻¹) did not produce results as good as the treatments receiving integrated nutrient management. Higher stover yield was obtained under T_8 (64.7 q ha⁻¹), T_9 (59.4 q ha⁻¹) and T_7 (58.2 q ha⁻¹). The latter two treatments were at par with each other. They were followed by T_3 (55.0 q ha⁻¹), T_6 (54.5 q ha⁻¹), T_2 (51.4 q ha⁻¹) and T_4 (50.0 q ha⁻¹). The lowest stover yield was recorded under T_1 (45.1 q ha⁻¹). Similar trend was observed in case of total dry matter yield. The highest dry matter yield of 87.1 q ha⁻¹ was produced under the sub-plot treatment M_3 . This was superior to the yields of 82.4 and 75.9 q ha⁻¹ produced under M_2 and M_1 , respectively (Figure 8).

Table 9. Effect of fertilizer and manurial treatments on P content (%) and P uptake (kg P ha⁻¹) by mungbean

Treatments	Grain		Stover		Root		Total uptake
	Content	Uptake	Content	Uptake	Content	Uptake	
T ₁	0.47	2.87	0.20	11.3	0.16	1.14	15.3
T ₂	0.46	3.50	0.22	13.6	0.14	1.12	18.2
T ₃	0.44	3.35	0.18	11.1	0.11	0.84	15.1
T ₄	0.48	4.03	0.24	17.3	0.14	1.02	22.3
T ₅	0.46	4.03	0.21	14.7	0.13	0.97	19.7
T ₆	0.46	3.68	0.21	13.9	0.13	0.97	18.5
T ₇	0.47	3.85	0.22	13.6	0.14	1.09	18.5
T ₈	0.48	3.77	0.24	17.0	0.14	1.12	21.8
T ₉	0.45	3.73	0.26	17.2	0.13	1.01	21.9
Mean	0.46	3.65	0.22	14.4	0.13	1.03	19.1
CD (<i>P</i> = 0.05)	NS	NS	0.03	2.6	0.01	NS	3.0

Table 10. Effect of fertilizer and manurial treatments on K content (%) and K uptake (kg K ha⁻¹) by mungbean

Treatments	Grain		Stover		Root		Total uptake
	Content	Uptake	Content	Uptake	Content	Uptake	
T ₁	1.47	9.0	2.16	124	1.40	10.0	143
T ₂	1.32	10.0	2.05	127	1.08	8.6	146
T ₃	1.29	9.7	1.68	100	1.19	8.7	118
T ₄	1.75	14.7	1.95	138	1.71	12.5	165
T ₅	1.65	14.5	2.04	143	1.01	7.9	165
T ₆	1.67	13.3	1.97	132	1.07	8.2	154
T ₇	1.60	13.1	1.89	119	1.08	8.3	140
T ₈	1.72	13.7	1.84	129	1.25	9.8	152
T ₉	1.63	13.4	1.63	110	1.44	11.5	134
Mean	1.57	12.4	1.91	125	1.25	9.5	146
CD (<i>P</i> = 0.05)	0.14	2.5	0.19	21	0.17	NS	24

T₁: control; T₂: FYM; T₃: N₁₂₀; T₄: P₆₀; T₅: N₆₀P₃₀K₃₀; T₆: N₉₀P₄₅K₄₅; T₇: N₁₂₀P₆₀K₆₀; T₈: T₆ + FYM; T₉: T₅ + FYM

Table 11. Effect of fertilizer and manurial treatments on yield (q ha⁻¹) of maize

Treatment	Grain				Stover				Total drymatter			
	M ₁	M ₂	M ₃	Mean	M ₁	M ₂	M ₃	Mean	M ₁	M ₂	M ₃	Mean
T ₁	18.2	22.6	25.7	22.2	40.2	45.9	49.2	45.1	58.4	68.6	74.9	67.3
T ₂	23.0	25.9	28.8	25.9	46.5	54.3	53.4	51.4	69.5	80.2	82.2	77.3
T ₃	23.7	26.4	28.7	26.3	54.1	51.4	59.4	55.0	77.9	77.9	88.2	81.3
T ₄	21.3	23.9	26.6	23.9	45.6	52.7	51.5	50.0	66.9	76.6	78.0	73.9
T ₅	23.6	26.7	28.8	26.3	49.3	54.8	55.8	53.3	73.0	81.4	84.6	79.7
T ₆	24.8	27.4	30.2	27.5	51.8	51.7	60.1	54.5	76.6	79.1	90.3	82.0
T ₇	25.7	30.6	31.4	29.2	52.2	59.7	62.7	58.2	77.9	90.3	94.1	87.4
T ₈	29.4	33.3	34.1	32.3	65.0	63.8	65.3	64.7	94.4	97.1	99.4	97.0
T ₉	28.9	31.2	31.9	30.7	59.3	58.8	59.9	59.4	88.2	90.1	91.9	90.0
Mean	24.3	27.6	29.6		51.6	54.8	57.4		75.9	82.4	87.1	
CD (P = 0.05)	T : 1.20; M : 0.64; T×M : NS				T : 3.87; M : 2.34; T×M : NS				T : 4.68; M : 2.74; T×M : NS			

T₁: control; T₂: FYM; T₃: N₁₂₀; T₄: P₆₀; T₅: N₆₀P₃₀K₃₀; T₆: N₉₀P₄₅K₄₅; T₇: N₁₂₀P₆₀K₆₀; T₈: T₆ + FYM;
T₉: T₅ + FYM
M₁: N₀P₀K₀; M₂: N₆₀P₃₀K₃₀; M₃: N₉₀P₄₅K₄₅

4.1.3.2 Nutrient content and uptake

Nitrogen: Nitrogen content in maize grain was found to increase with the application of fertilizers (Table 12). The treatment M_3 recorded N content of 1.53%, while the values under M_2 and M_1 were 1.48 and 1.41%, respectively. The treatments applied to wheat did not show any specific pattern with respect to N content of both grain and stover of maize. The N content of grain ranged from 1.44 to 1.55%, and that of straw, from 0.59 to 0.73%. As in case of grain, nitrogen content of stover increased as the treatments shifted from M_1 (0.57%) to M_3 (0.73%).

Consequent to the high yield, the nitrogen uptake by both grain and stover was highest under the treatment T_8 , as shown in Figure 7. The values were 48.0 and 47.0 kg ha⁻¹ for grain and stover, respectively (Table 13). In case of grain, T_8 was followed by T_9 (45.7 q ha⁻¹). Next were the treatments T_7 (42.2 kg ha⁻¹) and T_2 (40.2 kg ha⁻¹), both of which were at par. This indicates that there was a residual effect of FYM in terms of N release to maize. Incorporation of mungbean before sowing maize could enhance the N recovery from FYM applied to wheat due to increase in microbial population. Lower grain N uptake of 32.7 kg ha⁻¹ was registered under control T_1 (32.7 kg ha⁻¹) and T_4 (34.4 kg ha⁻¹). The same treatments recorded the lower stover N uptake values of 31.1 and 29.4 kg ha⁻¹ respectively. The order followed by the treatments applied to wheat in terms of total N uptake was: T_8 (95.1 kg ha⁻¹) > T_9 (84.7 kg ha⁻¹) > T_7 (81.2 kg ha⁻¹) > T_6 (76.9 kg ha⁻¹) > T_2 (75.0 kg ha⁻¹) > T_3 (72.4 kg ha⁻¹) > T_5 (70.8 kg ha⁻¹) > T_4 (63.8 kg ha⁻¹) = T_1 (63.8 kg ha⁻¹). The treatments applied to maize followed the order: M_3 (87.4 kg ha⁻¹) > M_2 (76.7 kg ha⁻¹) > M_1 (63.8 kg ha⁻¹) as is clear from Figure 9.

Phosphorus: Table 14 shows the influence of various treatments on the phosphorus (P) content of maize grain and stover. The P content of maize grain varied from 0.30 to 0.35%. While the lowest value was recorded under T_1 , the highest was obtained under T_4 . The subplot treatment M_3 resulted in a P content of 0.35%, and it was superior to M_2 (0.32%) and M_1 (0.32%). In case of stover, the order was: M_3 (0.18%)

Table 12. Effect of fertilizer and manurial treatments on the N content (%) of maize

Treatment	Grain				Stover			
	M ₁	M ₂	M ₃	Mean	M ₁	M ₂	M ₃	Mean
T ₁	1.41	1.43	1.56	1.47	0.55	0.72	0.77	0.68
T ₂	1.48	1.60	1.57	1.55	0.55	0.66	0.81	0.67
T ₃	1.36	1.53	1.55	1.48	0.56	0.59	0.66	0.60
T ₄	1.42	1.41	1.48	1.44	0.54	0.60	0.62	0.59
T ₅	1.33	1.49	1.56	1.46	0.57	0.59	0.65	0.60
T ₆	1.42	1.48	1.47	1.46	0.61	0.63	0.77	0.67
T ₇	1.42	1.43	1.49	1.44	0.51	0.73	0.74	0.66
T ₈	1.44	1.47	1.55	1.49	0.66	0.69	0.83	0.73
T ₉	1.43	1.49	1.54	1.49	0.54	0.68	0.74	0.65
Mean	1.41	1.48	1.53		0.57	0.65	0.73	
CD (<i>P</i> = 0.05)	T : 0.03; M : 0.04; T×N : NS				T : 0.07; M : 0.02; T×M : NS			

Table 13. Effect of fertilizer and manurial treatments on the N uptake (kg N ha⁻¹) by maize

Treatment	Grain				Stover				Total			
	M ₁	M ₂	M ₃	Mean	M ₁	M ₂	M ₃	Mean	M ₁	M ₂	M ₃	Mean
T ₁	25.7	32.4	40.1	32.7	22.2	33.1	37.9	31.1	47.9	65.5	78.0	63.8
T ₂	34.0	41.4	45.2	40.2	25.7	35.8	42.9	34.8	59.7	77.3	88.0	75.0
T ₃	32.3	40.4	44.5	39.1	30.4	30.4	39.2	33.3	62.7	70.8	83.7	72.4
T ₄	30.2	33.7	39.3	34.4	24.6	31.6	31.9	29.4	54.8	65.4	71.2	63.8
T ₅	31.4	39.8	44.9	38.7	28.1	32.1	36.1	32.1	59.5	71.9	80.9	70.8
T ₆	35.3	40.6	44.5	40.1	31.7	32.4	46.3	36.8	67.0	73.0	90.8	76.9
T ₇	36.3	43.7	46.7	42.2	26.6	43.7	46.4	38.9	63.0	87.4	93.1	81.2
T ₈	42.4	48.8	52.9	48.0	42.9	43.9	54.2	47.0	85.3	92.8	107.1	95.1
T ₉	41.4	46.5	49.2	45.7	32.7	40.0	44.3	39.0	74.1	86.5	93.5	84.7
Mean	34.3	40.8	45.2		29.4	35.9	42.1		63.8	76.7	87.4	
CD (<i>P</i> = 0.05)	T : 2.13; M : 1.20; T×M : NS				T : 4.0; M : 2.5; T×M : NS				T : 5.26; M : 3.30; T×M : NS			

T₁: control; T₂: FYM; T₃: N₁₂₀; T₄: P₆₀; T₅: N₆₀P₃₀K₃₀; T₆: N₉₀P₄₅K₄₅; T₇: N₁₂₀P₆₀K₆₀; T₈: T₆ + FYM;
T₉: T₅ + FYM

M₁: N₀P₀K₀; M₂: N₆₀P₃₀K₃₀; M₃: N₉₀P₄₅K₄₅

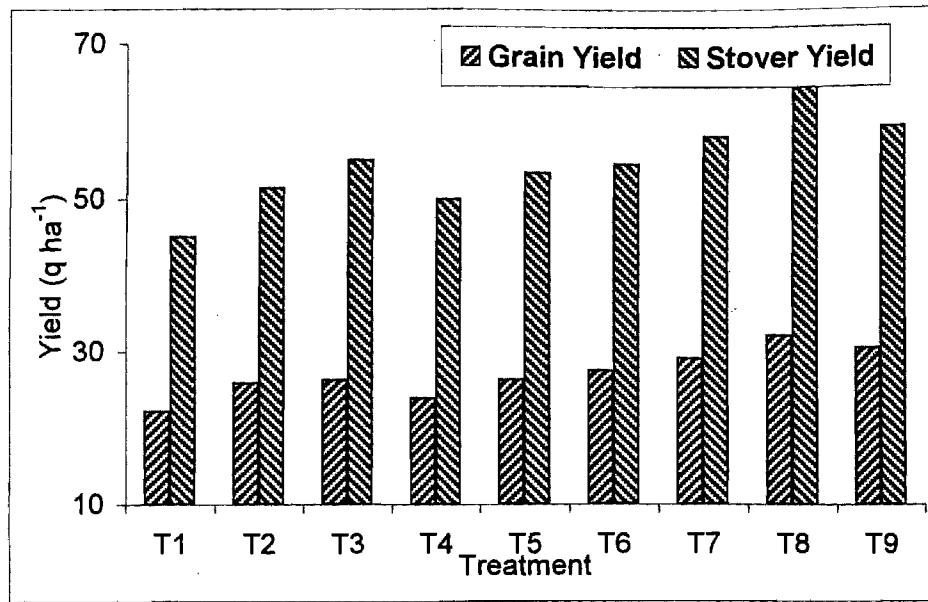


Figure 6. Effect of different treatments on the yield of maize

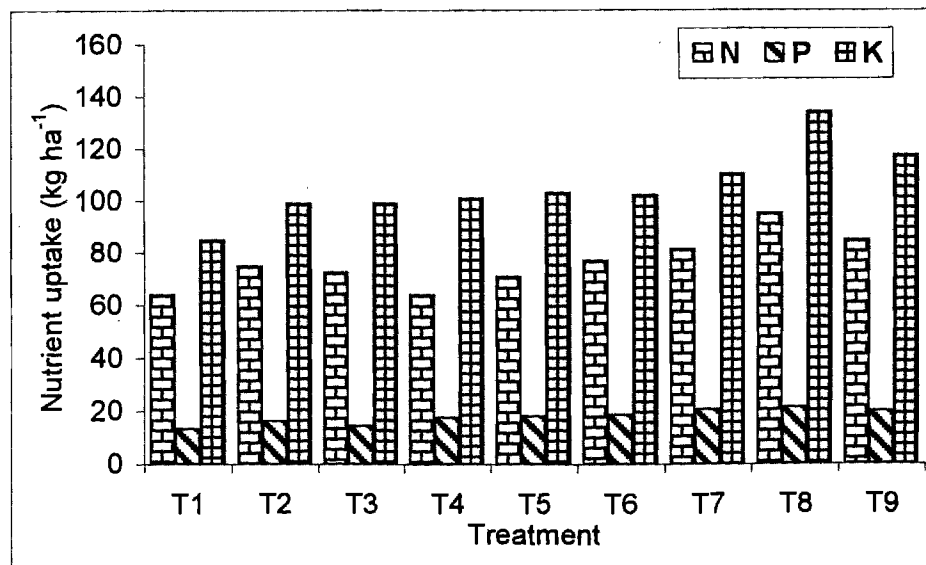


Figure 7. Effect of different treatments on the nutrient uptake by maize

T₁:Control; T₂:FYM; T₃:N₁₂₀; T₄:P₆₀; T₅:N₆₀P₃₀K₃₀; T₆:N₉₀P₄₅K₄₅; T₇:N₁₂₀P₆₀K₆₀;
T₈:T₆+FYM; T₉:T₅+FYM

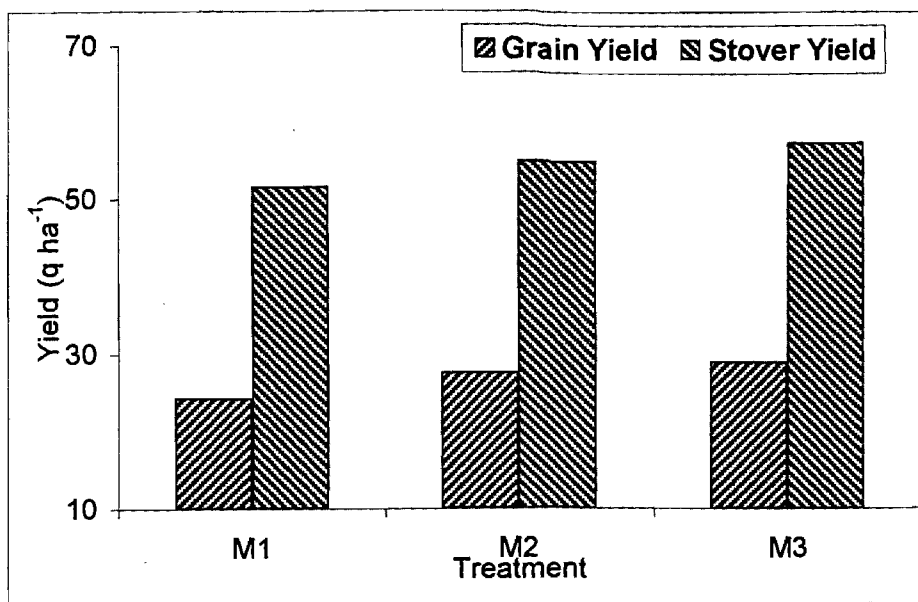


Figure 8. Effect of different treatments on the yield of maize

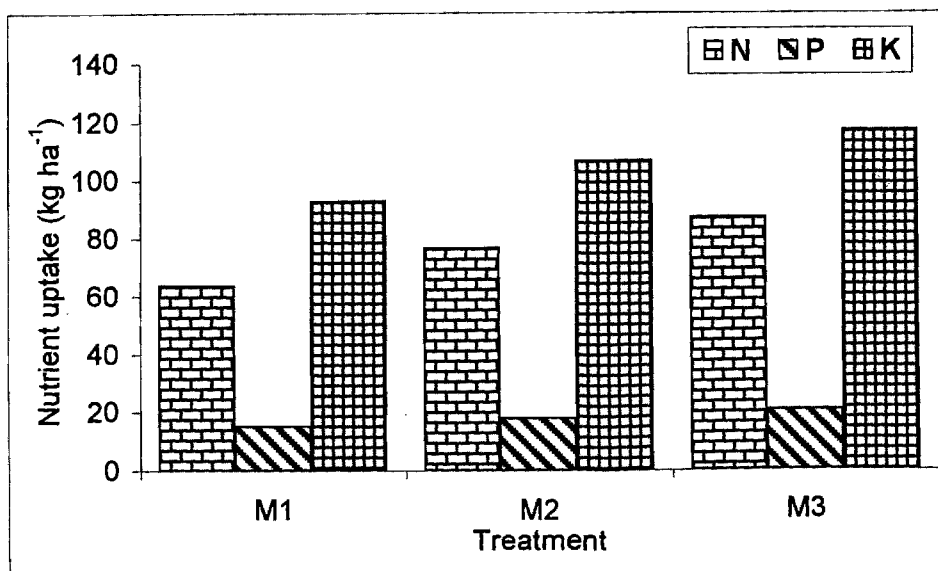


Figure 9. Effect of different treatments on the nutrient uptake by maize

M₁ : N₀P₀K₀; M₂ : N₆₀P₃₀K₃₀; M₃ : N₉₀P₄₅K₄₅

$> M_2$ (0.16%) $> M_1$ (0.14%). Maximum stover P content of 0.20% occurred under T_7 , and it was followed by T_4 , T_5 and T_6 , each with P content of 0.18%. The lowest was recorded under control (0.15%).

The treatments T_8 and T_9 , both of which received FYM during wheat season resulted in the highest P uptake by maize grain (Figure 7), the values being 11.08 and 10.55 kg ha⁻¹, respectively (Table 15). They were followed by the statistically-at-par treatments, T_7 (9.40 kg ha⁻¹), T_6 (9.01 kg ha⁻¹), T_3 (8.82 kg ha⁻¹), T_5 (8.70 kg ha⁻¹) and T_4 (8.52 kg ha⁻¹). In the bottom of the list was T_1 , with an uptake value of 6.57 kg ha⁻¹. In case of stover, P uptake ranged from 6.82 (T_1) to 11.40 (T_8) kg ha⁻¹. The treatments T_8 (21.4 kg ha⁻¹), T_7 (20.8 kg ha⁻¹) and T_9 (20.0 kg ha⁻¹) were statistically at par and superior to T_6 (18.9 kg ha⁻¹) and T_5 (18.4 kg ha⁻¹) in terms of total P uptake. They were followed by T_4 (16.6 kg ha⁻¹), T_2 (16.5 kg ha⁻¹) and T_3 (14.7 kg ha⁻¹), all of which were at par among themselves. The lowest total P uptake by maize was registered under T_1 (13.4 kg ha⁻¹). Phosphorus recovery and uptake has been observed to improve either by the application of P to maize crop (Sarkadi, 1995) or by application of FYM along with chemical fertilizers to the preceding wheat crop (Negi *et al.*, 1992).

Potassium: The treatment M_3 registered the highest K content of both maize grain (0.32%) and stover (1.86%), as is evident from Table 16. The treatment M_2 was statistically at par with M_3 in case of stover with a K content of 1.80%, but was inferior to the latter in case of grain (0.31%). The lowest values of 0.30 and 1.65%, respectively for grain and stover were recorded under M_1 . On comparing the treatments applied to wheat, T_8 , T_5 , T_6 and T_9 , with values of 0.34, 0.33, 0.32 and 0.32 %, respectively, were statistically at par and superior to the rest of the treatments in terms of K content of maize grain. The lowest K content of 0.27% was recorded under control. The K content of wheat stover ranged from 1.66 to 1.91%, with more or less the same trend being followed by the nine treatments.

Total K uptake by maize varied from 85 (T_1) to 134 (T_8) kg ha⁻¹ (Table 17), with the other treatments following the order: T_9 (117 kg ha⁻¹) $>$ T_7 (110 kg ha⁻¹) $>$ T_5 (103 kg ha⁻¹) $>$ T_6 (102 kg ha⁻¹) $>$ T_4 (101 kg ha⁻¹) $>$ $T_2 = T_3$ (99 kg ha⁻¹). The comparison

Table 14. Effect of fertilizer and manurial treatments on the P content (%) of maize

Treatment	Grain				Stover			
	M ₁	M ₂	M ₃	Mean	M ₁	M ₂	M ₃	Mean
T ₁	0.29	0.29	0.31	0.30	0.13	0.14	0.18	0.15
T ₂	0.30	0.29	0.36	0.32	0.14	0.16	0.18	0.16
T ₃	0.33	0.33	0.34	0.33	0.09	0.10	0.12	0.11
T ₄	0.33	0.35	0.39	0.35	0.13	0.17	0.25	0.18
T ₅	0.33	0.33	0.33	0.33	0.16	0.19	0.19	0.18
T ₆	0.33	0.32	0.34	0.33	0.16	0.19	0.19	0.18
T ₇	0.31	0.32	0.33	0.32	0.19	0.18	0.21	0.20
T ₈	0.31	0.34	0.37	0.34	0.14	0.17	0.18	0.16
T ₉	0.33	0.34	0.36	0.34	0.15	0.17	0.16	0.16
Mean	0.32	0.32	0.35		0.14	0.16	0.18	
CD (<i>P</i> = 0.05)	T : 0.03; M : 0.02; T×M : NS				T : 0.02; M : 0.01; T×M : NS			

Table 15. Effect of fertilizer and manurial treatments on the P uptake (kg P ha⁻¹) by maize

Treatment	Grain				Stover				Total			
	M ₁	M ₂	M ₃	Mean	M ₁	M ₂	M ₃	Mean	M ₁	M ₂	M ₃	Mean
T ₁	5.28	6.56	7.87	6.57	5.11	6.26	9.09	6.82	10.4	12.8	17.0	13.4
T ₂	6.81	7.58	10.12	8.17	6.51	8.52	9.63	8.22	13.3	16.1	20.0	16.5
T ₃	7.75	8.83	9.88	8.82	4.87	5.31	7.34	5.84	12.6	14.1	17.2	14.7
T ₄	6.94	8.33	10.28	8.52	6.17	8.79	12.77	9.24	13.1	17.1	23.0	17.8
T ₅	7.81	8.82	9.46	8.70	8.10	10.41	10.61	9.70	15.9	19.2	20.1	18.4
T ₆	8.11	8.74	10.19	9.01	8.56	9.82	11.42	9.93	16.7	18.6	21.6	18.9
T ₇	8.02	9.71	10.47	9.40	9.92	10.97	13.32	11.40	17.9	20.7	23.8	20.8
T ₈	9.17	11.45	12.62	11.08	9.09	10.52	11.41	10.34	18.3	22.0	24.0	21.4
T ₉	9.44	10.63	11.60	10.55	8.90	10.04	9.43	9.46	18.3	20.7	21.0	20.0
Mean	7.70	8.96	10.28		7.47	8.96	10.56		15.2	17.9	20.5	
CD (<i>P</i> = 0.05)	T : 1.02; M : 0.56; T×M : NS				T : 1.67; M : 0.82; T×M : NS				T : 2.2; M : 0.9; T×M : NS			

T₁: control; T₂: FYM; T₃: N₁₂₀; T₄: P₆₀; T₅: N₆₀P₃₀K₃₀; T₆: N₉₀P₄₅K₄₅; T₇: N₁₂₀P₆₀K₆₀; T₈: T₆ + FYM; T₉: T₅ + FYM
M₁: N₀P₀K₀; M₂: N₆₀P₃₀K₃₀; M₃: N₉₀P₄₅K₄₅

Table 16. Effect of fertilizer and manurial treatments on the K content (%) of maize

Treatment	Grain				Stover			
	M ₁	M ₂	M ₃	Mean	M ₁	M ₂	M ₃	Mean
T ₁	0.25	0.28	0.29	0.27	1.68	1.77	1.76	1.74
T ₂	0.28	0.28	0.31	0.29	1.55	1.85	1.92	1.77
T ₃	0.30	0.30	0.34	0.31	1.62	1.64	1.71	1.66
T ₄	0.29	0.30	0.29	0.30	1.71	1.97	1.92	1.87
T ₅	0.34	0.33	0.32	0.33	1.57	1.92	1.80	1.76
T ₆	0.31	0.32	0.32	0.32	1.48	1.69	1.92	1.70
T ₇	0.30	0.31	0.33	0.31	1.61	1.65	1.92	1.70
T ₈	0.31	0.36	0.35	0.34	1.81	1.93	1.99	1.91
T ₉	0.32	0.32	0.32	0.32	1.80	1.76	1.84	1.80
Mean	0.30	0.31	0.32		1.65	1.80	1.86	
CD (<i>P</i> = 0.05)	T : 0.03; M : 0.01; T×M : NS				T : 0.16; M : 0.09; T×M : NS			

Table 17. Effect of fertilizer and manurial treatments on the K uptake (kg K ha⁻¹) by maize

Treatment	Grain				Stover				Total			
	M ₁	M ₂	M ₃	Mean	M ₁	M ₂	M ₃	Mean	M ₁	M ₂	M ₃	Mean
T ₁	4.55	6.41	7.37	6.11	68	81	87	78	72	88	94	85
T ₂	6.52	7.21	8.83	7.52	72	100	102	92	79	107	111	99
T ₃	7.20	7.92	9.68	8.27	88	84	101	91	95	92	111	99
T ₄	6.24	7.18	7.80	7.07	78	104	99	94	84	111	107	101
T ₅	8.04	8.83	9.29	8.72	77	105	100	94	85	114	110	103
T ₆	7.78	8.66	9.59	8.68	76	88	115	93	84	96	125	102
T ₇	7.70	9.60	10.34	9.23	84	99	120	101	92	108	131	110
T ₈	9.26	12.62	11.93	11.27	118	124	129	123	127	136	141	134
T ₉	9.33	10.10	10.21	9.88	107	104	110	107	116	114	121	117
Mean	7.40	8.72	9.45		85	99	107		93	107	117	
CD (<i>P</i> = 0.05)	T : 1.02; M : 0.44; T×M : NS				T : 11; M : 6; T×M : NS				T : 11; M : 6; T×M : NS			

T₁: control; T₂: FYM; T₃: N₁₂₀; T₄: P₆₀; T₅: N₆₀P₃₀K₃₀; T₆: N₉₀P₄₅K₄₅; T₇: N₁₂₀P₆₀K₆₀; T₈: T₆ + FYM;
T₉: T₅ + FYM

M₁: N₀P₀K₀; M₂: N₆₀P₃₀K₃₀; M₃: N₉₀P₄₅K₄₅

can also be inferred from Figure 6. Among the treatments applied to maize, M_3 (117 kg ha⁻¹) was found to be superior to M_2 (107 kg ha⁻¹), which, in turn performed significantly better than M_1 (93 kg ha⁻¹). The trend of total K uptake was similar to that followed in case of K uptake by maize stover.

4.2 SOIL PROPERTIES

4.2.1 Forms of Nitrogen

4.2.1.1 Wheat

The average ammonium-N ($\text{NH}_4\text{-N}$), nitrate-N ($\text{NO}_3\text{-N}$), available N and total N content of the soil before sowing of wheat was observed to be 8.9, 15.0, 82.4 and 581 mg kg⁻¹, respectively, as shown in Table 18. The uniformity of field plot selected for this experiment stands confirmed by the non-significant differences noted for all the soil N attributes recorded in the various treatments in Table 18.

Application of fertilizer and manurial treatments influenced the different forms of nitrogen from their initial values at heading stage of wheat (i.e., 80 days after sowing of wheat). Maximum total N content was recorded under T_7 (600 mg kg⁻¹ soil) followed by T_3 (594 mg kg⁻¹ soil), both of which were statistically at par (Table 19). Next were the treatments T_6 (590 mg kg⁻¹ soil), T_9 (587 mg kg⁻¹ soil), T_8 (584 mg kg⁻¹ soil) and T_5 (583 mg kg⁻¹ soil), which were at par among themselves. At the bottom of the table was T_1 (570 mg kg⁻¹ soil), which was statistically similar to T_2 (577 mg kg⁻¹ soil). Control (T_1) registered the lowest available N content of 81 mg kg⁻¹ soil, which increased in the order: T_5 (96 mg kg⁻¹ soil) < T_4 (97 mg kg⁻¹ soil) < T_9 (99 mg kg⁻¹ soil) < T_2 (105 mg kg⁻¹ soil) < T_6 (106 mg kg⁻¹ soil) < T_8 (107 mg kg⁻¹ soil) < T_3 (110 mg kg⁻¹ soil) < T_7 (114 mg kg⁻¹ soil). Figure 10 shows a drastic increase in the available N content of the soil from sowing to the heading stage of wheat for all the treatments barring control. Increase in available N with the application of only phosphatic fertilizer (T_4), in comparison to control could be explained by the synergistic effect of P on N mineralization (Singh *et al.*, 1980). The increase was enhanced with the application of higher amounts of fertilizer

Table 18. Effect of fertilizer and manurial treatments on soil N (mg N kg⁻¹ soil) before sowing of wheat

Treatments	Total N	Available N ^a	NH ₄ -N	NO ₃ -N
T ₁	580	81.3	8.4	15.1
T ₂	583	82.7	9.2	15.2
T ₃	583	83.9	9.6	14.9
T ₄	587	81.7	8.8	15.1
T ₅	580	82.9	9.2	14.9
T ₆	585	81.1	8.8	15.1
T ₇	573	81.6	8.4	14.9
T ₈	579	84.5	8.8	14.8
T ₉	584	82.4	8.8	15.1
Mean	581	82.4	8.9	15.0
CD (<i>P</i> = 0.05)	NS	NS	NS	NS

Table 19. Effect of fertilizer and manurial treatments on soil N (mg N kg⁻¹ soil) at heading stage of wheat

Treatments	Total N	Available N ^a	NH ₄ -N	NO ₃ -N
T ₁	570	81	9.3	13.5
T ₂	577	105	11.5	19.1
T ₃	594	110	12.4	26.8
T ₄	576	97	9.7	17.5
T ₅	583	96	11.4	25.3
T ₆	590	106	13.5	27.3
T ₇	600	114	16.5	29.0
T ₈	584	107	13.5	27.9
T ₉	587	99	11.9	25.9
Mean	584	102	12.2	23.6
CD (<i>P</i> = 0.05)	8	3	2.6	3.5

^a Alkaline potassium permanganate oxidisable nitrogen

T₁: control; T₂: FYM; T₃: N₁₂₀; T₄: P₆₀; T₅: N₆₀P₃₀K₃₀; T₆: N₉₀P₄₅K₄₅; T₇: N₁₂₀P₆₀K₆₀; T₈: T₆ + FYM; T₉: T₅ + FYM

N. Increase in available N of soil by application of nitrogenous fertilizers was also obtained by Bansal *et al.* (1980) and Glendining and Powlson (1995).

Both $\text{NH}_4\text{-N}$ and $\text{NO}_3\text{-N}$ contents of soil increased substantially from heading stage of wheat (80 DAS) barring control. This followed the application of N through inorganics and/or organics. This supports the earlier results reported by Corbeels *et al.* (1999). The highest $\text{NH}_4\text{-N}$ and $\text{NO}_3\text{-N}$ content of 16.5 and 29.0 mg kg^{-1} soil were maintained under the treatment T_7 , where optimum dose of NPK was applied. This was probably due to the higher amount of soluble N supplied through the treatment. In case of $\text{NH}_4\text{-N}$, T_7 was followed by T_8 and T_6 , both with a value of 13.5 mg kg^{-1} soil, T_3 (12.4 mg kg^{-1} soil), T_9 (11.9 mg kg^{-1} soil), T_2 (11.5 mg kg^{-1} soil) and T_5 (11.2 mg kg^{-1} soil), all of which were statistically at par. The lowest $\text{NH}_4\text{-N}$ content was registered under T_1 (9.3 mg kg^{-1} soil), which was at par with T_4 (9.7 mg kg^{-1} soil). This was obviously due to no external addition of N. Application of whole of N through urea resulted in a rapid conversion to $\text{NH}_4\text{-N}$, which was further enhanced in the presence of optimum amount of P and K. This explains the steep increase in $\text{NH}_4\text{-N}$ content of soil under the treatment T_7 as compared to the rest of the treatments (Figure 11). Lesser $\text{NH}_4\text{-N}$ was formed as the amount of N added through fertilizers was reduced from its optimum dose (Rajput *et al.*, 1984; Sagwal and Rahul, 1984; Duraisami *et al.*, 2001). A positive effect of 25% N substitution through FYM was observed in terms of improved $\text{NH}_4\text{-N}$ content of the soil. Application of FYM results in a higher microbial activity and enhanced mineralization, resulting in the accumulation of $\text{NH}_4\text{-N}$ in the soil. This is in tune with the observations made by Udayasoorian *et al.* (1989) and Santhy *et al.* (2001a).

As the soil is well drained, the $\text{NO}_3\text{-N}$ content, on an average exceeded $\text{NH}_4\text{-N}$ content. It was about 60 to 70% of the total mineral nitrogen. The treatments T_8 (27.9 mg kg^{-1} soil), T_6 (27.3 mg kg^{-1} soil), T_3 (26.8 mg kg^{-1} soil) and T_9 (25.9 mg kg^{-1} soil) were all at par with T_7 (29.0 mg kg^{-1} soil) in terms of soil $\text{NO}_3\text{-N}$ content. These treatments were superior to T_5 (25.3 mg kg^{-1} soil), T_2 (19.1 mg kg^{-1} soil), T_4 (17.5 mg kg^{-1} soil) and finally T_1 (13.5 mg kg^{-1} soil). As in case of available N, there was a drastic increase in

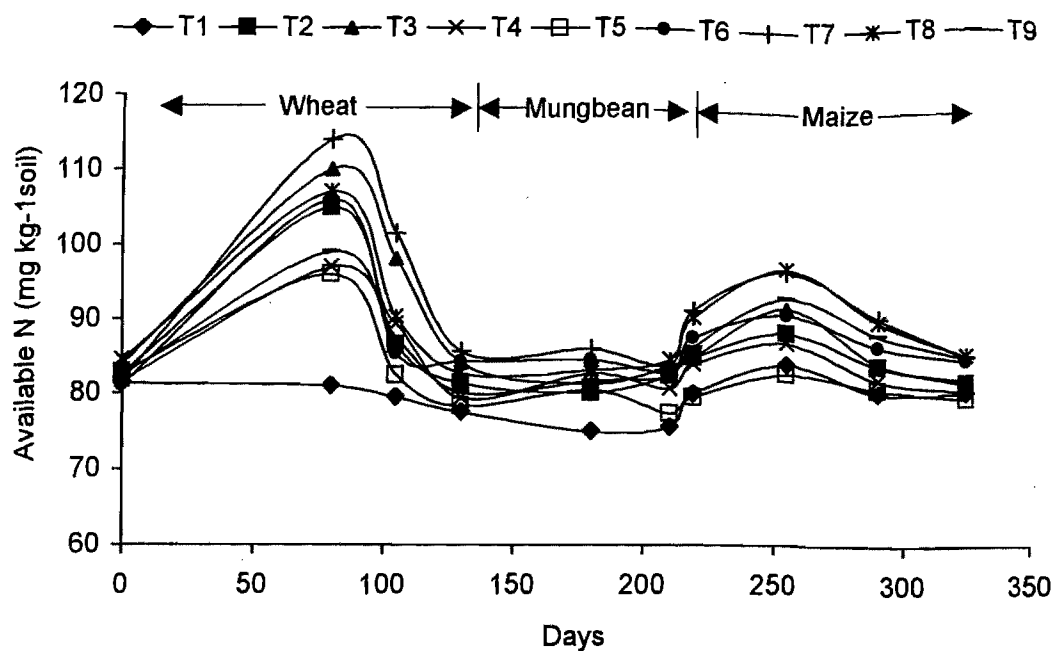


Figure 10. Influence of fertilizer and manurial treatments on the available N contents of soil at different stages of crop growth

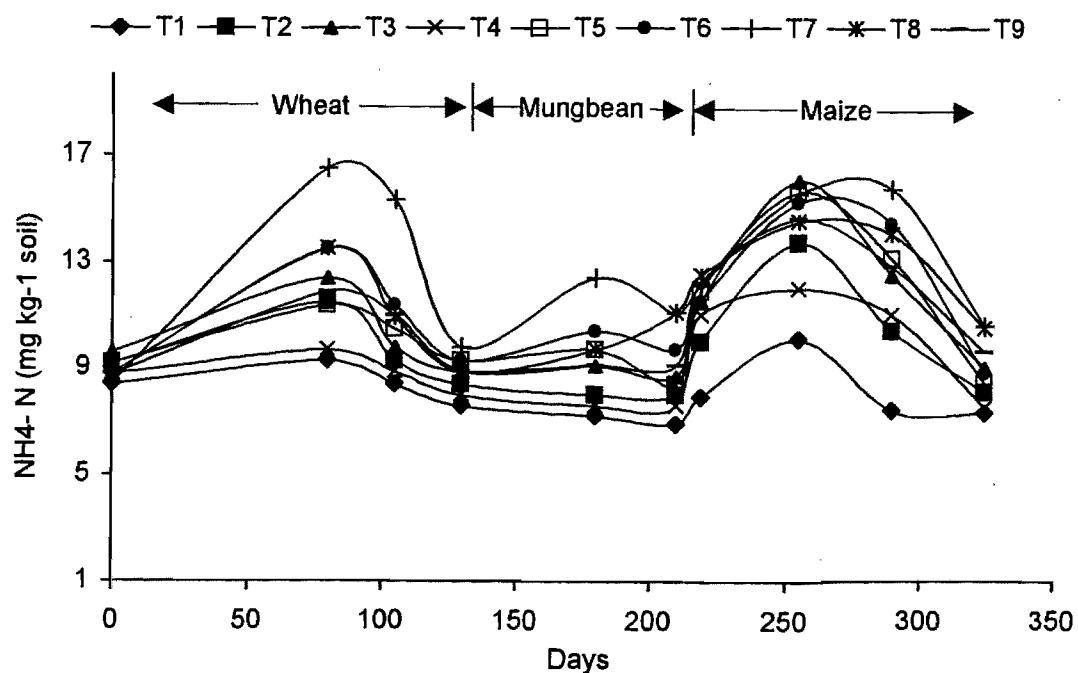


Figure 11. Influence of fertilizer and manurial treatments on the ammoniacal N contents of soil at different stages of crop growth

the $\text{NO}_3\text{-N}$ content of the soil on addition of nitrogenous fertilizer, one-fourth of which was added at the heading stage (Figure 12). Higher content $\text{NO}_3\text{-N}$ in soil as a result of increased N addition has also been reported by Benbi *et al.* (1991) and Brar and Brar (2002). Addition of FYM along with inorganic fertilizer also had a favourable impact on $\text{NO}_3\text{-N}$, as observed under T_8 and T_9 , and supports the earlier results obtained by various workers (Havanagi and Mann, 1970; Thakur *et al.*, 1992; Khankane and Yadav, 2000).

There was a general decrease in the values of the four forms of N described above at dough stage of wheat (i.e. 105 days after sowing of wheat), as can be seen in Figures 10 to 13. Decline in the $\text{NO}_3\text{-N}$ content of soil during wheat season after 79 days was observed by Corbeels *et al.* (1999). This could be attributed to the N uptake by wheat and its losses through various means. But the treatments receiving higher doses of fertilizers including INM had an upper hand over control. As in the previous stage, the treatment T_7 maintained the highest amount of total and available N in soil, with values of 596 and 101 mg kg^{-1} soil, respectively (Table 20). It was followed by the statistically-at-par treatments T_3 (587 mg kg^{-1} soil), T_6 (586 mg kg^{-1} soil), T_9 (585 mg kg^{-1} soil), T_8 (583 mg kg^{-1} soil) and T_5 (581 mg kg^{-1} soil), in respect of total N. The lowest total N content of 564 mg kg^{-1} soil was maintained under T_1 . This was at par with the treatments T_2 (570 mg kg^{-1} soil) and T_4 (572 mg kg^{-1} soil). In case of available N, T_7 was followed by T_3 (98.1 mg kg^{-1} soil), T_8 (90.3 mg kg^{-1} soil), T_4 (89.3 mg kg^{-1} soil), T_9 (87.5 mg kg^{-1} soil), T_2 (86.3 mg kg^{-1} soil), T_6 (85.4 mg kg^{-1} soil), T_5 (82.4 mg kg^{-1} soil) and finally T_1 (79.5 mg kg^{-1} soil). The $\text{NH}_4\text{-N}$ content varied from 8.4 (T_1) to 15.3 (T_7) mg kg^{-1} soil, and that of $\text{NO}_3\text{-N}$, between 14.0 (T_1) to 25.9 (T_7) mg kg^{-1} soil. The trend followed for all the treatments was more or less the same for both these forms of mineral N.

The values of total, available, $\text{NH}_4\text{-}$ and $\text{NO}_3\text{-N}$ further decreased at wheat harvest, i.e., 130 days after sowing of wheat (Figures 10 to 13). By this stage the differences among the treatments had narrowed down, particularly in case of available (Figure 10) and total N content (Figure 13). A decrease in total N with progress of time could be

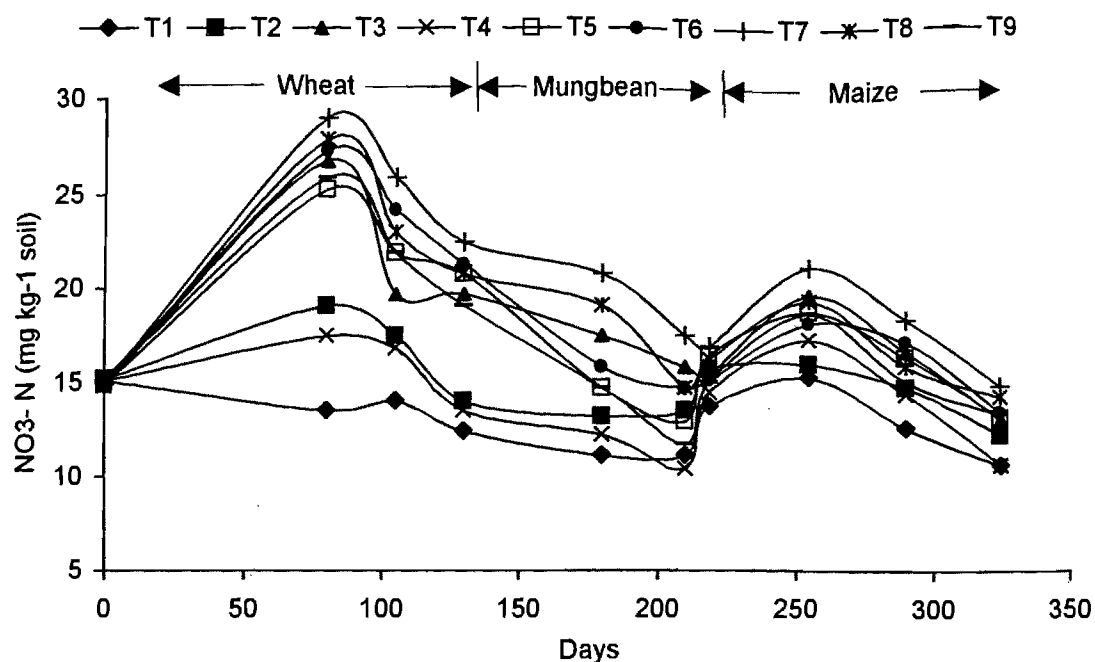


Figure 12. Influence of fertilizer and manural treatments on the nitrate-N contents of soil at different stages of crop growth

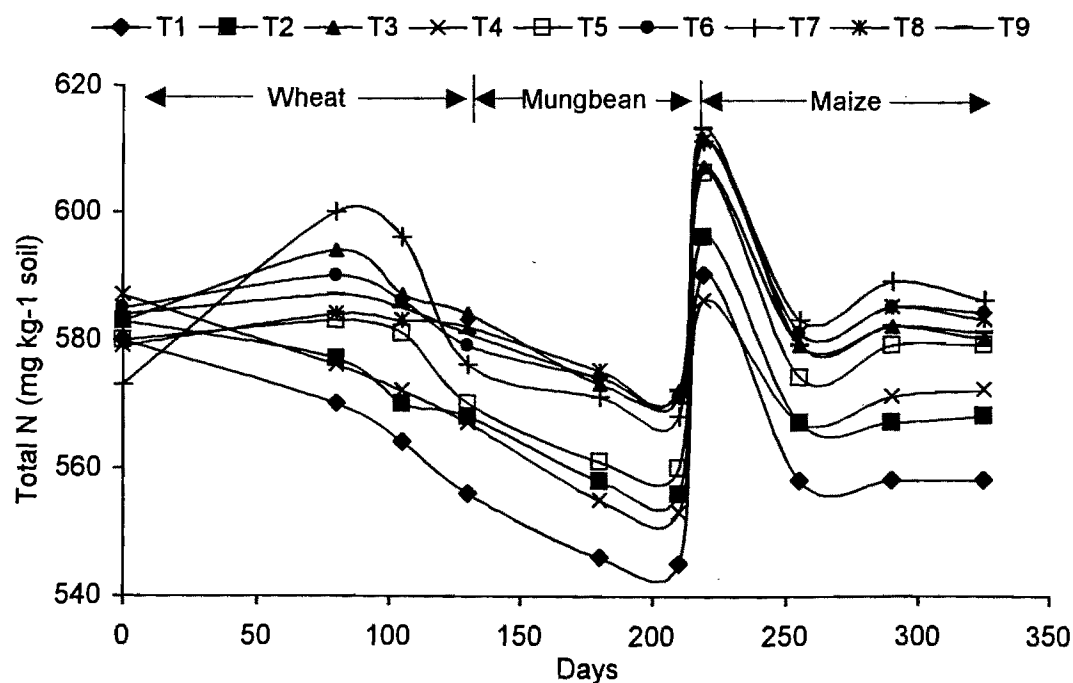


Figure 13. Influence of fertilizer and manural treatments on the total N contents of soil at different stages of crop growth

explained by the continuous mineralization process to release N for crop uptake, and the possible losses of mineral N from the soil. In case of total N, T₃ was found to lead the table with a value of 584 mg kg⁻¹ soil (Table 21). It was at par with T₈ (582 mg kg⁻¹ soil), T₉ (581 mg kg⁻¹ soil), T₆ (579 mg kg⁻¹ soil) and T₇ (576 mg kg⁻¹ soil). These are the treatments wherein N was applied at higher doses. They were followed by the treatments T₅ (570 mg kg⁻¹ soil), T₂ (568 mg kg⁻¹ soil) and T₄ (567 mg kg⁻¹ soil), which were at par among themselves. Lowest total N content of the soil was maintained by T₁ (556 mg kg⁻¹ soil). The order followed by the different treatments with respect to available N was T₇ (85.6 mg kg⁻¹ soil) > T₆ (84.2 mg kg⁻¹ soil) > T₃ (84.1 mg kg⁻¹ soil) > T₈ (82.7 mg kg⁻¹ soil) > T₂ (81.4 mg kg⁻¹ soil) > T₉ (80.1 mg kg⁻¹ soil) > T₄ (79.3 mg kg⁻¹ soil) > T₅ (78.3 mg kg⁻¹ soil) > T₁ (77.5 mg kg⁻¹ soil). The treatment T₇ (9.8 mg kg⁻¹ soil) maintained the highest level of NH₄-N in the soil after harvest of wheat. This was followed by T₅ and T₆, both with a value of 9.3 mg kg⁻¹ soil, and then by T₃, T₈ and T₉, all with a value of 8.9 mg kg⁻¹ soil). All the six treatments were statistically at par. The lowest NH₄-N level of 7.6 mg kg⁻¹ soil was maintained under control (T₁), but it was at par with T₂ (8.4 mg kg⁻¹ soil) and T₄ (8.0 mg kg⁻¹ soil). The same trend was followed in case of NO₃-N, with values ranging between 12.4 (T₁) to 22.5 (T₇) mg kg⁻¹ soil. In case of NO₃-N content, the treatments could be clearly divided into two groups, one either not receiving nitrogen (T₁ and T₄) or receiving it through FYM only (T₂), and the other comprising of the rest of the treatments. This can be inferred from Figure 12.

4.2.1.2 Mungbean

The same treatments *viz.*, T₃, T₆, T₇, T₈ and T₉, as in case of wheat harvest were found to maintain higher total N content of the soil at flowering stage (*i.e.* 180 days after sowing of wheat) of mungbean (Table 22), with the values ranging between 571 and 575 mg kg⁻¹ soil. They were superior to T₂ (558 mg kg⁻¹ soil), T₄ (555 mg kg⁻¹ soil) and T₅ (561 mg kg⁻¹ soil), which were at par among themselves. The lowest total N content was maintained under control (546 mg kg⁻¹ soil). The treatments T₇ (86.0 mg kg⁻¹ soil) and T₆ (84.5 mg kg⁻¹ soil) were at par with each other and superior to the rest

Table 20. Effect of fertilizer and manurial treatments on soil N (mg N kg⁻¹ soil) at dough stage of wheat

Treatments	Total N	Available N ^a	NH ₄ -N	NO ₃ -N
T ₁	564	79.5	8.4	14.0
T ₂	570	86.3	9.3	17.5
T ₃	587	98.1	9.8	19.7
T ₄	572	89.3	8.9	16.8
T ₅	581	82.4	10.5	21.9
T ₆	586	85.4	11.4	24.2
T ₇	596	101.4	15.3	25.9
T ₈	583	90.3	10.9	23.0
T ₉	585	87.5	11.0	21.9
Mean	581	88.9	10.6	20.5
CD (<i>P</i> = 0.05)	9	2.4	1.9	3.8

Table 21. Effect of fertilizer and manurial treatments on soil N (mg N kg⁻¹ soil) after harvest of wheat

Treatments	Total N	Available N ^a	NH ₄ -N	NO ₃ -N
T ₁	556	77.5	7.6	12.4
T ₂	568	81.4	8.4	14.0
T ₃	584	84.1	8.9	19.7
T ₄	567	79.3	8.0	13.5
T ₅	570	78.3	9.3	20.8
T ₆	579	84.2	9.3	21.3
T ₇	576	85.6	9.8	22.5
T ₈	582	82.7	8.9	20.8
T ₉	581	80.1	8.9	19.1
Mean	574	81.5	8.8	18.2
CD (<i>P</i> = 0.05)	11	2.3	1.1	3.2

^a Alkaline potassium permanganate oxidisable nitrogen

T₁: control; T₂: FYM; T₃: N₁₂₀; T₄: P₆₀; T₅: N₆₀P₃₀K₃₀; T₆: N₉₀P₄₅K₄₅; T₇: N₁₂₀P₆₀K₆₀; T₈: T₆ + FYM; T₉: T₅ + FYM

of the treatments in terms of available N content of the soil. They were followed by the treatments T₈ (83.1 mg kg⁻¹ soil), T₄ (82.7 mg kg⁻¹ soil), T₉ (81.7 mg kg⁻¹ soil) and T₃ (81.3 mg kg⁻¹ soil), all of which were at par. Next were the treatments T₅ (80.5 mg kg⁻¹ soil) and T₂ (80.1 mg kg⁻¹ soil), both of which were superior to T₁ (75.0 mg kg⁻¹ soil). From Figures 11, and Table 22, it can be inferred that the NH₄-N content of soil increased from its initial value at the flowering stage of mungbean. In case of NH₄-N, as after the harvest of wheat, the highest content was registered under T₇ (12.4 mg kg⁻¹ soil), with the other treatments following the order: T₆ (10.4 mg kg⁻¹ soil) > T₅ = T₈ (9.7 mg kg⁻¹ soil) > T₃ = T₉ (9.1 mg kg⁻¹ soil) > T₂ (8.0 mg kg⁻¹ soil) > T₄ (7.6 mg kg⁻¹ soil) > T₁ (7.2 mg kg⁻¹ soil). Highest values of soil NO₃-N content were recorded under T₇ (20.8 mg kg⁻¹ soil) and T₈ (19.1 mg kg⁻¹ soil) at the flowering stage of mungbean. These were followed by the treatments T₃ (17.5 mg kg⁻¹ soil), T₆ (15.8 mg kg⁻¹ soil), T₈ (14.7 mg kg⁻¹ soil) and T₅ (14.7 mg kg⁻¹ soil), which were statistically similar. The lowest NO₃-N content of 11.1 mg kg⁻¹ soil was maintained under T₁, which was at par with T₂ (13.2 mg kg⁻¹ soil) and T₄ (12.2 mg kg⁻¹ soil).

The values of all the four forms of N further got reduced before incorporation of mungbean (210 DAS of wheat) as shown in Table 23, but the decline was gradual, particularly under the treatments receiving higher doses of N during wheat, as shown in Figures 10 to 13. Highest total N content of the soil was maintained by T₃ and T₉ (with identical value of 572 mg kg⁻¹ soil) and were followed by T₈ (571 mg kg⁻¹ soil), T₆ (571 mg kg⁻¹ soil) and T₇ (568 mg kg⁻¹ soil). These five treatments were at par among themselves and were followed by T₅ (560 mg kg⁻¹ soil), T₂ (556 mg kg⁻¹ soil), T₄ (553 mg kg⁻¹ soil) and finally T₁ (545 mg kg⁻¹ soil).

The treatment T₈ recorded an available N content of 84.5 mg kg⁻¹ soil, which was at par with T₇ (83.8 mg kg⁻¹ soil), T₃ (83.6 mg kg⁻¹ soil) and T₆ (82.9 mg kg⁻¹ soil) and superior to T₂, T₉ and T₄, with values of 82.4, 82.3 and 80.6 mg kg⁻¹ soil, respectively. The lowest available N content of 75.6 mg kg⁻¹ soil was maintained under control (T₁). It can therefore be seen that, the treatments T₂ and T₈, particularly the former which

Table 22. Effect of fertilizer and manurial treatments on soil N (mg N kg⁻¹ soil) at flowering stage of mungbean

Treatments	Total N	Available N ^a	NH ₄ -N	NO ₃ -N
T ₁	546	75.0	7.2	11.1
T ₂	558	80.1	8.0	13.2
T ₃	573	81.3	9.1	17.5
T ₄	555	82.7	7.6	12.2
T ₅	561	80.5	9.7	14.7
T ₆	574	84.5	10.4	15.8
T ₇	571	86.0	12.4	20.8
T ₈	575	83.1	9.7	19.1
T ₉	574	81.7	9.1	14.7
Mean	565	81.7	9.2	15.4
CD (<i>P</i> = 0.05)	7	1.9	1.3	3.3

Table 23. Effect of fertilizer and manurial treatments on soil N (mg N kg⁻¹ soil) before incorporation of mungbean

Treatments	Total N	Available N ^a	NH ₄ -N	NO ₃ -N
T ₁	545	75.6	6.9	11.1
T ₂	556	82.4	8.0	13.5
T ₃	572	83.6	8.7	15.8
T ₄	553	80.6	7.6	10.4
T ₅	560	77.4	8.4	12.9
T ₆	571	82.9	9.7	14.7
T ₇	568	83.8	11.1	17.5
T ₈	571	84.5	11.1	14.7
T ₉	572	82.3	9.1	11.7
Mean	563	81.5	9.0	13.6
CD (<i>P</i> = 0.05)	6	1.8	2.1	3.8

^a Alkaline potassium permanganate oxidisable nitrogen

T₁: control; T₂: FYM; T₃: N₁₂₀; T₄: P₆₀; T₅: N₆₀P₃₀K₃₀; T₆: N₉₀P₄₅K₄₅; T₇: N₁₂₀P₆₀K₆₀; T₈: T₆ + FYM; T₉: T₅ + FYM

received only FYM during wheat, picked up in terms of available N content as a result of slow, but continuous N release.

The average $\text{NH}_4\text{-N}$ and $\text{NO}_3\text{-N}$ content of the soil before incorporation of mungbean were 9.0 and 13.6 mg kg^{-1} soil, respectively. In terms of $\text{NH}_4\text{-N}$, the treatments could be statistically divided into two groups. The superior group consisted of the treatments T_7 (11.1 mg kg^{-1} soil), T_8 (11.1 mg kg^{-1} soil), T_6 (9.7 mg kg^{-1} soil) and T_9 (9.1 mg kg^{-1} soil). The second group was formed by the treatments T_3 (8.7 mg kg^{-1} soil), T_5 (8.4 mg kg^{-1} soil), T_2 (8.0 mg kg^{-1} soil), T_4 (7.6 mg kg^{-1} soil) and T_1 (6.9 mg kg^{-1} soil). Similar was with the case of $\text{NO}_3\text{-N}$, with the first group consisting of T_7 (17.5 mg kg^{-1} soil), T_3 (15.8 mg kg^{-1} soil), T_6 (14.7 mg kg^{-1} soil) and T_8 (14.7 mg kg^{-1} soil), and the rest of the treatments constituting the inferior group. The lowest $\text{NO}_3\text{-N}$ value was recorded under T_1 (11.1 mg kg^{-1} soil). Integrated use of FYM and inorganic N maintained a higher mineral N content in the soil as compared to FYM alone. This could be attributed to the higher rate of decomposition in case of the former treatment, although the latter treatment contained higher amount of potentially mineralizable N.

4.2.1.3 Maize

Table 24 shows the concentration of total, available and mineral ($\text{NH}_4\text{-N}$ and $\text{NO}_3\text{-N}$) nitrogen of the soil before sowing of maize (219 DAS of wheat) as obtained from the composite soil samples. The average values were 603 for total N, 85.3 for available N, 11.2 for $\text{NH}_4\text{-N}$ and 15.4 mg kg^{-1} soil for $\text{NO}_3\text{-N}$. The sharp increase in the total N content of the soil irrespective of the treatments, as shown in Figure 13 can be explained by the addition of N through mungbean residues. Srivastava *et al.* (1984) had observed an increase in total N content of soil in an incubation study by the incorporation of crop residues.

There was a decrease in the total N content of the soil at silking stage of maize (255 DAS of wheat) from its value before sowing (Figure 13). This could be attributed to the decomposition of mungbean residues, N uptake by maize and its losses. The treatment receiving 75% of the recommended dose of fertilizers during maize (M_3)

Table 24. Effect of fertilizer and manurial treatments on soil N (mg N kg⁻¹ soil) before sowing of maize

Treatments	Total N	Available N ^a	NH ₄ -N	NO ₃ -N
T ₁	590	79.9	7.9	13.7
T ₂	596	84.8	10.0	15.7
T ₃	607	84.8	11.5	15.4
T ₄	586	83.9	11.0	14.4
T ₅	606	79.5	11.9	16.4
T ₆	611	87.5	11.5	15.1
T ₇	611	91.1	12.1	16.9
T ₈	611	90.2	12.5	16.2
T ₉	613	86.2	12.2	15.0
Mean	603	85.3	11.2	15.4

^a Alkaline potassium permanganate oxidisable nitrogen

T₁: control; T₂: FYM; T₃: N₁₂₀; T₄: P₆₀; T₅: N₆₀P₃₀K₃₀; T₆: N₉₀P₄₅K₄₅; T₇: N₁₂₀P₆₀K₆₀; T₈: T₆ + FYM;
T₉: T₅ + FYM

maintained the highest amount of total N ($578 \text{ mg kg}^{-1} \text{ soil}$), and was followed by the treatments receiving 50% of the recommended dose (M_2 , $575 \text{ mg kg}^{-1} \text{ soil}$) and control (M_1 , $570 \text{ mg kg}^{-1} \text{ soil}$) (Table 25). Among the treatments applied to wheat, T_7 ($583 \text{ mg kg}^{-1} \text{ soil}$) maintained the highest level of total N, and was at par with T_8 ($581 \text{ mg kg}^{-1} \text{ soil}$) and T_6 ($581 \text{ mg kg}^{-1} \text{ soil}$). Treatment T_7 was superior to T_9 ($579 \text{ mg kg}^{-1} \text{ soil}$) and T_3 ($579 \text{ mg kg}^{-1} \text{ soil}$), which were followed by statistically inferior treatments, T_4 ($567 \text{ mg kg}^{-1} \text{ soil}$), T_2 ($567 \text{ mg kg}^{-1} \text{ soil}$) and T_1 ($558 \text{ mg kg}^{-1} \text{ soil}$). This indicates a residual effect of the treatments receiving 100% N through inorganics (T_7) or substitution of 25% of N through FYM (T_8) during wheat. In case of available N also, the subplot treatments followed the order: M_3 ($95.9 \text{ mg kg}^{-1} \text{ soil}$) > M_2 ($90.4 \text{ mg kg}^{-1} \text{ soil}$) > M_1 ($84.2 \text{ mg kg}^{-1} \text{ soil}$). Among the main plot treatments, the treatments T_8 ($97.0 \text{ mg kg}^{-1} \text{ soil}$) and T_7 ($96.6 \text{ mg kg}^{-1} \text{ soil}$) were at par with each other and superior to T_9 ($93.1 \text{ mg kg}^{-1} \text{ soil}$), T_3 ($91.7 \text{ mg kg}^{-1} \text{ soil}$) and T_6 ($90.9 \text{ mg kg}^{-1} \text{ soil}$). The latter three treatments were at par among themselves. The lowest available N was maintained under T_5 ($82.8 \text{ mg kg}^{-1} \text{ soil}$), which was at par with T_1 ($84.1 \text{ mg kg}^{-1} \text{ soil}$). The treatment interaction was not found to be significant. Figure 10 shows an increase in the available N content of the soil from sowing to silking stage of maize. This can be explained on the basis of N application to the plots. Nitrogen in the form of urea was applied in three splits, half at sowing (219 DAS of wheat) and the rest was applied equally at knee-high stage (235 DAS of wheat) and before silking of maize (250 DAS of wheat).

From Figures 11 and 12, it can be seen that there was a substantial increase in the $\text{NH}_4\text{-N}$ and $\text{NO}_3\text{-N}$ content of the soil at silking stage of maize. This could be attributed to the application of fertilizer-N just before this stage. In respect of $\text{NH}_4\text{-N}$ content of the soil at silking stage of maize, the treatments T_3 ($16.0 \text{ mg kg}^{-1} \text{ soil}$), T_5 ($15.6 \text{ mg kg}^{-1} \text{ soil}$), T_7 ($15.5 \text{ mg kg}^{-1} \text{ soil}$), T_6 ($15.2 \text{ mg kg}^{-1} \text{ soil}$), T_9 ($14.6 \text{ mg kg}^{-1} \text{ soil}$) and T_8 ($14.5 \text{ mg kg}^{-1} \text{ soil}$) were at par among themselves. They were superior to T_2 ($13.7 \text{ mg kg}^{-1} \text{ soil}$) and T_4 ($12.0 \text{ mg kg}^{-1} \text{ soil}$), which were statistically similar. The lowest $\text{NH}_4\text{-N}$ was maintained under T_1 ($10.1 \text{ mg kg}^{-1} \text{ soil}$). The treatments applied to maize followed the

Table 25. Effect of fertilizer and manurial treatments on different forms of soil N (mg N kg⁻¹ soil) at silking stage of maize

Treatment	Total N				Available N ^a			
	M ₁	M ₂	M ₃	Mean	M ₁	M ₂	M ₃	Mean
T ₁	553	559	561	558	77.3	87.6	87.3	84.1
T ₂	564	567	569	567	83.1	89.0	93.1	88.4
T ₃	575	581	582	579	84.2	93.0	98.0	91.7
T ₄	564	567	570	567	84.1	86.6	90.2	87.0
T ₅	571	576	577	574	77.6	82.4	88.4	82.8
T ₆	577	582	584	581	87.2	89.9	95.7	90.9
T ₇	576	585	587	583	89.2	95.5	105.0	96.6
T ₈	577	580	585	581	90.0	96.2	104.9	97.0
T ₉	577	579	581	579	85.6	93.3	100.4	93.1
Mean	570	575	578		84.2	90.4	95.9	
CD (<i>P</i> = 0.05)	T : 3; M : 2; T×M : NS				T : 3; M : 1.5; T×M : NS			
	NH ₄ -N				NO ₃ -N			
T ₁	8.4	10.0	11.9	10.1	13.5	15.8	16.5	15.3
T ₂	11.9	14.7	14.7	13.7	14.8	16.5	16.8	16.0
T ₃	15.8	15.8	16.5	16.0	14.7	21.3	23.2	19.7
T ₄	12.4	11.9	11.9	12.0	15.8	17.8	18.3	17.3
T ₅	14.7	15.5	16.8	15.6	15.5	19.5	21.3	18.8
T ₆	13.9	15.0	16.8	15.2	15.1	18.1	21.3	18.2
T ₇	13.5	16.1	16.8	15.5	16.1	21.9	25.5	21.2
T ₈	12.4	14.7	16.5	14.5	15.8	19.5	23.0	19.4
T ₉	13.5	15.0	15.3	14.6	15.1	19.1	21.9	18.7
Mean	12.9	14.3	15.2		15.2	18.8	20.9	
CD (<i>P</i> = 0.05)	T : 1.8; M : 0.6; T×M : NS				T : 1.9; M : 0.8; T×M : 2.5			

^a Alkaline potassium permanganate oxidisable nitrogen

T₁: control; T₂: FYM; T₃: N₁₂₀; T₄: P₆₀; T₅: N₆₀P₃₀K₃₀; T₆: N₉₀P₄₅K₄₅; T₇: N₁₂₀P₆₀K₆₀; T₈: T₆ + FYM;

T₉: T₅ + FYM

M₁: N₀P₀K₀; M₂: N₆₀P₃₀K₃₀; M₃: N₉₀P₄₅K₄₅

order $M_3 > M_2 > M_1$ for both $\text{NH}_4\text{-N}$ and $\text{NO}_3\text{-N}$ content of soil which could be attributed to the decreasing order of fertilizer application. The order followed by the treatments applied to wheat in terms of soil $\text{NO}_3\text{-N}$ was T_7 (21.2 mg kg^{-1} soil) $>$ T_3 (19.7 mg kg^{-1} soil) $>$ T_8 (19.4 mg kg^{-1} soil) $>$ T_5 (18.8 mg kg^{-1} soil) $>$ T_9 (18.7 mg kg^{-1} soil) $>$ T_6 (18.2 mg kg^{-1} soil) $>$ T_4 (17.3 mg kg^{-1} soil) $>$ T_2 (16.0 mg kg^{-1} soil) $>$ T_1 (15.3 mg kg^{-1} soil). The treatment interaction $T \times M$ was found to be significant. This implies that the $\text{NO}_3\text{-N}$ of the soil increased for all the treatments as the fertilizer dose was increased from M_1 to M_3 in maize.

There were significant differences among the treatments applied to both wheat and maize with respect to the different forms of N at the dough stage of maize, i.e., 290 DAS of wheat (Table 26). All the forms of N were found to increase with increased amounts of fertilizer addition to maize, i.e., as one moves from M_1 (no fertilizer addition) to M_3 (75% of the recommended fertilizer dose). For example, the total N content of the soil under the treatments M_1 , M_2 and M_3 was 572, 579 and 582 mg kg^{-1} soil, respectively. The treatments were statistically different from one another. Similarly, the values were 81.5, 85.6 and 88.3 mg kg^{-1} soil, respectively in case of available N; 11.0, 12.4 and 13.7 mg kg^{-1} soil, respectively in respect of $\text{NH}_4\text{-N}$; and 13.3, 15.7 and 18.2 mg kg^{-1} soil, respectively in terms of $\text{NO}_3\text{-N}$. On comparing the main plot treatments with respect to total N content of the soil, it was found that the highest content of 589 mg kg^{-1} soil was obtained under the treatment T_7 . This was superior to the statistically similar values of 585, 585, 582 and 582 mg kg^{-1} soil under T_6 , T_8 , T_3 and T_9 , respectively. Then followed the treatments T_5 (579 mg kg^{-1} soil), T_4 (571 mg kg^{-1} soil), T_2 (567 mg kg^{-1} soil) and T_1 (558 mg kg^{-1} soil). The last two treatments were statistically at par.

From Figure 13, it can be seen that the total N content was more or less maintained at a constant level for all the treatments from silking stage of maize till harvest. It is interesting to note that the total N content was reduced from its initial level (before sowing of wheat) in case of the treatments T_1 (control), T_2 (FYM only) and T_4 (P_{60} only). Application of fertilizers in a balanced (T_5 , T_6 , T_7) and integrated (T_8 , T_9) manner helped

Table 26. Effect of fertilizer and manurial treatments on different forms of soil N (mg N kg⁻¹ soil) at dough stage of maize

Treatment	Total N				Available N ^a			
	M ₁	M ₂	M ₃	Mean	M ₁	M ₂	M ₃	Mean
T ₁	550	561	565	558	74.2	80.7	85.9	80.3
T ₂	564	568	571	567	78.6	85.4	88.0	84.0
T ₃	577	584	586	582	80.4	83.7	88.4	84.2
T ₄	565	571	577	571	80.3	81.7	84.0	82.0
T ₅	573	580	584	579	78.6	80.4	83.5	80.8
T ₆	579	586	589	585	82.6	87.4	89.9	86.6
T ₇	581	592	594	589	87.7	91.1	92.4	90.4
T ₈	581	586	589	585	87.5	90.1	90.0	89.9
T ₉	579	583	584	582	83.9	89.6	90.9	88.1
Mean	572	579	582		81.5	85.6	88.3	
CD (<i>P</i> = 0.05)	T : 4; M : 2; T×M : NS				T : 2; M : 2; T×M : NS			
	NH ₄ -N				NO ₃ -N			
T ₁	6.9	7.6	7.7	7.4	11.9	12.9	13.5	12.6
T ₂	9.2	10.8	11.3	10.4	13.5	15.0	15.8	14.8
T ₃	11.9	12.2	13.5	12.5	12.4	16.8	20.8	16.7
T ₄	10.0	11.1	11.9	11.0	13.0	13.9	16.5	14.4
T ₅	10.8	13.5	15.0	13.1	14.7	16.5	18.1	16.4
T ₆	12.0	14.7	16.5	14.4	15.3	16.8	19.5	17.2
T ₇	14.1	16.1	16.8	15.7	14.1	19.1	21.9	18.4
T ₈	12.4	13.5	16.1	14.0	12.4	15.8	19.5	15.9
T ₉	11.2	12.4	14.7	12.8	12.4	14.7	18.1	15.1
Mean	11.0	12.4	13.7		13.3	15.7	18.2	
CD (<i>P</i> = 0.05)	T : 1.3; M : 0.9; T×M : NS				T : 2.2; M : 0.9; T×M : NS			

^a Alkaline potassium permanganate oxidisable nitrogen

T₁: control; T₂: FYM; T₃: N₁₂₀; T₄: P₆₀; T₅: N₆₀P₃₀K₃₀; T₆: N₉₀P₄₅K₄₅; T₇: N₁₂₀P₆₀K₆₀; T₈: T₆ + FYM;

T₉: T₅ + FYM

M₁: N₀P₀K₀; M₂: N₆₀P₃₀K₃₀; M₃: N₉₀P₄₅K₄₅

in maintaining the total N content after one year of the cropping system. A significant change in the total N of soil is unexpected in a one-year period. But its increase due to long term application of fertilizers (Glendining *et al.*, 1996), manures (Jenkinson and Johnston, 1977; Udayasoorian *et al.*, 1989), and their integrated application (Subramanian and Kumaraswamy, 1989b; Kanchikerimath and Singh, 2001) were reported earlier by others. Inclusion of mungbean in the system acted as a buffer in maintaining the total N content which is known to deplete in intensive cropping systems. Similar results with inclusion of mungbean were obtained by Rao and Sharma (1978).

The treatments T₇ (90.4 mg kg⁻¹ soil) and T₈ (89.9 mg kg⁻¹ soil) were statistically at par and superior to the rest of the treatments in influencing the available N content of the soil during the dough stage of maize (Table 26). They were followed by the treatments T₉ (88.1 mg kg⁻¹ soil) and T₆ (86.6 mg kg⁻¹ soil), which were at par, and then by the treatments T₃ (84.2 mg kg⁻¹ soil) and T₂ (84.0 mg kg⁻¹ soil). The lowest available N content of 80.3 mg kg⁻¹ soil was recorded under control (T₁), which was at par with T₄ (82.0 mg kg⁻¹ soil) and T₅ (80.8 mg kg⁻¹ soil). In case of NH₄-N, the highest content was maintained by the treatment T₇ (15.7 mg kg⁻¹ soil), and the lowest, by T₁ (7.4 mg kg⁻¹ soil). The order followed by the rest of the treatments was: T₆ (14.4 mg kg⁻¹ soil) > T₈ (14.0 mg kg⁻¹ soil) > T₅ (13.1 mg kg⁻¹ soil) > T₉ (12.8 mg kg⁻¹ soil) > T₃ (12.5 mg kg⁻¹ soil) > T₄ (11.0 mg kg⁻¹ soil) > T₂ (10.4 mg kg⁻¹ soil). The lowest NO₃-N content of the soil was maintained under T₁ (12.6 mg kg⁻¹ soil). The rest of the treatments could be divided into two groups, the superior one comprising statistically similar T₇ (18.4 mg kg⁻¹ soil), T₆ (17.2 mg kg⁻¹ soil), T₃ (16.7 mg kg⁻¹ soil) and T₅ (16.4 mg kg⁻¹ soil), and the inferior group, of T₈ (15.9 mg kg⁻¹ soil), T₉ (15.1 mg kg⁻¹ soil), T₂ (14.8 mg kg⁻¹ soil) and T₄ (14.4 mg kg⁻¹ soil).

As in case of the dough stage, the different forms of N continued to remain higher under the treatments receiving higher amount of fertilizers at the harvest of maize i.e., M₃ > M₂ > M₁ (Table 27). Total N content was highest under T₇ (586 mg kg⁻¹ soil) followed by T₆ (584 mg kg⁻¹ soil), T₈ (583 mg kg⁻¹ soil) and T₉ (581 mg kg⁻¹ soil). All

Table 27. Effect of fertilizer and manurial treatments on different forms of soil N (mg kg⁻¹ soil) after harvest of maize

Treatment	Total N				Available N ^a			
	M ₁	M ₂	M ₃	Mean	M ₁	M ₂	M ₃	Mean
T ₁	548	559	565	558	74.1	80.9	85.7	80.3
T ₂	564	569	572	568	76.4	82.0	86.4	81.6
T ₃	575	580	584	580	80.9	80.6	84.2	81.9
T ₄	565	573	578	572	78.0	80.5	82.9	80.5
T ₅	573	581	582	579	76.5	79.9	82.3	79.5
T ₆	579	586	588	584	80.6	84.5	88.6	84.6
T ₇	580	588	589	586	81.6	84.7	88.9	85.1
T ₈	580	584	587	583	82.4	85.3	88.3	85.3
T ₉	579	582	582	581	82.9	84.5	87.5	85.0
Mean	572	578	581		79.3	82.5	86.1	
CD (<i>P</i> = 0.05)	T : 5; M : 3; T×M : NS				T : 2.0; M : 1.4; T×M : NS			
	NH ₄ -N				NO ₃ -N			
T ₁	6.9	7.6	7.7	7.3	9.2	10.8	11.9	10.6
T ₂	8.0	8.0	8.4	8.1	11.1	11.9	13.5	12.2
T ₃	8.5	8.4	10.0	9.0	10.8	12.3	15.8	13.0
T ₄	7.3	7.6	7.6	7.5	9.2	11.7	10.8	10.6
T ₅	7.6	7.7	10.0	8.4	10.8	14.1	14.5	13.1
T ₆	7.1	8.8	10.5	8.8	11.1	13.0	16.1	13.4
T ₇	7.6	11.9	12.4	10.6	11.9	14.7	17.8	14.8
T ₈	8.8	10.8	11.9	10.5	11.3	14.7	16.5	14.2
T ₉	8.4	9.2	11.3	9.6	10.5	14.5	15.0	13.3
Mean	7.7	8.9	10.0		10.6	13.1	14.6	
CD (<i>P</i> = 0.05)	T : 1.2; M : 0.6; T×M : NS				T : 2.1; M : 1.1; T×M : NS			

^a Alkaline potassium permanganate oxidisable nitrogen

T₁: control; T₂: FYM; T₃: N₁₂₀; T₄: P₆₀; T₅: N₆₀P₃₀K₃₀; T₆: N₉₀P₄₅K₄₅; T₇: N₁₂₀P₆₀K₆₀; T₈: T₆ + FYM;

T₉: T₅ + FYM

M₁: N₀P₀K₀; M₂: N₆₀P₃₀K₃₀; M₃: N₉₀P₄₅K₄₅

these treatments were at par. They were followed by the statistically-at-par treatments, T₃ (580 mg kg⁻¹ soil) and T₅ (579 mg kg⁻¹ soil). The lowest total N content was maintained by T₁ (558 mg kg⁻¹ soil). The treatments were divided into three groups with respect to available N content of soil at this stage. The treatments T₈ (85.3 mg kg⁻¹ soil), T₇ (85.1 mg kg⁻¹ soil), T₉ (85.0 mg kg⁻¹ soil) and T₆ (84.6 mg kg⁻¹ soil) were at par among themselves and superior to T₃ (81.9 mg kg⁻¹ soil), T₂ (81.6 mg kg⁻¹ soil), T₄ (80.5 mg kg⁻¹ soil) and T₁ (80.3 mg kg⁻¹ soil). The lowest available N was maintained by T₅ (79.5 mg kg⁻¹ soil) which was, however, statistically similar to T₄ and T₁. While the treatments T₇ (10.6 mg kg⁻¹ soil), T₈ (10.5 mg kg⁻¹ soil) and T₉ (9.6 mg kg⁻¹ soil) were at par in terms of NH₄-N content of the soil, they were superior to statistically similar T₃ (9.0 mg kg⁻¹ soil), T₆ (8.8 mg kg⁻¹ soil), T₅ (8.4 mg kg⁻¹ soil) and T₂ (8.1 mg kg⁻¹ soil). The lowest NH₄-N content of 7.3 mg kg⁻¹ soil was maintained under T₁, which was at par with T₄ (7.5 mg kg⁻¹ soil). The treatments could be divided into two groups with respect to the NO₃-N content. The superior group was led by T₇ (14.8 mg kg⁻¹ soil) and followed by T₈ (14.2 mg kg⁻¹ soil), T₆ (13.4 mg kg⁻¹ soil), T₉ (13.3 mg kg⁻¹ soil), T₅ (13.1 mg kg⁻¹ soil) and T₃ (13.0 mg kg⁻¹ soil). The group inferior to T₇ consisted of T₂ (12.2 mg kg⁻¹ soil), T₄ (10.6 mg kg⁻¹ soil) and T₁ (10.6 mg kg⁻¹ soil).

As seen from Figure 11 and 12, the NH₄- and NO₃-N content of the soil decreased at harvest of maize, which could be explained by the crop uptake and losses through various means. It can be observed from Figure 11 that the NH₄-N content of the soil was higher at maize harvest as compared to its initial value recorded before sowing of wheat under the treatments T₇, T₈ and T₉. This indicates that application of N through conjunctive use of organics and inorganics helps in increased accumulation of NH₄-N in the soil, which could be attributed to the continuous decomposition of organics (FYM in this study). Some of the NH₄-N may get sorbed on the exchange sites of soil, and is therefore not subjected to crop uptake or losses. In contrast, the NH₄-N, which is further converted to NO₃-N through mineralization is preferably taken up by crops and is amenable to losses through leaching, particularly during the maize (*kharif*) season under

upland conditions and high rainfall. This could possibly explain the decline in the $\text{NO}_3\text{-N}$ content of soil from sowing of wheat to maize harvest (Figure 12), irrespective of the treatments. The same explanation can be provided for the decrease in available N content of the soil from silking to harvest of maize, i.e., 325 DAS of wheat (Figure 10).

After one cycle of the cropping system, it was observed that the available N content of the soil increased from its initial value (82.4 mg kg^{-1} soil) under the treatments T_6 , T_7 , T_8 and T_9 . These treatments involved the application of N in a balanced and integrated manner. Increase in available N content of the soil by balanced fertilization was also observed by Hegde and Katyal (1998). Supplementing organics (FYM) with inorganic nitrogen also enhances the available N content of the soil (Subramanian and Kumaraswamy, 1989b; Sharma and Gupta, 1998) as a result of the hastened mineralization, once the requirement of N by microbes was fulfilled through inorganic nitrogen.

4.2.2 Nitrogen Fractions

4.2.2.1 Wheat

The average total organic, amino acid, amino sugar, ammonia, unidentified and acid insoluble N in soil before sowing of wheat were 558, 134, 19.9, 122, 140 and 143 mg kg^{-1} soil, respectively (Table 28). The total organic N (TON) was about 96% of the total N. As observed earlier (Table 18), absence of significant differences among the different sites within the experimental field is further confirmed by the data and statistical inferences arising from Table 28.

The treatments did not differ among themselves in respect of the TON of the soil at heading stage of wheat (Table 29), with the average content being 549 mg kg^{-1} . It was found to have reduced from its initial value recorded before sowing of wheat (Figure 14). Total hydrolyzable nitrogen (THN), which represents the easily decomposable fraction of soil organic nitrogen, was found to increase after application of fertilizers and manures (Figure 15). It was observed that THN accounted for 74% of the total organic

Table 28. Organic N fractions (mg N kg⁻¹ soil) before sowing of wheat

Treatment	Total organic N	Hydrolysable N					Acid insoluble N
		Amino acid N	Amino sugar N	NH ₃ -N	Unidentified N	Total	
T ₁	557	135	19.6	123	135	412	145
T ₂	558	135	19.2	124	134	412	146
T ₃	559	135	20.5	124	138	417	141
T ₄	563	137	19.5	120	139	416	147
T ₅	556	133	19.6	120	139	412	144
T ₆	561	130	20.2	121	143	414	147
T ₇	549	131	20.1	120	144	416	133
T ₈	556	133	20.5	122	141	416	140
T ₉	560	132	19.9	121	143	417	144
Mean	558	134	19.9	122	140	415	143
CD (<i>P</i> = 0.05)	NS	NS	NS	NS	NS	NS	NS

Table 29. Organic N fractions (mg N kg⁻¹ soil) at heading stage of wheat

Treatment	Total organic N	Hydrolysable N					Acid insoluble N
		Amino acid N	Amino sugar N	NH ₃ -N	Unidentified N	Total	
T ₁	547	133	14.9	124	139	410	137
T ₂	546	140	18.5	133	126	417	129
T ₃	555	143	21.2	149	127	441	114
T ₄	549	135	16.9	124	146	422	127
T ₅	547	139	18.3	133	131	422	125
T ₆	549	142	19.3	143	127	431	118
T ₇	555	153	23.0	155	115	447	108
T ₈	543	150	21.8	151	113	435	107
T ₉	549	144	19.8	143	117	424	125
Mean	549	142	19.3	139	127	428	121
CD (<i>P</i> = 0.05)	NS	3	0.9	4	8	7	11

T₁: control; T₂: FYM; T₃: N₁₂₀; T₄: P₆₀; T₅: N₆₀P₃₀K₃₀; T₆: N₉₀P₄₅K₄₅; T₇: N₁₂₀P₆₀K₆₀; T₈: T₆ + FYM;
T₉: T₅ + FYM

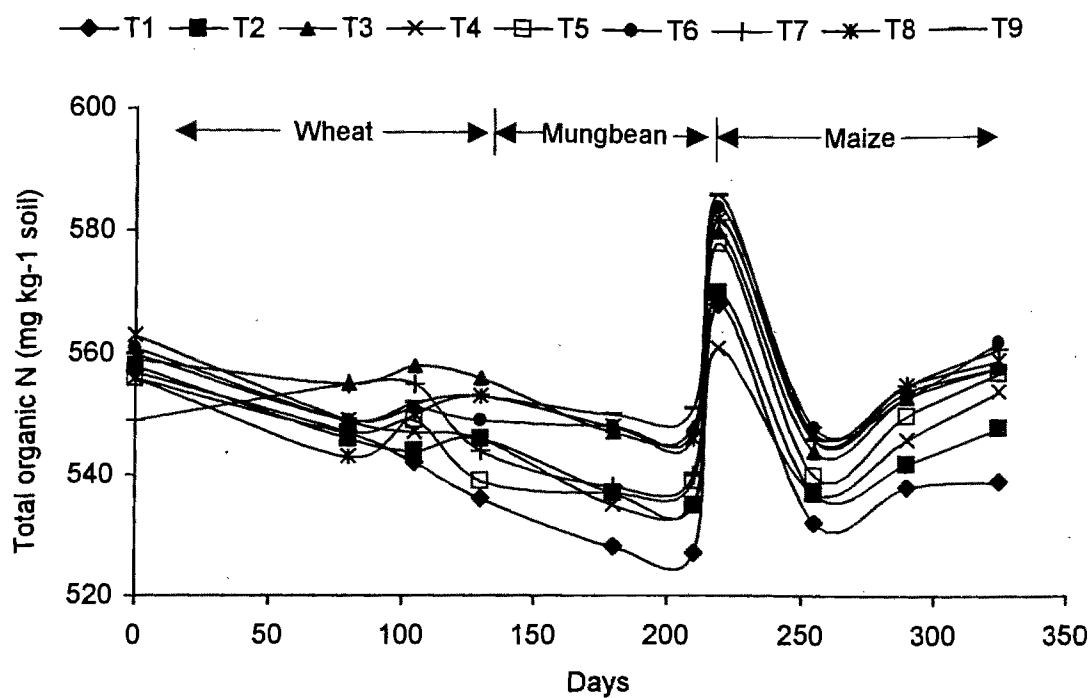


Figure 14. Influence of fertilizer and manurial treatments on the total organic N contents of soil at different stages of crop

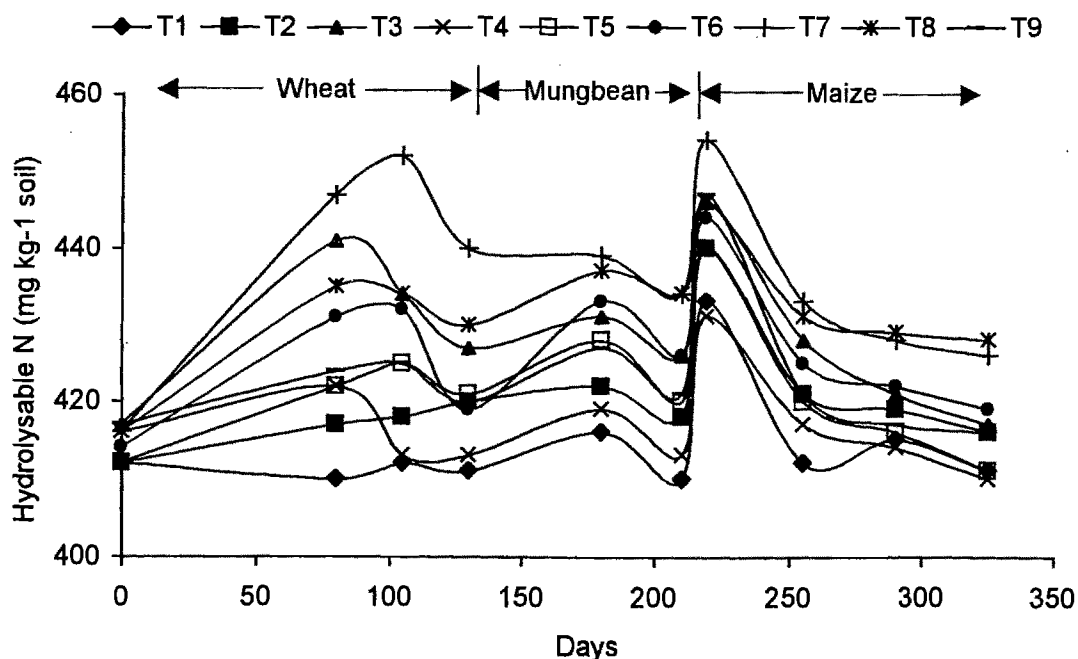


Figure 15. Influence of fertilizer and manurial treatments on the hydrolysable-N contents of soil at different stages of crop growth

nitrogen before sowing of wheat, which increased to 78% at the heading stage. This is explained by the fact that, along with meeting the immediate need of the crops for N, part of the fertilizer N is immobilized temporarily by the increased microbial population into the easily degradable compounds, such as amino sugars and amino acids. These compounds could be again broken down on the death of microbes to supply N to the crop. Maximum THN fraction was recorded under T_7 (447 mg kg⁻¹ soil), followed by T_3 (441 mg kg⁻¹ soil), which were at par. The rest of the treatments followed the sequence: T_8 (435 mg kg⁻¹ soil) > T_6 (431 mg kg⁻¹ soil) > T_9 (424 mg kg⁻¹ soil) > $T_4 = T_5$ (422 mg kg⁻¹ soil) > T_2 (417 mg kg⁻¹ soil) > T_1 (410 mg kg⁻¹ soil). Therefore, it can be inferred that increase in THN was higher under the treatments receiving higher amounts of soluble N fertilizer, and also when FYM was used in conjunction with inorganics. This is in concurrence with the results obtained by Subba Rao and Ghosh (1981), Prasad and Rokima (1991a) and Pathak and Sarkar (1995).

There was an increase in the amino acid N (AAN) content of soil (barring T_1 and T_4) with the highest value being exhibited by T_7 (153 mg kg⁻¹). It was superior to T_8 (150 mg kg⁻¹ soil), which, in turn, performed better than T_9 (144 mg kg⁻¹ soil), T_3 (143 mg kg⁻¹ soil) and T_6 (142 mg kg⁻¹ soil). The lowest amino acid N was registered under T_1 (133 mg kg⁻¹ soil). The increase in the amino acid N content from sowing to heading stage of wheat in the plots receiving higher doses of N can be inferred from Figure 16. This could be explained by the temporary immobilization of N into certain amino acids by the microorganisms. The same explanation can be offered for an increase in ASN and NHN contents of the soil, as a more or less similar trend was followed by the treatments in respect of amino sugar N content (ASN) (range- 14.9-23.0 mg kg⁻¹ soil) (Figure 17) and ammonia N (NHN) (range- 124-155 mg kg⁻¹ soil) (Figure 18). Thus, the different identified fractions of hydrolyzable N were found to increase with increased amounts of manure and fertilizer addition. Highest amount of unidentified N (Figure 19) fraction was maintained under T_4 (146 mg kg⁻¹ soil), followed by T_1 (139 mg kg⁻¹ soil). Both the treatments were at par. They were followed by the statistically similar treatments T_5 (131

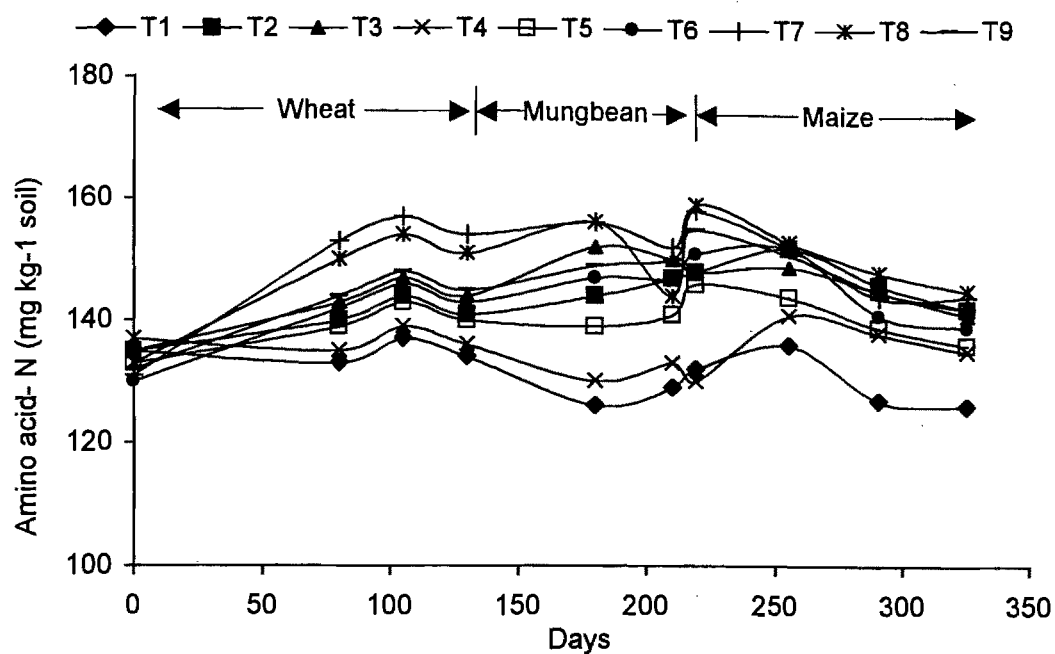


Figure 16. Influence of fertilizer and manurial treatments on the amino acid- N contents of soil at different stages of crop growth

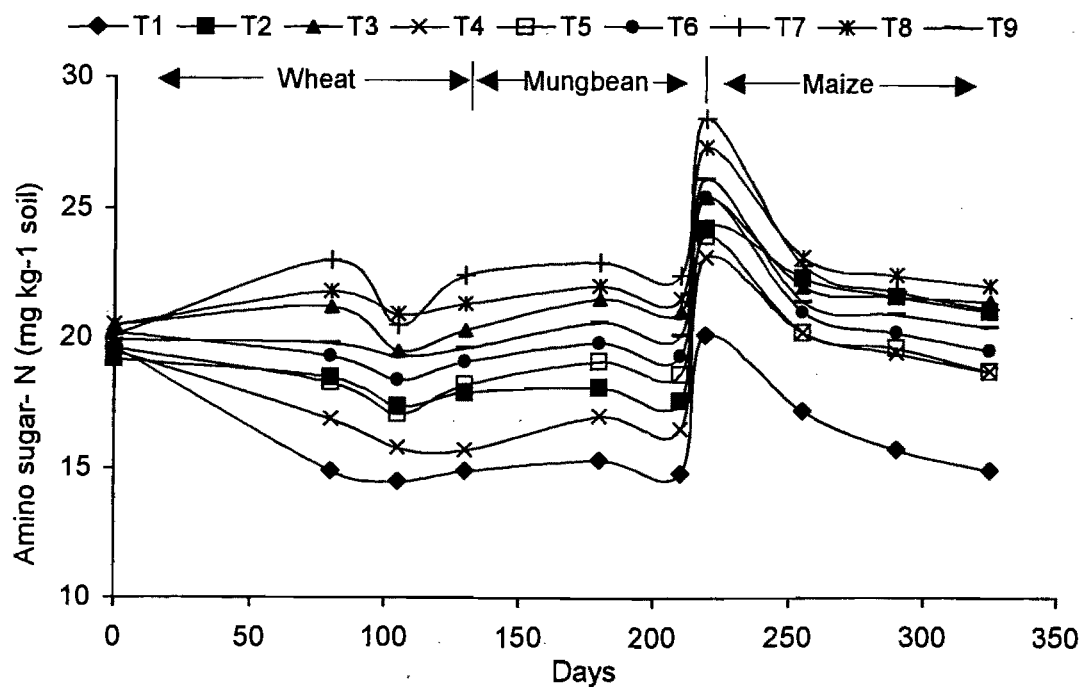


Figure 17. Influence of fertilizer and manurial treatments on the amino sugar-N contents of soil at different stages of crop growth

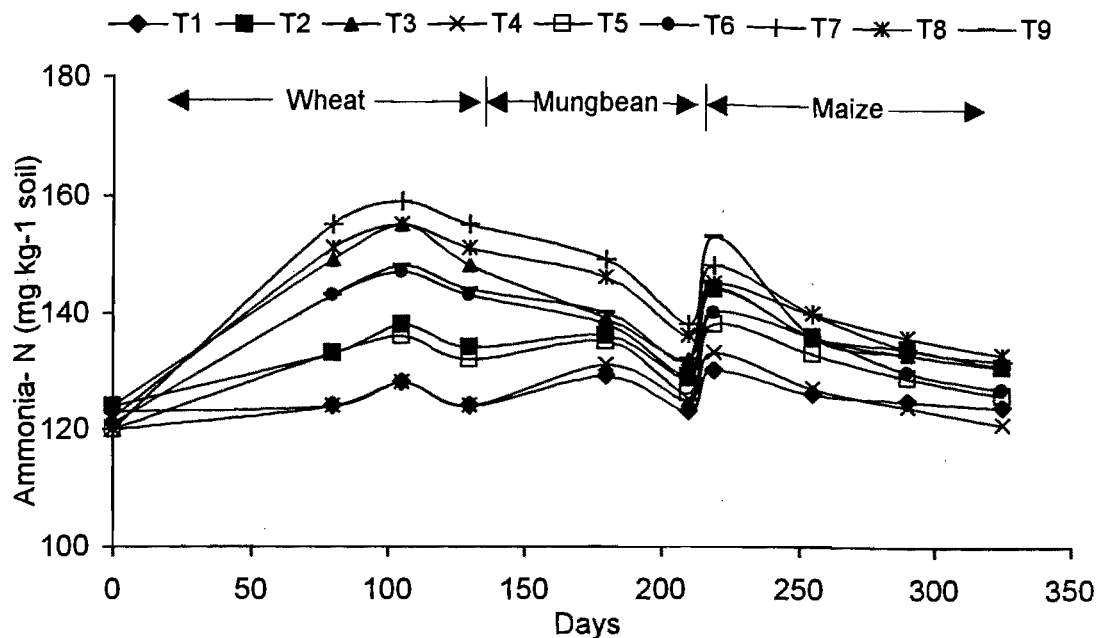


Figure 18. Influence of fertilizer and manurial treatments on the ammonia-N contents of soil at different stages of crop growth

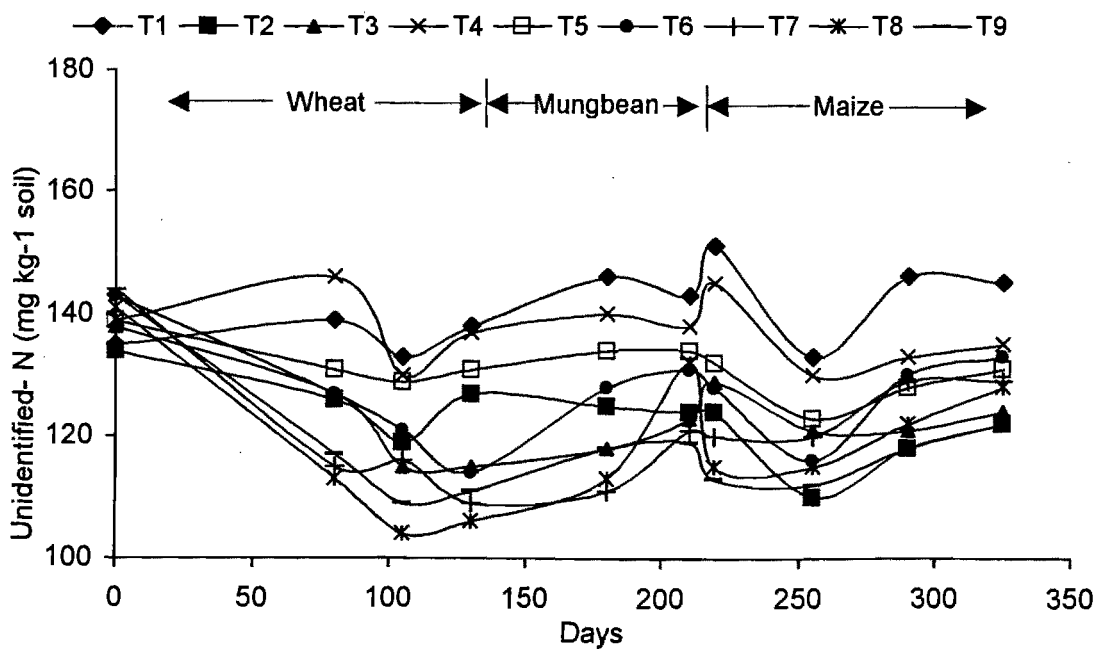


Figure 19. Influence of fertilizer and manurial treatments on the unidentified-N contents of soil at different stages of crop growth.

mg kg⁻¹ soil), T₆ (127 mg kg⁻¹ soil), T₃ (127 mg kg⁻¹ soil) and T₂ (126 mg kg⁻¹ soil). The lowest value of unidentified N fraction was recorded under T₈ (113 mg kg⁻¹ soil), which was at par with T₇ (115 mg kg⁻¹ soil) and T₉ (117 mg kg⁻¹ soil) (Table 29).

The acid insoluble N fraction (AIN) obtained from the difference between total organic N (TON) and THN, was highest under T₁ (137 mg kg⁻¹ soil), which was at par with T₂ (129 mg kg⁻¹ soil) and T₄ (127 mg kg⁻¹ soil). These treatments were followed by T₅ (125 mg kg⁻¹ soil), T₉ (125 mg kg⁻¹ soil) and T₆ (118 mg kg⁻¹ soil), the three of which were statistically similar. The lowest value of AIN was recorded under T₈ (107 mg kg⁻¹ soil), which performed similarly as T₇ (108 mg kg⁻¹ soil) and T₃ (114 mg kg⁻¹ soil). Therefore, it can be seen that wherever the amount of N applied through fertilizers or manures was low, the soil maintained most of the N in forms not easily mineralizable. This means that the demand of N by the crops could not be met, which, in turn led to lower N uptake and yield under these treatments.

There was not much change in the TON, THN and AIN content of the soil between heading and dough stage of wheat (Table 30). With respect to TON, there were no significant differences among the treatments. The treatment T₁ (412 mg kg⁻¹ soil) maintained the lowest amount of THN in the soil, and was at par with T₂ (418 mg kg⁻¹ soil) and T₄ (413 mg kg⁻¹ soil). The highest amount of THN was recorded under T₇ (452 mg kg⁻¹ soil). In case of AAN, the order followed by the treatments was the same as in heading stage, with the maximum value of 157 mg kg⁻¹ soil being exhibited under T₇, and the minimum of 137 mg kg⁻¹ soil, under T₁. The treatments T₇ (20.5 mg kg⁻¹ soil) and T₈ (20.9 mg kg⁻¹ soil) were statistically at par and superior to the rest of the treatments in terms of ASN. They were followed by the statistically-at-par treatments T₃ (19.5 mg kg⁻¹ soil), T₉ (19.3 mg kg⁻¹ soil) and T₆ (18.4 mg kg⁻¹ soil). The lowest value of 14.5 mg kg⁻¹ soil was recorded under control, which was at par with T₄ (15.8 mg kg⁻¹ soil). The order followed by different treatments in influencing NHN content of the soil was: T₇ (159 mg kg⁻¹) > T₈ = T₃ (155 mg kg⁻¹) > T₉ (148 mg kg⁻¹) > T₆ (147 mg kg⁻¹) > T₂ (138 mg kg⁻¹) > T₅ (136 mg kg⁻¹) > T₄ = T₁ (128 mg kg⁻¹). The statistically higher values of

unidentified-N fraction of the hydrolysable N were obtained under the treatments T_1 (133 mg kg⁻¹ soil), T_4 (130 mg kg⁻¹ soil) and T_5 (129 mg kg⁻¹ soil), which were at par among themselves. They were followed by T_6 (121 mg kg⁻¹ soil), T_2 (119 mg kg⁻¹ soil), T_7 (116 mg kg⁻¹ soil) and T_3 (115 mg kg⁻¹ soil). The lowest values were obtained under T_8 (104 mg kg⁻¹ soil) and T_9 (109 mg kg⁻¹ soil), both of which were at par. The lowest value of AIN was recorded under T_7 (103 mg kg⁻¹ soil). The rest of the treatments formed two groups, with the superior one comprising T_1 to T_5 (range- 124 to 134 mg kg⁻¹ soil), and the rest the treatments forming the inferior group.

There was a slight decrease in the TON and THN content of soil between dough stage and harvest of wheat. This could be attributed to the continuous mineralization process and removal of N from soil by crop uptake and various loss mechanisms. Total organic N was higher under T_3 (556 mg kg⁻¹ soil), T_8 (553 mg kg⁻¹ soil), T_9 (553 mg kg⁻¹ soil), T_6 (549 mg kg⁻¹ soil), T_2 (546 mg kg⁻¹ soil) and T_4 (546 mg kg⁻¹ soil), all of which were statistically at par (Table 31). The lowest TON content was maintained under T_1 (536 mg kg⁻¹ soil), which was at par with T_5 (539 mg kg⁻¹ soil) and T_7 (544 mg kg⁻¹ soil). The highest AAN content was obtained under T_7 (154 mg kg⁻¹ soil), which was superior to T_8 (151 mg kg⁻¹ soil). Next were the treatments T_9 (145 mg kg⁻¹ soil), T_3 (144 mg kg⁻¹ soil) and T_6 (143 mg kg⁻¹ soil), which were at par among themselves. Lowest AAN content of 134 mg kg⁻¹ soil was maintained under control, which was at par with T_4 (136 mg kg⁻¹ soil). The treatments T_7 (22.4 mg kg⁻¹ soil) and T_8 (21.3 mg kg⁻¹ soil), both at par, maintained the highest level of ASN in the soil at wheat harvest. They were followed by T_3 (20.3 mg kg⁻¹ soil), T_9 (19.6 mg kg⁻¹ soil) and T_6 (19.1 mg kg⁻¹ soil), which were all at par. Next in line were T_2 (17.9 mg kg⁻¹ soil), T_4 (15.7 mg kg⁻¹ soil) and T_1 (14.9 mg kg⁻¹ soil), the later two treatments being statistically similar. The highest NHN level of 155 mg kg⁻¹ soil was maintained under T_7 , while the lowest level was maintained under T_1 (124 mg kg⁻¹ soil). The values maintained under the rest of the treatments ranged from 124 to 151 mg kg⁻¹ soil. The order followed by different treatments in respect of UIN was: T_1 (138 mg kg⁻¹ soil) > T_4 (137 mg kg⁻¹ soil) > T_5 (131 mg kg⁻¹ soil).

Table 30. Organic N fractions (mg N kg⁻¹ soil) at dough stage of wheat

Treatment	Total organic N	Hydrolysable N					Acid insoluble N
		Amino acid N	Amino sugar N	NH ₃ -N	Unidentified N	Total	
T ₁	542	137	14.5	128	133	412	130
T ₂	544	144	17.4	138	119	418	125
T ₃	558	147	19.5	155	115	434	124
T ₄	547	139	15.8	128	130	413	134
T ₅	549	143	17.1	136	129	425	124
T ₆	551	146	18.4	147	121	432	119
T ₇	555	157	20.5	159	116	452	103
T ₈	550	154	20.9	155	104	434	116
T ₉	552	148	19.3	148	109	425	127
Mean	550	146	18.2	144	120	427	122
CD (<i>P</i> = 0.05)	NS	3	1.4	4	10	8	12

Table 31. Organic N fractions (mg N kg⁻¹ soil) after harvest of wheat

Treatment	Total organic N	Hydrolysable N					Acid insoluble N
		Amino acid N	Amino sugar N	NH ₃ -N	Unidentified N	Total	
T ₁	536	134	14.9	124	138	411	125
T ₂	546	141	17.9	134	127	420	126
T ₃	556	144	20.3	148	115	427	128
T ₄	546	136	15.7	124	137	413	133
T ₅	539	140	18.2	132	131	421	118
T ₆	549	143	19.1	143	114	419	130
T ₇	544	154	22.4	155	109	440	104
T ₈	553	151	21.3	151	106	430	123
T ₉	553	145	19.6	144	111	420	132
Mean	547	143	18.8	140	121	422	124
CD (<i>P</i> = 0.05)	12	3	1.5	4	11	7	12

T₁: control; T₂: FYM; T₃: N₁₂₀; T₄: P₆₀; T₅: N₆₀P₃₀K₃₀; T₆: N₉₀P₄₅K₄₅; T₇: N₁₂₀P₆₀K₆₀; T₈: T₆ + FYM;
T₉: T₅ + FYM

soil) > T₂ (127 mg kg⁻¹ soil) > T₃ (115 mg kg⁻¹ soil) > T₆ (114 mg kg⁻¹ soil) > T₉ (111 mg kg⁻¹ soil) > T₇ (109 mg kg⁻¹ soil) > T₈ (106 mg kg⁻¹ soil). Total hydrolysable N, which is the sum of AAN, ASN, NHN and UIN was found to be highest under T₇ (440 mg kg⁻¹ soil) and lowest under T₁ (411 mg kg⁻¹ soil), with the rest of the treatments falling in between. The lowest value of AIN was registered under T₇ (104 mg kg⁻¹ soil), with the rest of the treatments being divided into two groups. The first group consisting of only T₅ (118 mg kg⁻¹ soil) was inferior to the remaining treatments (range- 123-133 mg kg⁻¹ soil).

From the above paragraphs, it is clear that all the forms of hydrolysable N *viz.*, ASN, AAN and NHN were maintained at higher levels under the treatments T₆ and T₇, where fertilizer N was applied at 75 and 100% of the recommended dose; and also T₈ and T₉, where FYM was applied along with inorganic fertilizers. This emphasizes the need to go for application of N in a balanced and integrated manner to ensure continuous N supply to the crop through the hydrolysable fractions.

4.2.2.2 Mungbean

There occurred a decrease in the total organic and acid insoluble N from the harvest of wheat to flowering stage of mungbean while total hydrolysable N was found to increase. Decrease in TON could be a result of not applying any N fertilizer to mungbean. Increase in THN could be attributed to the increased microbial activity in the presence of a leguminous crop such as mungbean. This also explains the reduction in the AIN fraction, which gets broken down to hydrolysable forms. In case of TON, the highest content was observed under T₉ (550 mg kg⁻¹ soil) followed by T₈ (548 mg kg⁻¹ soil), T₆ (548 mg kg⁻¹ soil) and T₃ (547 mg kg⁻¹ soil), all of which were at par among themselves (Table 32). They were followed by T₇ (538 mg kg⁻¹ soil), T₅ (537 mg kg⁻¹ soil), T₂ (537 mg kg⁻¹ soil) and T₄ (535 mg kg⁻¹ soil), which were also at par. The lowest TON content was maintained by T₁ (528 mg kg⁻¹ soil). The importance of applying FYM to wheat is therefore clear from the higher amounts of TON under the treatments T₈ and T₉, even after wheat was harvested. The lowest THN of the soil was obtained

under T_1 (416 mg kg⁻¹ soil), and the highest, under T_7 (439 mg kg⁻¹ soil), with the rest of the treatments falling in between.

Both T_7 and T_8 , each with an AAN content of 156 mg kg⁻¹ soil, and T_3 (152 mg kg⁻¹ soil) were superior to T_9 (149 mg kg⁻¹ soil), T_6 (147 mg kg⁻¹ soil) and T_2 (144 mg kg⁻¹ soil), the three of which were statistically at par. The lowest AAN content was maintained under T_1 (126 mg kg⁻¹ soil), which was at par with T_4 (130 mg kg⁻¹ soil). The various fertilizer and manurial treatments could be grouped into pairs with respect to the differences in the ASN content. The highest level was maintained by T_7 (22.9 mg kg⁻¹ soil) and T_8 (22.0 mg kg⁻¹ soil), followed by T_3 (21.5 mg kg⁻¹ soil) and T_9 (20.6 mg kg⁻¹ soil); then by T_6 (19.8 mg kg⁻¹ soil) and T_5 (19.1 mg kg⁻¹ soil). The lowest ASN content was maintained under control, T_1 (15.3 mg kg⁻¹ soil). The order followed by the treatments in influencing the NHN content of the soil was: T_7 (149 mg kg⁻¹ soil) > T_8 (146 mg kg⁻¹ soil) > T_9 (140 mg kg⁻¹ soil) > T_3 (139 mg kg⁻¹ soil) > T_6 (138 mg kg⁻¹ soil) > T_2 (136 mg kg⁻¹ soil) > T_5 (135 mg kg⁻¹ soil) > T_4 (131 mg kg⁻¹ soil) > T_1 (129 mg kg⁻¹ soil). In contrast to NHN, the UIN followed the order: T_1 (146 mg kg⁻¹ soil) > T_4 (140 mg kg⁻¹ soil) > T_5 (134 mg kg⁻¹ soil) > T_6 (128 mg kg⁻¹ soil) > T_2 (125 mg kg⁻¹ soil) > $T_3 = T_9$ (118 mg kg⁻¹ soil) > T_8 (113 mg kg⁻¹ soil) > T_7 (111 mg kg⁻¹ soil). The treatment T_9 (123 mg kg⁻¹ soil) was found to lead the table in terms of AIN, followed by T_3 (116 mg kg⁻¹ soil), T_4 (116 mg kg⁻¹ soil) and T_6 (115 mg kg⁻¹ soil), all of which were at par among themselves. Next were the statistically-at-par treatments T_2 (114 mg kg⁻¹ soil), T_1 (112 mg kg⁻¹ soil), T_8 (111 mg kg⁻¹ soil) and T_5 (109 mg kg⁻¹ soil). The lowest value of 99 mg kg⁻¹ soil was registered under T_7 .

Table 33 shows the various organic N fractions of soil before incorporation of mungbean. The total organic N ranged from 527 to 551 mg kg⁻¹ soil, with the THN and AIN ranging from 410 to 434 mg kg⁻¹ soil and 106 to 130 mg kg⁻¹ soil, respectively. Of the hydrolysable N fractions, the AAN fraction was highest under the treatment T_7 , with a value of 152 mg kg⁻¹ soil. It was at par with T_9 (150 mg kg⁻¹ soil), T_3 (150 mg kg⁻¹ soil), T_6 (147 mg kg⁻¹ soil) and T_2 (147 mg kg⁻¹ soil). The lowest AAN content was obtained

Table 32. Organic N fractions (mg N kg⁻¹ soil) at flowering stage of mungbean

Treatment	Total organic N	Hydrolysable N					Acid insoluble N
		Amino acid N	Amino sugar N	NH ₃ -N	Unidentified N	Total	
T ₁	528	126	15.3	129	146	416	112
T ₂	537	144	18.1	136	125	422	114
T ₃	547	152	21.5	139	118	431	116
T ₄	535	130	17.0	131	140	419	116
T ₅	537	139	19.1	135	134	428	109
T ₆	548	147	19.8	138	128	433	115
T ₇	538	156	22.9	149	111	439	99
T ₈	548	156	22.0	146	113	437	111
T ₉	550	149	20.6	140	118	427	123
Mean	541	144	19.6	138	126	428	113
CD (<i>P</i> = 0.05)	7	7	1.1	3	11	6	9

Table 33. Organic N fractions (mg N kg⁻¹ soil) before incorporation of mungbean

Treatment	Total organic N	Hydrolysable N					Acid insoluble N
		Amino acid N	Amino sugar N	NH ₃ -N	Unidentified N	Total	
T ₁	527	129	14.8	123	143	410	117
T ₂	535	147	17.6	129	124	418	117
T ₃	548	150	21.0	132	123	426	122
T ₄	535	133	16.5	125	138	413	122
T ₅	539	141	18.6	126	134	420	119
T ₆	547	147	19.3	129	131	426	121
T ₇	540	152	22.4	138	121	434	106
T ₈	546	144	21.5	136	132	434	112
T ₉	551	150	20.1	132	119	421	130
Mean	541	144	19.1	130	129	422	118
CD (<i>P</i> = 0.05)	8	7	1.1	4	11	5	8

T₁: control; T₂: FYM; T₃: N₁₂₀; T₄: P₆₀; T₅: N₆₀P₃₀K₃₀; T₆: N₉₀P₄₅K₄₅; T₇: N₁₂₀P₆₀K₆₀; T₈: T₆ + FYM;
T₉: T₅ + FYM

under T_1 (129 mg kg⁻¹ soil), which was at par with T_4 (133 mg kg⁻¹ soil). In case of ASN, the high contents of 22.4 and 21.5 mg kg⁻¹ soil were maintained by T_7 and T_8 , respectively, followed by T_3 (21.0 mg kg⁻¹ soil) and T_9 (20.1 mg kg⁻¹ soil). Next to follow were the treatments T_6 (19.3 mg kg⁻¹ soil) and T_5 (18.6 mg kg⁻¹ soil). The lowest ASN content of 14.8 mg kg⁻¹ soil was maintained under T_1 . As in case of ASN, the NHN content was also higher under T_7 and T_8 , with values of 138 and 136 mg kg⁻¹ soil, respectively. They were superior to T_3 (132 mg kg⁻¹ soil), T_9 (132 mg kg⁻¹ soil), T_2 (129 mg kg⁻¹ soil) and T_6 (129 mg kg⁻¹ soil). At the bottom of the table was T_1 (123 mg kg⁻¹ soil). The lowest UIN fraction was maintained under T_9 (119 mg kg⁻¹ soil). The rest of the treatments were divided into two groups, with the superior group comprising of the treatments T_1 (143 mg kg⁻¹ soil), T_4 (138 mg kg⁻¹ soil) and T_5 (134 mg kg⁻¹ soil).

Throughout the mungbean season, the various hydrolysable N pools were found to be maintained at highest level under the treatment T_7 , where N was applied at 100% of recommended dose. Reducing the N dose by 25%, but applying FYM to supplement N (T_8) was the next best treatment in this respect. Thus, these two treatments could sustain a crop of mungbean even though no fertilizer N was applied after the wheat season, through their positive effects on the hydrolysable N fractions.

4.2.2.3 Maize

The average total organic, hydrolysable and acid insoluble N fractions of the soil before sowing maize were 577, 442 and 134 mg kg⁻¹, respectively (Table 34). Among the hydrolysable N fractions, the values increased in the order: ASN (24.9 mg kg⁻¹ soil) < UIN (129 mg kg⁻¹ soil) < NHN (142 mg kg⁻¹ soil) < AAN (147 mg kg⁻¹ soil).

As can be seen from Table 35, TON was higher under T_6 (548 mg kg⁻¹ soil), T_8 (547 mg kg⁻¹ soil), T_7 (546 mg kg⁻¹ soil) and T_9 (546 mg kg⁻¹ soil), all of which were statistically at par. The lowest TON content was maintained under T_1 (532 mg kg⁻¹ soil). Total hydrolysable N was found to be highest under T_7 (433 mg kg⁻¹ soil), this was followed by T_8 (431 mg kg⁻¹ soil), T_3 (428 mg kg⁻¹ soil) and T_6 (425 mg kg⁻¹ soil). The

Table 34. Organic N fractions (mg N kg⁻¹ soil) before sowing of maize

Treatment	Total organic N	Hydrolysable N					Acid insoluble N
		Amino acid N	Amino sugar N	NH ₃ -N	Unidentified N	Total	
T ₁	568	132	20.1	130	151	433	135
T ₂	570	148	24.2	144	124	440	130
T ₃	580	148	25.4	144	129	446	134
T ₄	561	130	23.1	133	145	431	130
T ₅	578	146	23.9	138	132	440	138
T ₆	584	151	25.4	140	128	444	140
T ₇	582	158	28.4	148	120	454	128
T ₈	582	159	27.3	145	115	446	136
T ₉	586	155	26.1	153	113	447	139
Mean	577	147	24.9	142	129	442	134

Table 35. Effect of fertilizer and manurial treatments on different forms of soil N (mg kg⁻¹ soil) at silking stage of maize

	Total organic N				Hydrolysable N				Acid insoluble N			
	M ₁	M ₂	M ₃	Mean	M ₁	M ₂	M ₃	Mean	M ₁	M ₂	M ₃	Mean
T ₁	531	533	533	532	407	411	419	412	124	122	114	120
T ₂	536	535	538	537	415	420	428	421	121	115	110	115
T ₃	545	544	543	544	420	428	435	428	125	116	108	116
T ₄	535	537	540	537	408	418	425	417	127	119	115	120
T ₅	541	541	540	540	414	419	427	420	127	123	112	121
T ₆	549	549	546	548	418	426	431	425	131	123	114	123
T ₇	546	547	545	546	426	435	439	433	121	113	106	113
T ₈	549	546	546	547	422	433	439	431	127	113	107	116
T ₉	549	545	543	546	414	422	426	421	135	123	117	125
Mean	542	542	542		416	424	430		126	118	112	
CD (P = 0.05)	T : 4; M : NS; T×M : NS				T : 2; M : 1; T×M : NS				T : 6; M : 3; T×M : NS			

T₁: control; T₂: FYM; T₃: N₁₂₀; T₄: P₆₀; T₅: N₆₀P₃₀K₃₀; T₆: N₉₀P₄₅K₄₅; T₇: N₁₂₀P₆₀K₆₀; T₈: T₆ + FYM; T₉: T₅ + FYM
M₁: N₀P₀K₀; M₂: N₆₀P₃₀K₃₀; M₃: N₉₀P₄₅K₄₅

lowest THN value was obtained under T_1 (412 mg kg⁻¹ soil). The subplot treatments followed the order: M_3 (430 mg kg⁻¹ soil) > M_2 (424 mg kg⁻¹ soil) > M_1 (416 mg kg⁻¹ soil). Thus, the THN content of the soil was a direct function of the amount of fertilizer N applied, as was observed in case of wheat. The lowest value of AIN was registered under T_7 (113 mg kg⁻¹ soil), with the rest of the treatments being divided into two groups. The first group comprised of T_2 (115 mg kg⁻¹ soil), T_3 (116 mg kg⁻¹ soil) and T_8 (116 mg kg⁻¹ soil), which were inferior to the remaining treatments (range 120-125 mg kg⁻¹ soil). In case of the treatments applied to maize, M_1 was found to maintain the highest value of AIN (126 mg kg⁻¹ soil), and was followed by M_2 (118 mg kg⁻¹ soil) and M_3 (112 mg kg⁻¹ soil).

The highest AAN content at silking stage of maize (Table 36) was obtained under T_8 (153 mg kg⁻¹ soil), which was at par with T_2 , T_6 and T_7 (152 mg kg⁻¹ soil), and T_9 (151 mg kg⁻¹ soil). Lowest AAN content of 136 mg kg⁻¹ soil was maintained under control. The subplot treatment M_3 (159 mg kg⁻¹ soil) was superior to M_2 (151 mg kg⁻¹ soil) and M_1 (133 mg kg⁻¹ soil) in terms of the AAN content. Similar trend was obtained with respect to subplot treatments (i.e., $M_3 > M_2 > M_1$) in case of ASN and NHN fractions. Interaction between T (treatments given to wheat) and M (treatments applied to maize) was significant in the case of AAN, NHN and UIN fractions. This effect was particularly high when the fertilizer application to maize was increased from 0 (M_1) to 50% (M_2). The treatments T_8 (23.1 mg kg⁻¹ soil) and T_7 (22.8 mg kg⁻¹ soil), both at par, maintained the high level of ASN in the soil. They were followed by T_2 (22.3 mg kg⁻¹ soil) and T_3 (22.0 mg kg⁻¹ soil), which were at par with each other. Next in line were T_9 (21.4 mg kg⁻¹ soil), T_6 (21.0 mg kg⁻¹ soil) and T_4 (20.2 mg kg⁻¹ soil), the former two treatments being statistically similar. The highest NHN level of 140 mg kg⁻¹ soil was maintained under T_7 and T_8 , while the lowest level was maintained under T_1 (126 mg kg⁻¹ soil). The values maintained under the rest of the treatments ranged from 127 to 136 mg kg⁻¹ soil. The order followed by different treatments in respect of UIN was: T_1 (133 mg kg⁻¹ soil) > T_4 (130 mg kg⁻¹ soil) > T_5 (123 mg kg⁻¹ soil) > T_3 (121 mg kg⁻¹ soil) > T_7 (120 mg kg⁻¹ soil)

Table 36. Hydrolysable N fractions (mg N kg⁻¹ soil) at silking stage of maize

Treatment	Amino acid-N				Amino sugar-N			
	M ₁	M ₂	M ₃	Mean	M ₁	M ₂	M ₃	Mean
T ₁	121	138	148	136	14.6	17.0	20.0	17.2
T ₂	141	156	160	152	19.7	23.3	24.0	22.3
T ₃	130	155	161	149	19.9	22.6	23.5	22.0
T ₄	126	140	156	141	17.3	20.8	22.5	20.2
T ₅	127	148	157	144	17.3	21.0	22.5	20.2
T ₆	137	156	162	152	18.4	21.8	22.8	21.0
T ₇	137	158	160	152	19.7	22.8	25.0	22.8
T ₈	138	157	164	153	20.4	24.0	24.9	23.1
T ₉	140	151	161	151	19.4	21.8	23.0	21.4
Mean	133	151	159		18.5	21.8	23.1	
CD (<i>P</i> = 0.05)	T : 3; M : 2; T×M : 5				T : 0.5; M : 0.2; T×M : NS			
	NH ₃ -N				Unidentified-N			
T ₁	120	127	131	126	151	129	120	133
T ₂	133	137	140	136	122	104	104	110
T ₃	132	136	141	136	138	115	109	121
T ₄	123	127	130	127	142	130	117	130
T ₅	124	134	140	133	145	115	108	123
T ₆	125	135	147	136	137	113	99	116
T ₇	133	137	148	140	136	117	106	120
T ₈	136	141	143	140	128	111	107	115
T ₉	132	137	140	136	123	111	102	112
Mean	129	135	140		136	116	108	
CD (<i>P</i> = 0.05)	T : 3; M : 1; T×M : 3				T : 5; M : 1; T×M : 3			

T₁: control; T₂: FYM; T₃: N₁₂₀; T₄: P₆₀; T₅: N₆₀P₃₀K₃₀; T₆: N₉₀P₄₅K₄₅; T₇: N₁₂₀P₆₀K₆₀; T₈: T₆ + FYM;
T₉: T₅ + FYM

M₁: N₀P₀K₀; M₂: N₆₀P₃₀K₃₀; M₃: N₉₀P₄₅K₄₅

$> T_6$ (116 mg kg⁻¹ soil) $> T_8$ (115 mg kg⁻¹ soil) $> T_9$ (112 mg kg⁻¹ soil) $> T_2$ (110 mg kg⁻¹ soil). The order followed by the subplot treatments was: M_1 (136 mg kg⁻¹ soil) $> M_2$ (116 mg kg⁻¹ soil) $> M_3$ (108 mg kg⁻¹ soil). These three treatments were significantly different from one another.

While the THN content decreased, there was a slight increase in the TON and the AIN content of the soil, between the silking and dough stage of maize. Decrease in THN content could be ascribed to mineralization, and subsequent uptake and loss of N from the soil. Also, with passage of time, the N in THN fractions could be incorporated into the structures of difficultly degradable compounds, which is reason for an increase in the AIN content during this period. As shown in Table 37, the lowest TON content was registered under T_1 (538 mg kg⁻¹ soil), which was at par with T_2 (542 mg kg⁻¹ soil). The highest TON content of 555 mg kg⁻¹ soil was maintained under T_7 and T_8 . They were at par with the treatments T_9 (554 mg kg⁻¹ soil), T_3 (553 mg kg⁻¹ soil) and T_6 (553 mg kg⁻¹ soil). The subplot treatments M_2 (551 mg kg⁻¹ soil) and M_3 (550 mg kg⁻¹ soil) were at par in terms of TON content, and were superior to M_1 (548 mg kg⁻¹ soil). The highest THN content of the soil was maintained under T_8 (429 mg kg⁻¹ soil), which was at par with T_7 (428 mg kg⁻¹ soil). They were followed by the statistically similar treatments T_6 (422 mg kg⁻¹ soil) and T_3 (421 mg kg⁻¹ soil). The lowest THN content was obtained under T_1 (415 mg kg⁻¹ soil), which was at par with T_4 (414 mg kg⁻¹ soil). The order followed by the subplot treatments was: M_3 (426 mg kg⁻¹ soil) $> M_2$ (420 mg kg⁻¹ soil) $> M_1$ (414 mg kg⁻¹ soil). The reverse order was followed in case of the AIN content i.e., M_1 (134 mg kg⁻¹ soil) $> M_2$ (131 mg kg⁻¹ soil) $> M_3$ (124 mg kg⁻¹ soil). The treatments T_9 (137 mg kg⁻¹ soil) and T_5 (134 mg kg⁻¹ soil) were at par with each other and superior to the statistically-at-par treatments T_3 (132 mg kg⁻¹ soil), T_4 and T_6 (131 mg kg⁻¹ soil, each) in terms of the AIN content of the soil. The lowest content of 122 mg kg⁻¹ soil was maintained under T_2 .

The treatments T_8 (148 mg kg⁻¹ soil), T_2 (146 mg kg⁻¹ soil), T_3 and T_9 (145 mg kg⁻¹ soil each) were at par among themselves and superior to T_7 (144 mg kg⁻¹ soil) and

Table 37. Effect of fertilizer and manurial treatments on different forms of soil N (mg kg⁻¹ soil) at dough stage of maize

	Total organic N				Hydrolysable N				Acid insoluble N			
	M ₁	M ₂	M ₃	Mean	M ₁	M ₂	M ₃	Mean	M ₁	M ₂	M ₃	Mean
T ₁	531	541	544	538	408	413	423	415	123	128	121	124
T ₂	541	541	544	542	413	420	425	419	127	121	119	122
T ₃	553	555	552	553	415	423	425	421	137	132	127	132
T ₄	542	546	549	546	409	413	421	414	133	133	128	131
T ₅	548	550	551	550	410	415	422	416	138	135	129	134
T ₆	552	554	553	553	416	420	429	422	136	144	124	131
T ₇	553	557	556	555	424	428	433	428	129	129	123	127
T ₈	556	557	553	555	421	430	435	429	135	127	118	126
T ₉	556	556	551	554	413	419	419	417	143	137	132	137
Mean	548	551	550		414	420	426		134	131	124	
CD (<i>P</i> = 0.05)	T : 5; M : 3; T×M : NS				T : 2; M : 1; T×M : NS				T : 4; M : 3; T×M : NS			

T₁: control; T₂: FYM; T₃: N₁₂₀; T₄: P₆₀; T₅: N₆₀P₃₀K₃₀; T₆: N₉₀P₄₅K₄₅; T₇: N₁₂₀P₆₀K₆₀; T₈: T₆ + FYM;

T₉: T₅ + FYM

M₁: N₀P₀K₀; M₂: N₆₀P₃₀K₃₀; M₃: N₉₀P₄₅K₄₅

T₆ (141 mg kg⁻¹ soil) in terms of the AAN content. The lowest content was registered under T₁ (127 mg kg⁻¹ soil). The ASN content was highest under T₈ (22.4 mg kg⁻¹ soil) and lowest under T₁ (15.7 mg kg⁻¹ soil). The rest of the treatments registered ASN content between 19.4 and 21.8 mg kg⁻¹ soil. The treatment T₈ was also responsible for maintaining the highest amount of NHN content (136 mg kg⁻¹ soil). This treatment was followed by T₂ and T₇ (134 mg kg⁻¹ soil each), and T₉ and T₃ (133 mg kg⁻¹ soil each). The lowest NHN content was maintained under T₄ (124 mg kg⁻¹ soil), which was at par with T₁ (125 mg kg⁻¹ soil). The highest UIN fraction was exhibited under T₁ (146 mg kg⁻¹ soil), which was superior to T₄ (133 mg kg⁻¹ soil), T₆ (130 mg kg⁻¹ soil), T₇ (129 mg kg⁻¹ soil) and T₅ (128 mg kg⁻¹ soil), the four of which were at par among themselves. The rest of the treatments were statistically similar, resulting in UIN contents between 118 and 122 mg kg⁻¹ soil. With the exception of UIN fraction, all other N fractions *viz.*, AAN, ASN and NHN were found to decrease in the order: M₃ > M₂ > M₁ (Table 38). In case of UIN, M₁ (141 mg kg⁻¹ soil) was superior to M₂ (124 mg kg⁻¹ soil), which performed better than M₃ (116 mg kg⁻¹ soil). The treatment interactions (between T and M) were found to be significant in case of AAN, NHN and UIN fractions of soil organic nitrogen, this was particularly evident when the fertilizer dose in maize was increased from zero (M₁) to 50% (M₂).

The lowest TON content of the soil after harvest of maize was exhibited under T₁ (539 mg kg⁻¹) as evident from Table 39. The treatments T₂ (548 mg kg⁻¹ soil) and T₄ (554 mg kg⁻¹ soil), both of which were statistically different, performed significantly better than T₁. The rest of the treatments were superior and at par among themselves in this regards (range- 557 to 562 mg kg⁻¹ soil). Total hydrolysable N was found to be highest under T₈ (428 mg kg⁻¹ soil), which was at par with T₇ (426 mg kg⁻¹ soil). They were followed by T₆ (419 mg kg⁻¹ soil) and T₃ (417 mg kg⁻¹ soil). The lowest THN value was obtained under T₄ (410 mg kg⁻¹ soil), which was at par with T₁ (411 mg kg⁻¹ soil). The subplot treatments followed the order: M₃ (422 mg kg⁻¹ soil) > M₂ (418 mg kg⁻¹ soil) > M₁ (412 mg kg⁻¹ soil). The same was the case with TON content of the soil. The

Table 38. Hydrolysable N fractions (mg N kg⁻¹ soil) at dough stage of maize

Treatment	Amino acid-N				Amino sugar-N			
	M ₁	M ₂	M ₃	Mean	M ₁	M ₂	M ₃	Mean
T ₁	119	125	138	127	13.9	15.0	18.1	15.7
T ₂	135	150	153	146	19.5	22.3	23.1	21.6
T ₃	130	150	157	145	19.9	21.7	23.2	21.6
T ₄	122	140	153	138	17.5	19.6	21.0	19.4
T ₅	126	136	153	139	17.4	20.1	21.3	19.6
T ₆	128	143	153	141	18.4	20.5	21.7	20.2
T ₇	133	149	150	144	20.0	22.2	23.4	21.8
T ₈	133	152	159	148	20.3	23.0	23.8	22.4
T ₉	132	148	155	145	19.2	21.4	22.1	20.9
Mean	129	144	152		18.5	20.6	22.0	
CD (<i>P</i> = 0.05)	T : 4; M : 2; T×M : 5				T : 0.6; M : 0.4; T×M : NS			
	NH ₃ -N				Unidentified-N			
T ₁	123	126	127	125	152	147	140	146
T ₂	129	135	137	134	129	113	112	118
T ₃	129	131	139	133	136	120	106	121
T ₄	120	124	127	124	150	129	120	133
T ₅	123	130	134	129	143	129	113	128
T ₆	123	130	137	130	147	126	117	130
T ₇	128	135	138	134	143	121	122	129
T ₈	131	137	139	136	137	117	113	122
T ₉	129	133	137	133	133	116	104	118
Mean	126	131	135		141	124	116	
CD (<i>P</i> = 0.05)	T : 2; M : 1; T×M : 3				T : 6; M : 2; T×M : 6			

T₁: control; T₂: FYM; T₃: N₁₂₀; T₄: P₆₀; T₅: N₆₀P₃₀K₃₀; T₆: N₉₀P₄₅K₄₅; T₇: N₁₂₀P₆₀K₆₀; T₈: T₆ + FYM;
T₉: T₅ + FYM
M₁: N₀P₀K₀; M₂: N₆₀P₃₀K₃₀; M₃: N₉₀P₄₅K₄₅

Table 39. Effect of fertilizer and manurial treatments on different forms of soil N (mg kg⁻¹ soil) after harvest of maize

	Total organic N				Hydrolysable N				Acid insoluble N			
	M ₁	M ₂	M ₃	Mean	M ₁	M ₂	M ₃	Mean	M ₁	M ₂	M ₃	Mean
T ₁	532	540	545	539	402	411	419	411	130	129	126	129
T ₂	545	549	551	548	411	419	419	416	134	130	132	132
T ₃	556	560	558	558	413	417	422	417	143	143	136	141
T ₄	548	554	560	554	405	411	415	410	143	143	145	144
T ₅	555	559	558	557	406	410	418	411	149	149	141	146
T ₆	562	564	562	562	414	419	423	419	148	145	139	144
T ₇	561	561	559	561	422	425	430	426	139	136	129	135
T ₈	560	559	559	559	420	431	432	428	140	128	127	132
T ₉	560	558	556	558	412	417	419	416	148	141	137	142
Mean	553	556	557		412	418	422		142	138	135	
CD (P = 0.05)	T : 6; M : 3; T×M : NS				T : 3; M : 1; T×M : 4				T : 5; M : 3; T×M : NS			

T₁: control; T₂: FYM; T₃: N₁₂₀; T₄: P₆₀; T₅: N₆₀P₃₀K₃₀; T₆: N₉₀P₄₅K₄₅; T₇: N₁₂₀P₆₀K₆₀; T₈: T₆ + FYM;

T₉: T₅ + FYM

M₁: N₀P₀K₀; M₂: N₆₀P₃₀K₃₀; M₃: N₉₀P₄₅K₄₅

lowest value of AIN was registered under T_1 (129 mg kg⁻¹ soil), while the highest value was registered under T_5 (146 mg kg⁻¹ soil). The rest of the treatments resulted in AIN values varying between 132 and 144 mg kg⁻¹ soil. In case of the treatments applied to maize, M_1 was found to maintain the highest value of AIN (142 mg kg⁻¹ soil), and was followed by M_2 (138 mg kg⁻¹ soil) and M_3 (135 mg kg⁻¹ soil)

The highest AAN content after harvest of maize (Table 40) was obtained under T_8 (145 mg kg⁻¹ soil), which was at par with T_7 (144 mg kg⁻¹ soil each), followed by statistically similar $T_2=T_4$ (142 mg kg⁻¹ soil) and T_3 (141 mg kg⁻¹ soil). Lowest AAN content of 126 mg kg⁻¹ soil was maintained under control. The subplot treatment M_3 (150 mg kg⁻¹ soil) was superior to M_2 (141 mg kg⁻¹ soil) and M_1 (126 mg kg⁻¹ soil) in terms of the AAN content. Similar trend was obtained (i.e., $M_3 > M_2 > M_1$) in case of ASN and NHN fractions. Interaction between T and M was significant in the case of AAN, NHN and UIN fractions. The treatments T_8 (22 mg kg⁻¹ soil) maintained the highest level of ASN in the soil. It was followed by T_3 (21.4 mg kg⁻¹ soil), T_7 (21.1 mg kg⁻¹ soil) and T_2 (21.0 mg kg⁻¹ soil), which were at par with each other. Next in line were T_9 (20.4 mg kg⁻¹ soil) > T_6 (19.5 mg kg⁻¹ soil) > $T_4=T_5$ (18.7 mg kg⁻¹ soil). The highest NHN level of 130 mg kg⁻¹ soil was maintained under T_8 , while the lowest level was maintained under T_4 (121 mg kg⁻¹ soil). The values maintained under the rest of the treatments ranged from 124 to 132 mg kg⁻¹ soil. The order followed by different treatments in respect of UIN was: T_1 (146 mg kg⁻¹ soil) > T_4 (135 mg kg⁻¹ soil) > T_6 (133 mg kg⁻¹ soil) > T_5 (131 mg kg⁻¹ soil) > T_7 (129 mg kg⁻¹ soil) > T_8 (128 mg kg⁻¹ soil) > T_3 (124 mg kg⁻¹ soil) > T_9 (122 mg kg⁻¹ soil) = T_2 (122 mg kg⁻¹ soil). The order followed by the subplot treatments was: M_1 (142 mg kg⁻¹ soil) > M_2 (129 mg kg⁻¹ soil) > M_3 (119 mg kg⁻¹ soil). These three treatments were significantly different from one another.

From the preceding sections, it is conclusively evident that the treatments T_6 and T_7 , where N was applied to wheat through inorganic fertilizers (75 and 100% of the recommended dose, respectively), and T_8 and T_9 , where FYM was applied along with inorganic N, were the best treatments in terms of maintaining the levels of total, available

Table 40. Hydrolysable N fractions (mg N kg⁻¹ soil) after harvest of maize

Treatment	Amino acid-N				Amino sugar-N			
	M ₁	M ₂	M ₃	Mean	M ₁	M ₂	M ₃	Mean
T ₁	117	123	138	126	13.6	14.8	16.2	14.9
T ₂	130	143	153	142	19.1	21.3	22.4	21.0
T ₃	125	147	151	141	19.6	21.3	23.3	21.4
T ₄	120	135	150	135	17.3	18.7	20.1	18.7
T ₅	123	136	150	136	17.6	18.7	19.9	18.7
T ₆	123	144	151	139	18.4	19.7	20.4	19.5
T ₇	130	148	153	144	20.0	21.1	22.1	21.1
T ₈	131	150	153	145	21.0	21.9	23.1	22.0
T ₉	131	143	153	142	19.5	20.2	21.5	20.4
Mean	126	141	150		18.5	19.8	21.0	
CD (<i>P</i> = 0.05)	T : 3; M : 2; T×M : 5				T : 0.6; M : 0.3; T×M : NS			
	NH ₃ -N				Unidentified-N			
T ₁	122	125	126	124	149	149	139	146
T ₂	127	131	133	131	134	123	111	122
T ₃	129	130	134	131	140	119	114	124
T ₄	119	121	125	121	149	136	121	135
T ₅	122	125	129	126	143	130	119	131
T ₆	121	127	133	127	151	128	119	133
T ₇	128	131	136	132	144	124	119	129
T ₈	129	133	137	133	138	126	119	128
T ₉	129	132	133	131	133	122	112	122
Mean	125	128	132		142	129	119	
CD (<i>P</i> = 0.05)	T : 2; M : 1; T×M : 2				T : 5; M : 2; T×M : 6			

T₁: control; T₂: FYM; T₃: N₁₂₀; T₄: P₆₀; T₅: N₆₀P₃₀K₃₀; T₆: N₉₀P₄₅K₄₅; T₇: N₁₂₀P₆₀K₆₀; T₈: T₆ + FYM;
T₉: T₅ + FYM

M₁: N₀P₀K₀; M₂: N₆₀P₃₀K₃₀; M₃: N₉₀P₄₅K₄₅

and mineral N (NH_4^- and NO_3^- -N) in the soil. These treatments also had a favourable impact on the various hydrolysable N fractions. Incorporation of mungbean before sowing of maize further boosted these treatments, resulting in higher maize yield and N uptake. Also, the various forms and hydrolysable N fractions of soil organic N were direct functions of the amount of fertilizer N applied to the maize crop, due to which the performance of M_3 was better than M_2 and M_1 . In some cases, the incorporated mungbean residues augmented the beneficial effect of fertilizer applied to maize in terms of the hydrolysable N levels in the soil. This was reflected in the significant interaction effects.

In order to obtain a clear picture about the behaviour of various N fractions in the experimental soil, the values of the fractions were plotted against time for the whole cropping cycle. Figure 14 shows that there was a decrease in the TON content during the wheat and mungbean seasons, which increased sharply before sowing of maize. The decrease during the first two seasons was probably due to the decomposition process to supply N to the two crops, while the addition of mungbean residue before sowing of maize was responsible for the sudden rise of TON. The decrease thereafter up to silking was again due to the mineralization process to meet N demand of maize. After the silking stage of maize, the TON content of the soil was found to increase, which was possibly due to the immobilization of N into resistant humic fractions. The dynamics of AIN was similar to TON as can be inferred from Figure 20.

With passage of time, the THN content of the soil decreased, except the period following application of fertilizer and/or manures (Figure 15), for example, before heading stage of wheat or before sowing of maize. A decrease in the THN content with increasing time period was also reported by Pal *et al.* (1987) and Pathak and Sarkar (1995). However, the decline in THN levels was buffered by the treatments T_7 and T_8 , which supplied higher doses of N to the wheat crop. Application of FYM along with 75% recommended N (as in T_8), proved to be better than 100% N applied through inorganics alone (T_7) during the latter stages of the maize crop. This indicates that application of FYM results in a more sustained maintenance of hydrolysable N fractions, and therefore

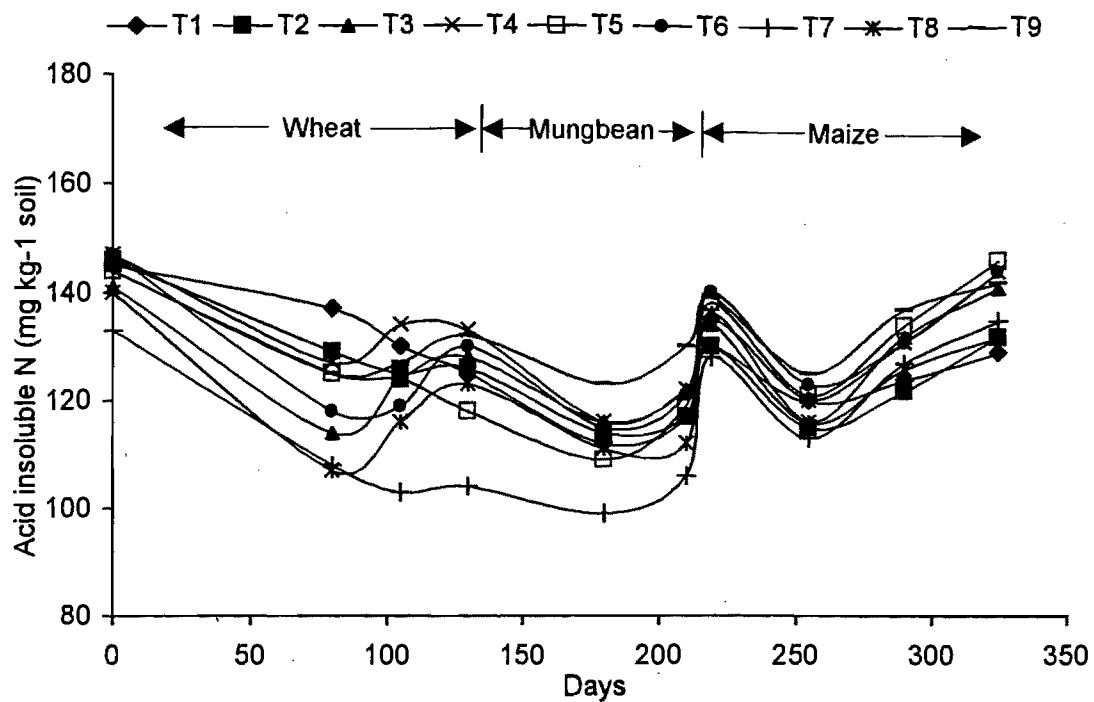


Figure 20. Influence of fertilizer and manurial treatments on the acid insoluble- N contents of soil at different stages of crop growth

could be more beneficial to both soil quality and crop yields in the long run. Similar findings were reported earlier by Singh *et al.* (2001).

On comparing Figures 14, 15 and 20, it can be observed that a decrease in THN was accompanied by an increase in the AIN and TON. According to Kelley and Stevenson (1995), after the requirement of the crop for N is met, about one-third of the added fertilizer-N is retained in organic form. Therefore, as each of the three crops neared maturity, there was a marked decrease in THN and increase in AIN contents, while the TON content increased in case of the treatments T₆, T₇, T₈ and T₉. This, as discussed earlier, was due to the incorporation of N in the stable humic compounds. Also, as a sizeable portion of THN is prone to mineralization to release N to the crops, its value might have decreased with the age of the crop. However, the application of fertilizer and/or manure resulted in an increase in TON, THN and AIN contents of the soil.

Computation of the relative proportion of various fractions with respect to the TON content of the soil shows that the AIN varied between 22 and 26% of the TON. The ASN comprised 3 to 4% of TON, while AAN, NHN and UIN fractions constituted 24-26, 23-25 and 22-25% of TON, respectively. These values fall within the range mentioned by Kelley and Stevenson (1995). As the relative proportions of all the fractions did not change much throughout the experimental period, it can be said with confidence that these fractions are biodegradable and form different parts of a dynamic equilibrium identifiable with the mineralization-immobilization process.

Figure 16 shows that the values of AAN were less variable about the initial values through out the experimental period as compared to ASN or THN, although the final AAN content under the treatments T₆, T₇, T₈ and T₉ were higher than the initial values. This indicates that the AAN fraction is quite stable, and is less sensitive to external inputs. In contrast, the ASN fraction was found to be very responsive to addition of external inputs. For example, the sudden rise of ASN with addition of mungbean residues and the steep decline thereafter (Figure 17) suggest that ASN is very much prone to mineralization and is the immediate supplier of N to the crops. This is further supported

by the fact that the pattern of changes in the ASN fraction is just the opposite to that of $\text{NH}_4\text{-N}$ (Figure 11) and $\text{NO}_3\text{-N}$ (Figure 12) contents of soil. For example, during the silking stage of maize, while there was a steep fall in the ASN levels, the $\text{NH}_4\text{-N}$ and $\text{NO}_3\text{-N}$ contents were found to peak. This was also true when the period between sowing of wheat and heading stage is considered, which coincides with the period of peak N demand by the crop. These evidences suggest that ASN fraction of THN is the pool of organic N responsible for supplying N to the crops through mineralization. This fraction also accumulates N through immobilization when residues are added to the soil (e.g., before sowing of maize). This study confirms the results obtained by Mulvaney *et al.* (2001). However, in order to ascertain these results, it is necessary to conduct in-depth kinetic studies, so that one can predict N supply to and uptake by a crop by determining the ASN content of the soil.

Ammonia-N fraction of the soil behaved more or less similarly as AAN, with a higher variability over time (Figure 18) as compared to the latter. The NHN content of the soil was found to increase with addition of fertilizers and manures, for example, between sowing and heading stages of wheat, and before sowing of maize. Pal *et al.* (1987) have also reported an increase in hydrolysable NHN content on application of fertilizers. The relatively lesser variability of NHN content with time indicates that, like AAN, it is a stable fraction, less prone to mineralization; it releases N only when the available N pool of the soil is exhausted.

The hydrolysable unidentified N fraction was highly variable in the soil and did not follow any fixed pattern for any of the treatments. This fraction differed widely among the treatments. While UIN content did not vary much through out the experimental period under T_1 , T_4 and T_5 , it declined steeply before recovering under the treatments T_7 , T_8 and T_9 . This indicates that the rate of mineralization was higher in the latter treatments, and with passage of time, the available N got locked into more resistant hydrolysable N fraction (UIN). Higher amount of UIN coupled with lower amounts of ASN, AAN and NHN under T_1 , T_4 and T_5 (where lesser amount of fertilizer

were added), imply that these treatments would not be able to meet the N demands of the crops through mineralization owing to a lower microbial activity in such plots.

4.2.3 Forms of phosphorus

4.2.3.1 Wheat

Table 41 shows the effect of various fertilizer and manurial treatments on the different forms of soil phosphorus (P). The average total P content of the soil was 570 mg kg⁻¹ soil; the contents of organic, inorganic and Olsen (0.5 M NaHCO₃ extractable) P were 210, 360 and 10.4 mg kg⁻¹ soil respectively. As seen in case of N fertility status of the experimental field, the initial P status too was uniform in the field, as plots assigned to different fertilizer-manure treatments did not record any significant difference with respect to several P parameters recorded in Table 41. This strengthens the authenticity of the subsequent observations recorded in terms of differential treatment effects. Inorganic P comprised about 63% of the total P. This is within the range of values reported for Indian soils by Tandon (1987).

There were no significant differences among the different treatments in terms of total and organic P at heading stage of wheat (Table 42). There was a general increase in the inorganic (Figure 21) and Olsen P (Figure 23) content of the soil from sowing to heading stage of wheat. This could be attributed to the decrease in extractable organic P (Figure 22) by mineralization (Sekhon and Black, 1969), due to which P is released into the solution and the inorganic P content is increased. The increase was higher for the treatments receiving higher doses of P. Similar observations were also made by Kumar *et al.* (2000) and Bhardwaj *et al.* (2000). The increase in Olsen P in all the treatments including control could be attributed to higher dissolution of soil-P through root exudates. In case of inorganic P, the treatments T₇ (427 mg kg⁻¹ soil), T₄ (417 mg kg⁻¹ soil), T₅ (416 mg kg⁻¹ soil), T₈ (412 mg kg⁻¹ soil) and T₆ (407 mg kg⁻¹ soil) were at par and superior to the treatments T₃ (374 mg kg⁻¹ soil), T₉ (371 mg kg⁻¹ soil), T₁ (369 mg kg⁻¹ soil) and T₂ (366 mg kg⁻¹ soil). The treatment T₈ recorded the highest amount of 0.5M NaHCO₃-extractable P (Olsen P) with a value of 28.4 mg kg⁻¹ soil. It was at par

Table 41. Effect of fertilizer and manurial treatments on soil P (mg P kg⁻¹ soil) before sowing of wheat

Treatments	Total P	Organic P	Inorganic P	Olsen P
T ₁	571	209	362	10.7
T ₂	545	195	350	10.3
T ₃	563	215	348	10.4
T ₄	572	206	366	10.3
T ₅	577	213	364	10.9
T ₆	567	190	377	10.4
T ₇	582	213	369	10.5
T ₈	581	236	345	10.3
T ₉	575	212	363	10.0
Mean	570	210	360	10.4
CD (<i>P</i> = 0.05)	NS	NS	NS	NS

Table 42. Effect of fertilizer and manurial treatments on soil P (mg P kg⁻¹ soil) at heading stage of wheat

Treatments	Total P	Organic P	Inorganic P	Olsen P
T ₁	568	199	369	14.9
T ₂	540	174	366	20.2
T ₃	532	158	374	15.5
T ₄	582	165	417	25.5
T ₅	576	160	416	18.9
T ₆	574	167	407	22.2
T ₇	593	166	427	27.8
T ₈	595	183	412	28.4
T ₉	578	207	371	22.6
Mean	571	176	395	21.8
CD (<i>P</i> = 0.05)	NS	NS	45	3.6

T₁: control; T₂: FYM; T₃: N₁₂₀; T₄: P₆₀; T₅: N₆₀P₃₀K₃₀; T₆: N₉₀P₄₅K₄₅; T₇: N₁₂₀P₆₀K₆₀; T₈: T₆ + FYM;
T₉: T₅ + FYM

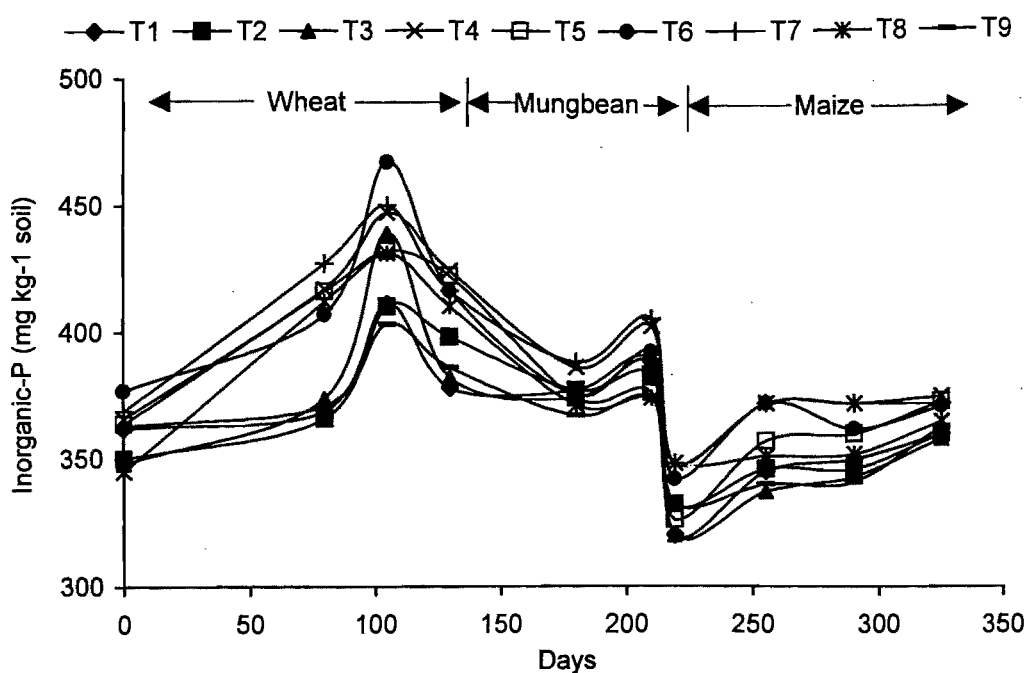


Figure 21. Influence of fertilizer and manurial treatments on the inorganic P contents of soil at different stages of crop growth

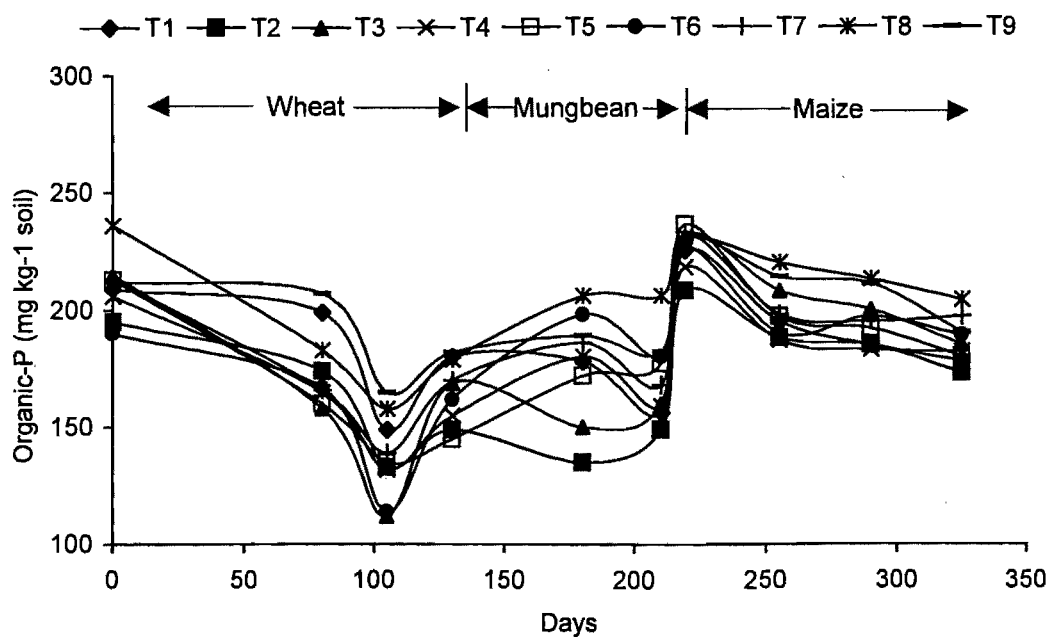


Figure 22. Influence of fertilizer and manurial treatments on the organic P contents of soil at different stages of crop growth

with the treatments T₇ (27.8 mg kg⁻¹ soil) and T₄ (25.5 mg kg⁻¹ soil). Then followed the statistically similar treatments T₉ (22.6 mg kg⁻¹ soil), T₆ (22.2 mg kg⁻¹ soil) and T₂ (20.2 mg kg⁻¹ soil). The treatments T₅ (18.9 mg kg⁻¹ soil) and T₃ (15.5 mg kg⁻¹ soil), were the next to follow, both of which were at par. The lowest value of Olsen P was obtained under control (T₁, 14.9 mg kg⁻¹ soil). This indicates that application of no or low amount of P fertilizer was unable to maintain high amounts of available P in soil.

At dough stage of wheat, the treatments were divided into three groups with respect to their influence on Olsen P as shown in Table 43. The most superior group consisted of the treatments T₇ (25.2 mg kg⁻¹ soil), T₄ (24.8 mg kg⁻¹ soil), T₈ (23.8 mg kg⁻¹ soil) and T₆ (21.3 mg kg⁻¹ soil). The next group comprised the treatments in the descending order: T₉ (19.3 mg kg⁻¹ soil) > T₅ (15.2 mg kg⁻¹ soil) > T₂ = T₃ (14.5 mg kg⁻¹ soil). The treatment T₁ (12.2 mg kg⁻¹ soil) recorded the lowest value. None of the other three forms, viz. total, organic and inorganic were influenced by the treatments at that stage and up to the silking stage of maize (Tables 44-47).

The lowest Olsen P content of the soil (8.3 mg kg⁻¹ soil) was noted under T₂ after wheat harvest (Table 44). It was at par with T₁ (8.9 mg kg⁻¹ soil). The statistically-at-par and superior treatments T₄, T₆, T₇, T₈ and T₉ maintained Olsen P values ranging from 20.7 to 24.0 mg kg⁻¹ soil. The treatments T₁ and T₂, where no inorganic N or P was externally applied exhibited a decline in available P status from the initial value as shown in Figure 23. The treatment T₃, where only N was applied also showed signs of decreasing Olsen P content. This emphasizes the need for application of P to the soil along with N, mention of which was made earlier by Biswas (1977) and Singh *et al.* (1998).

4.2.3.2 Mungbean

Being a leguminous crop, mungbean releases certain organic acids to the soil through its roots. The organic acids enhance the dissolution of native phosphates. This could possibly explain the more or less constant value of Olsen P in the soil though no P was externally applied to mungbean. The order in which the treatments influenced

Table 43. Effect of fertilizer and manurial treatments on soil P (mg P kg⁻¹ soil) at dough stage of wheat

Treatments	Total P	Organic P	Inorganic P	Olsen P
T ₁	560	149	411	12.2
T ₂	543	133	410	14.5
T ₃	551	112	439	14.5
T ₄	579	132	447	24.8
T ₅	567	135	432	15.2
T ₆	581	114	467	21.3
T ₇	589	139	450	25.2
T ₈	589	158	431	23.8
T ₉	568	165	403	19.3
Mean	570	137	433	19.0
CD (<i>P</i> = 0.05)	NS	NS	NS	4.1

Table 44. Effect of fertilizer and manurial treatments on soil P (mg P kg⁻¹ soil) after harvest of wheat

Treatments	Total P	Organic P	Inorganic P	Olsen P
T ₁	558	180	378	8.9
T ₂	547	149	398	8.3
T ₃	551	169	382	12.8
T ₄	579	155	424	21.5
T ₅	567	145	422	13.7
T ₆	578	162	416	21.5
T ₇	586	170	416	24.0
T ₈	589	179	410	22.3
T ₉	568	182	386	20.7
Mean	569	166	403	17.1
CD (<i>P</i> = 0.05)	NS	NS	NS	4.7

T₁: control; T₂: FYM; T₃: N₁₂₀; T₄: P₆₀; T₅: N₆₀P₃₀K₃₀; T₆: N₉₀P₄₅K₄₅; T₇: N₁₂₀P₆₀K₆₀; T₈: T₆ + FYM;
T₉: T₅ + FYM

the Olsen P content of the soil at flowering stage of mungbean (Table 45) was: T_7 (26.0 mg kg⁻¹ soil) > T_4 (23.4 mg kg⁻¹ soil) > T_6 (22.6 mg kg⁻¹ soil) > T_8 (21.5 mg kg⁻¹ soil) > T_9 (19.8 mg kg⁻¹ soil) > T_5 (15.4 mg kg⁻¹ soil) > T_2 (10.4 mg kg⁻¹ soil) > T_3 (8.2 mg kg⁻¹ soil) > T_1 (7.6 mg kg⁻¹ soil). The Olsen P content of the soil further decreased before incorporation of mungbean (Figure 23) under all the treatments, with the lowest value being exhibited under T_1 (5.6 mg kg⁻¹ soil). This was at par with the values of 5.8 and 7.2 mg kg⁻¹ soil obtained under T_3 and T_2 , respectively (Table 46). The highest Olsen P content was maintained under T_7 (25.0 mg kg⁻¹ soil) as in the previous stage. It was followed by T_6 , T_8 and T_9 with P content of 20.4, 19.1 and 17.6 mg kg⁻¹ soil, respectively, with the former two treatments being at par with each other. Inclusion of mungbean in the system did buffer the decline of Olsen P values under those treatments, which had earlier received higher doses (>75%) of recommended fertilizer P. However, the decline in Olsen P could not be stopped in case of other treatments.

4.2.3.3. Maize

The average values of the total, organic, inorganic and Olsen P of the soil before sowing of maize were 561, 226, 335 and 13.6 mg kg⁻¹ soil, respectively, as shown in Table 47. Incorporation of mungbean increased the organic P level of the soil as evident from Figure 22. But the inorganic P content showed a decline, probably due to P uptake by wheat and mungbean. This is clear from Figure 21. The net effect however, was a slight increase in total P content for most of the treatments applied to wheat (Figure 24).

From Table 48, it can be seen that while the subplot treatment M_3 was superior to M_1 and M_2 in influencing the inorganic P content of the soil, it was inferior to the latter two treatments in terms of organic P content at silking stage of maize. The former effect was probably due to the addition of inorganic P to the maize crop. The overall effect of the subplot treatments in terms of total P was that M_3 (555 mg kg⁻¹ soil) emerged superior to M_2 (554 mg kg⁻¹ soil), which, in turn, was superior to M_1 (553 mg kg⁻¹ soil). The order followed by the treatments applied to wheat in affecting the total P content of the soil was: T_8 (571 mg kg⁻¹ soil) > T_7 (570 mg kg⁻¹ soil) > T_6 (561 mg kg⁻¹ soil) > T_4 (559 mg

Table 45. Effect of fertilizer and manurial treatments on soil P (mg P kg⁻¹ soil) at flowering stage of mungbean

Treatments	Total P	Organic P	Inorganic P	Olsen P
T ₁	555	178	377	7.6
T ₂	512	135	377	10.4
T ₃	524	150	374	8.2
T ₄	567	180	386	23.4
T ₅	546	172	374	15.4
T ₆	573	198	375	22.6
T ₇	574	186	388	26.0
T ₈	577	206	371	21.5
T ₉	556	189	367	19.8
Mean	554	177	377	17.2
CD (<i>P</i> = 0.05)	NS	NS	NS	0.9

Table 46. Effect of fertilizer and manurial treatments on soil P (mg P kg⁻¹ soil) before incorporation of mungbean

Treatments	Total P	Organic P	Inorganic P	Olsen P
T ₁	544	156	388	5.6
T ₂	532	149	383	7.2
T ₃	547	160	387	5.8
T ₄	561	159	402	17.4
T ₅	553	177	376	10.1
T ₆	572	180	392	20.4
T ₇	573	168	405	25.0
T ₈	580	206	374	19.1
T ₉	556	182	374	17.6
Mean	558	171	387	14.2
CD (<i>P</i> = 0.05)	NS	NS	NS	2.6

T₁: control; T₂: FYM; T₃: N₁₂₀; T₄: P₆₀; T₅: N₆₀P₃₀K₃₀; T₆: N₉₀P₄₅K₄₅; T₇: N₁₂₀P₆₀K₆₀; T₈: T₆ + FYM;
T₉: T₅ + FYM

Table 47. Effect of fertilizer and manurial treatments on soil P (mg P kg⁻¹ soil) before sowing of maize

Treatments	Total P	Organic P	Inorganic P	Olsen P
T ₁	545	225	320	8.3
T ₂	540	208	332	9.7
T ₃	551	231	320	10.4
T ₄	566	218	348	15.5
T ₅	562	236	326	12.4
T ₆	569	227	342	17.2
T ₇	579	231	348	17.6
T ₈	579	231	348	18.1
T ₉	562	230	332	13.3
Mean	561	226	335	13.6

T₁: control; T₂: FYM; T₃: N₁₂₀; T₄: P₆₀; T₅: N₆₀P₃₀K₃₀; T₆: N₉₀P₄₅K₄₅; T₇: N₁₂₀P₆₀K₆₀; T₈: T₆ + FYM;
T₉: T₅ + FYM

Table 48. Effect of fertilizer and manurial treatments on soil P (mg P kg⁻¹ soil) at silking stage of maize

Treatment	Total P				Organic P			
	M ₁	M ₂	M ₃	Mean	M ₁	M ₂	M ₃	Mean
T ₁	538	539	541	539	212	204	169	195
T ₂	533	533	535	534	191	188	184	188
T ₃	545	545	546	545	216	205	203	208
T ₄	557	559	560	559	206	191	164	187
T ₅	554	554	556	555	206	192	194	197
T ₆	560	561	563	561	197	203	169	190
T ₇	569	570	571	570	205	195	193	198
T ₈	570	571	572	571	230	238	193	220
T ₉	554	554	555	554	222	211	209	214
Mean	553	554	555		209	203	186	
CD (<i>P</i> = 0.05)	T : 1; M : 1; T×M : NS				T : 8; M : 9; T×M : NS			
Treatment	Inorganic P				Olsen P			
	M ₁	M ₂	M ₃	Mean	M ₁	M ₂	M ₃	Mean
T ₁	326	335	372	345	5.4	8.6	8.8	7.6
T ₂	342	345	351	346	6.9	7.6	9.3	7.9
T ₃	329	340	343	337	4.8	7.7	11.1	7.9
T ₄	351	368	396	372	10.9	12.4	14.3	12.5
T ₅	348	362	362	357	10.1	12.1	16.8	13.0
T ₆	363	358	394	372	13.0	13.5	17.5	14.7
T ₇	364	375	378	372	15.1	15.6	18.0	16.2
T ₈	340	333	379	351	14.7	16.1	17.5	16.1
T ₉	332	343	346	340	11.5	13.2	16.8	13.9
Mean	343	351	369		10.3	11.9	14.4	
CD (<i>P</i> = 0.05)	T : 15; M : 12; T×M : NS				T : 1.0; M : 0.6; T×M : 1.8			

T₁: control; T₂: FYM; T₃: N₁₂₀; T₄: P₆₀; T₅: N₆₀P₃₀K₃₀; T₆: N₉₀P₄₅K₄₅; T₇: N₁₂₀P₆₀K₆₀; T₈: T₆ + FYM;
T₉: T₅ + FYM

M₁: N₀P₀K₀; M₂: N₆₀P₃₀K₃₀; M₃: N₉₀P₄₅K₄₅

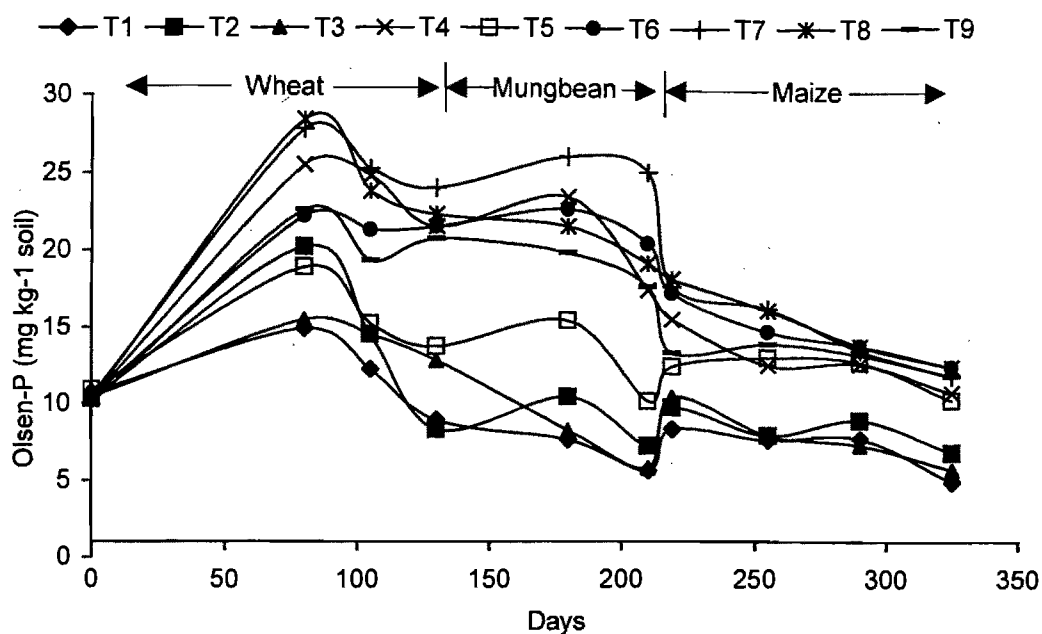


Figure 23. Influence of fertilizer and manurial treatments on the Olsen P contents of soil at different stages of crop growth

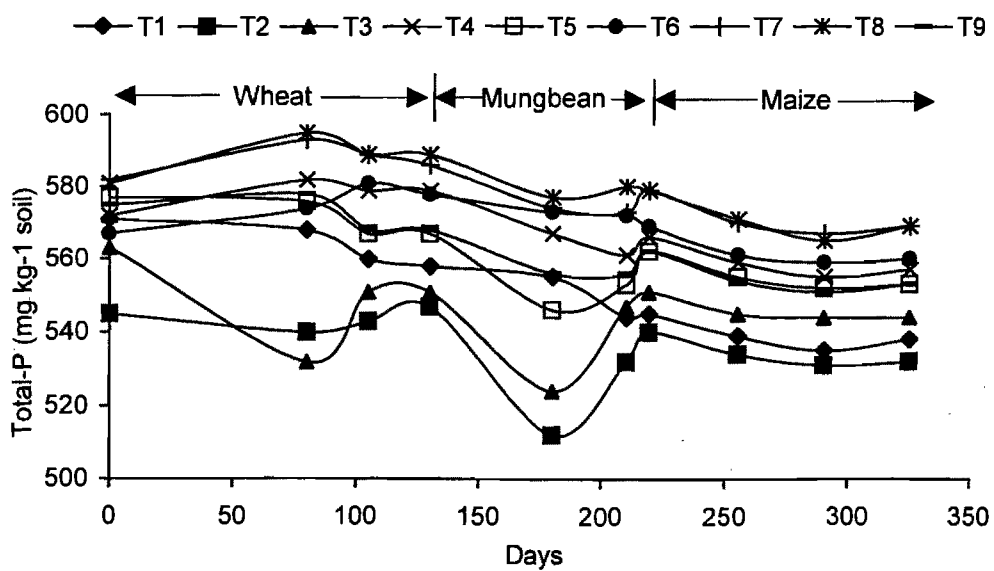


Figure 24. Influence of fertilizer and manurial treatments on total-P contents of soil at different stages of crop growth

kg⁻¹ soil) > T₅ (555mg kg⁻¹ soil) > T₉ (554 mg kg⁻¹ soil) > T₃ (545 mg kg⁻¹ soil) > T₁ (539 mg kg⁻¹ soil) > T₂ (534 mg kg⁻¹ soil). The highest value of organic P was also exhibited under T₈ (220 mg kg⁻¹ soil), which was at par with T₉ (214 mg kg⁻¹ soil) and T₃ (208 mg kg⁻¹ soil). The rest of the treatments were at par among themselves and exhibited values ranging from 187 to 198 mg kg⁻¹ soil. The lowest inorganic P content of the soil (337 mg kg⁻¹ soil) was maintained under the treatment T₃. This was at par with the value of 340 mg kg⁻¹ soil registered under T₉. The highest inorganic P content of 372 mg kg⁻¹ soil was recorded under T₄, T₆ and T₇. They were followed by the statistically similar treatments T₅ (357 mg kg⁻¹ soil), T₈ (351 mg kg⁻¹ soil), T₂ (346 mg kg⁻¹ soil) and T₁ (345 mg kg⁻¹ soil). Olsen P values under all the treatments were found to decrease over their values before sowing of maize (Figure 23), with the treatments T₇ (16.2 mg kg⁻¹ soil) and T₈ (16.1 mg kg⁻¹ soil) being superior to the rest of the treatments. They were followed by T₆ (14.7 mg kg⁻¹ soil) and T₉ (13.9 mg kg⁻¹ soil), both of which were statistically at par. The lowest value was registered under T₁ (7.6 mg kg⁻¹ soil), which was at par with the value of 7.9 mg kg⁻¹ soil exhibited under T₂ and T₃. The interaction effect between treatments applied to wheat (T) and that to maize (M) was found to be significant. This implies that when the dose of fertilizer addition to maize increased, the Olsen P content under all the treatments increased. This stresses the necessity for continuous P fertilizer application to the crops in a cropping system. Several workers (Rao and Sharma, 1978; McCollum, 1991; Benbi and Biswas, 1999) have also raised this point earlier.

During dough stage of maize, while there was no influence of the subplot treatments on the total P, the main plot treatments (treatments applied to wheat) did not influence the organic P content (Table 49). The order followed by the different main plot treatments in terms of total P was: T₇ (567 mg kg⁻¹ soil) > T₈ (565 mg kg⁻¹ soil) > T₆ (559 mg kg⁻¹ soil) > T₄ (555 mg kg⁻¹ soil) > T₅ (552 mg kg⁻¹ soil) > T₉ (551 mg kg⁻¹ soil) > T₃ (544 mg kg⁻¹ soil) > T₁ (535 mg kg⁻¹ soil) > T₂ (531 mg kg⁻¹ soil). The treatment M₃ (187 mg kg⁻¹ soil) was found to be inferior to M₁ (207 mg kg⁻¹ soil) and M₂ (193 mg kg⁻¹ soil) in terms of organic P content. The latter two treatments were statistically at par.

Table 49. Effect of fertilizer and manurial treatments on soil P (mg P kg⁻¹ soil) at dough stage of maize

Treatment	Total P				Organic P			
	M ₁	M ₂	M ₃	Mean	M ₁	M ₂	M ₃	Mean
T ₁	537	535	534	535	198	183	175	185
T ₂	530	530	534	531	184	172	199	185
T ₃	542	541	547	544	216	199	186	200
T ₄	555	555	554	555	193	171	183	183
T ₅	551	551	553	552	223	171	183	192
T ₆	557	558	561	559	200	192	198	197
T ₇	566	568	567	567	200	203	182	195
T ₈	567	567	562	565	231	225	184	213
T ₉	551	550	554	551	222	218	192	211
Mean	551	551	552		207	193	187	
CD (<i>P</i> = 0.05)	T : 4; M : NS; T×M : NS				T : NS; M : 15; T×M : NS			
	Inorganic P				Olsen P			
T ₁	339	352	360	350	6.9	6.8	9.3	7.7
T ₂	346	358	335	346	7.7	8.8	10.1	8.9
T ₃	326	343	361	343	5.5	7.8	8.7	7.3
T ₄	361	384	371	372	12.3	13.2	12.3	12.6
T ₅	328	381	371	360	10.6	11.5	16.0	12.7
T ₆	357	366	363	362	12.5	12.9	16.0	13.8
T ₇	365	367	385	372	11.2	13.4	15.8	13.5
T ₈	336	343	378	352	11.3	13.9	16.3	13.8
T ₉	328	332	362	341	11.3	13.0	15.3	13.2
Mean	343	358	365		9.9	11.3	13.3	
CD (<i>P</i> = 0.05)	T : 21; M : 15; T×M : NS				T : 2.0; M : 1.0; T×M : NS			

T₁: control; T₂: FYM; T₃: N₁₂₀; T₄: P₆₀; T₅: N₆₀P₃₀K₃₀; T₆: N₉₀P₄₅K₄₅; T₇: N₁₂₀P₆₀K₆₀; T₈: T₆ + FYM;
T₉: T₅ + FYM
M₁: N₀P₀K₀; M₂: N₆₀P₃₀K₃₀; M₃: N₉₀P₄₅K₄₅

But the treatments M_3 (365 mg kg⁻¹ soil) and M_2 (358 mg kg⁻¹ soil) were at par and performed significantly better than M_1 (343 mg kg⁻¹ soil) in influencing the inorganic P content of the soil at the dough stage. The main plot treatments could be divided into two groups in this respect. The superior group consisted of the treatments T_4 to T_8 , with a range between 352 and 372 mg kg⁻¹ soil, while the rest of the treatments exhibited inorganic P values between 341 and 350 mg kg⁻¹ soil, with the lowest content recorded under T_1 . This indicates the possibility of a residual effect of P added to wheat (T_4 to T_8), which was accumulated in the inorganic P pools. The treatments T_1 , T_2 and T_3 , with Olsen P values of 7.7, 8.9 and 7.3 mg kg⁻¹ soil, were at par and inferior to the rest of the treatments in this regard. The highest Olsen P content of 13.8 mg kg⁻¹ soil was maintained under T_6 and T_8 . The Olsen P content was found to increase as the fertilizer dose (applied to maize) was increased. The values under M_1 , M_2 and M_3 were 9.9, 11.3 and 13.3 mg kg⁻¹ soil, respectively.

The treatments applied to wheat did not influence the organic and inorganic P content of the soil after harvest of maize, as can be seen in Table 50. But they did influence the total P content, with the maximum value of 569 mg kg⁻¹ soil being exhibited by T_7 and T_8 . They were followed by T_6 (560 mg kg⁻¹ soil), T_4 (557 mg kg⁻¹ soil), T_5 (553 mg kg⁻¹ soil), T_9 (553 mg kg⁻¹ soil), T_3 (544 mg kg⁻¹ soil), T_1 (538 mg kg⁻¹ soil) and T_2 (538 mg kg⁻¹ soil). The subplot treatments were not found to be significant. In case of organic P, the treatment M_1 and M_2 , with values of 196 and 187 mg kg⁻¹ soil, respectively were at par and superior to M_3 (175 mg kg⁻¹ soil); whereas in case of inorganic P, the three treatments were significantly different from one another, and the order followed was: M_3 (378 mg kg⁻¹ soil) > M_2 (366 mg kg⁻¹ soil) > M_1 (357 mg kg⁻¹ soil). The same order was followed in case of Olsen P as well, with values of 8.6, 9.5 and 10.8 mg kg⁻¹ soil under M_1 , M_2 and M_3 , respectively. Among the main plot treatments, T_6 (12.4 mg kg⁻¹ soil), T_7 (11.8 mg kg⁻¹ soil), T_8 (12.4 mg kg⁻¹ soil) and T_9 (11.8 mg kg⁻¹ soil) were statistically at par and superior to the rest of the treatments, with the minimum value being exhibited under T_1 (4.9 mg kg⁻¹ soil).

Table 50. Effect of fertilizer and manurial treatments on soil P (mg P kg⁻¹ soil) after harvest of maize

Treatment	Total P				Organic P			
	M ₁	M ₂	M ₃	Mean	M ₁	M ₂	M ₃	Mean
T ₁	539	538	536	538	186	182	167	178
T ₂	532	532	532	532	176	171	171	173
T ₃	544	543	544	544	197	183	175	185
T ₄	557	558	557	557	193	171	182	182
T ₅	553	553	553	553	206	167	166	180
T ₆	559	560	560	560	194	192	180	189
T ₇	568	568	570	569	202	199	190	197
T ₈	569	568	570	569	212	212	188	204
T ₉	552	552	555	553	198	198	173	190
Mean	553	553	553		196	186	177	
CD (<i>P</i> = 0.05)	T : 2; M : NS; T×M : NS				T : NS; M : 13; T×M : NS			
	Inorganic P				Olsen P			
T ₁	353	356	370	360	4.9	4.5	5.4	4.9
T ₂	356	362	361	360	6.1	6.5	7.9	6.8
T ₃	346	360	368	358	4.9	5.6	6.5	5.7
T ₄	364	387	376	375	10.0	10.5	11.5	10.7
T ₅	347	386	386	373	9.0	10.2	11.4	10.2
T ₆	365	368	380	371	11.3	12.2	13.8	12.4
T ₇	366	370	380	372	10.2	12.1	13.2	11.8
T ₈	357	356	382	365	10.3	13.0	13.8	12.4
T ₉	354	354	382	363	11.2	11.0	13.3	11.8
Mean	357	366	378		8.6	9.5	10.8	
CD (<i>P</i> = 0.05)	T : NS; M : 12; T×M : NS				T : 1.1; M : 0.5; T×M : NS			

T₁: control; T₂: FYM; T₃: N₁₂₀; T₄: P₆₀; T₅: N₆₀P₃₀K₃₀; T₆: N₉₀P₄₅K₄₅; T₇: N₁₂₀P₆₀K₆₀; T₈: T₆ + FYM;
T₉: T₅ + FYM
M₁: N₀P₀K₀; M₂: N₆₀P₃₀K₃₀; M₃: N₉₀P₄₅K₄₅

There was a steep decrease in the organic P content of the soil from sowing of wheat to heading stage (Figure 22), as explained earlier, due to the mineralization process. As a consequence, inorganic P (Figure 21) and Olsen P (Figure 23) registered steep increase. This increase was particularly higher under the treatments T₄, T₆, T₇, T₈ and T₉, where higher amounts of P were applied. These treatments would have triggered higher microbial activity. After the heading stage, however, the Olsen P content was found to decline and remain more or less stable till the incorporation of mungbean residues. This decline could be attributed to the fixation of P into different stable compounds. However, throughout this period, higher amounts of Olsen P were maintained under the treatments receiving higher doses of P. After incorporation of mungbean residues, there was a slight increase in the soil Olsen P values under the treatments T₁, T₂ and T₃ where, earlier, no P was applied. This could be due to the release of P from the fixed sites by the enhanced microbial activity on addition of mungbean residues. On the other hand, the treatments T₄, T₆, T₇, T₈ and T₉, where higher doses of P were applied during wheat, registered decline in Olsen P. This could be ascribed to the immobilization of the solution P by the increased microbial population. After this stage (sowing of maize), the Olsen P gradually declined up to maize harvest. This, again could be due to crop uptake and P fixation.

As the wheat crop matured, *i.e.* crossed the dough stage, due to increased litter fall and release of organic acids through root exudates (Jain and Sarkar, 1979; Iyamuremye *et al.*, 1996b), the P sorbed in sesquioxides and other exchange sites are released into the soil solution. Owing to the the dynamic equilibrium among the various pools of P, the solution P gets locked in the organic compounds. Therefore, till the harvest of wheat, the soil organic P content was found to increase. This fraction remained more or less stable up to the incorporation of mungbean. After the residues were incorporated into the soil, there was an obvious rise in the organic P content. Owing to subsequent mineralization, it decreased gradually until maize was harvested (Figure 22). Inorganic P showed an inverse relationship with the organic P content at all the

growth stages, as can be inferred from Figures 21 and 22, while the total P remained more or less stable for all the treatments throughout the experimental period. Organic P is released into the solution through microbially mediated mineralization process, and inorganic P, through the interplay of dissolution-precipitation and adsorption-desorption processes. The two forms of P are interrelated. Thus, the increase in one form brings about a decrease in the other (Thompson *et al.*, 1954; van Diest and Black, 1959).

After one year of the cropping system, it was observed that there was not much change in the total P content of the soil from its initial value under all the treatments applied to wheat. However, in order to confirm the positive influence of phosphatic fertilizer addition in a balanced and integrated manner, as has been reported by several workers (Sharma *et al.*, 1987a; Santhy *et al.*, 2001; Turner *et al.*, 2002), the experiment needs to be run for a few more years.

4.2.4 Phosphorus Fractions

4.2.4.1 Wheat

Table 51 shows the different P fractions obtained before sowing of wheat. Non-significant differences among the values of each P-fraction further attest to the uniformity of the field where this experiment was conducted. The dominant P fraction was calcium-P (Ca-P) with an average value of 181 mg kg⁻¹ soil, which was followed by reductant soluble-P (RS-P), with an average value of 63.0 mg kg⁻¹ soil. The other fractions followed the order: Residual P (53.2 mg kg⁻¹ soil) > Aluminium-P (29.7 mg kg⁻¹ soil) > Iron-P (22.3 mg kg⁻¹ soil) > Loosely Bound-P (11.0 mg kg⁻¹ soil).

There was an increase in all the inorganic P fractions of the soil from sowing to the heading stage of wheat (Table 52). This follows the increase in inorganic P content (Figure 21), after the addition of phosphatic fertilizers and manures (FYM). The positive effect of phosphatic fertilizers on the different soil P fractions has also been reported by McKenzie *et al.* (1992); Singaram and Kothandaraman (1993) and Kumar *et al.* (2000). Further, the increase in P fractions was a direct function of the amount of P added

Table 51. Inorganic P fractions (mg P kg⁻¹ soil) before sowing of wheat

Treatment	Loosely bound P	Al-P	Fe-P	RS-P	Ca-P	Residual P
T ₁	10.3	29.7	22.0	63.2	183	53.7
T ₂	11.3	29.8	22.2	63.1	181	42.0
T ₃	11.6	29.8	22.3	62.3	183	38.3
T ₄	11.2	29.5	22.4	61.8	181	59.7
T ₅	10.7	29.1	22.3	64.2	178	59.7
T ₆	10.9	29.9	22.0	64.8	180	69.0
T ₇	10.7	29.8	22.5	62.9	182	61.0
T ₈	10.5	29.8	22.4	63.1	179	40.3
T ₉	10.3	29.0	22.4	61.8	183	56.0
Mean	11.0	29.7	22.3	63.0	181	53.2
CD (<i>P</i> = 0.05)	NS	NS	NS	NS	NS	NS

Table 52. Inorganic P fractions (mg P kg⁻¹ soil) at heading stage of wheat

Treatment	Loosely bound P	Al-P	Fe-P	RS-P	Ca-P	Residual P
T ₁	12.3	36.0	23.0	60.8	178	59.3
T ₂	12.5	35.7	24.2	62.5	188	43.7
T ₃	12.2	34.5	26.8	63.2	182	55.7
T ₄	16.3	44.0	30.0	71.6	189	64.0
T ₅	15.1	42.2	24.2	67.7	188	79.0
T ₆	15.3	44.0	24.2	70.9	190	62.0
T ₇	16.5	52.2	28.6	76.7	202	51.3
T ₈	14.3	45.0	24.2	71.2	200	56.7
T ₉	15.5	39.4	23.7	69.0	189	35.0
Mean	14.5	41.4	25.4	68.2	190	56.3
CD (<i>P</i> = 0.05)	0.8	7.2	5.3	6.5	16.3	NS

T₁: control; T₂: FYM; T₃: N₁₂₀; T₄: P₆₀; T₅: N₆₀P₃₀K₃₀; T₆: N₉₀P₄₅K₄₅; T₇: N₁₂₀P₆₀K₆₀; T₈: T₆ + FYM;
T₉: T₅ + FYM

through fertilizers (More and Agale, 1993; Santhy *et al.*, 1998). Highest loosely bound-P (LB-P) content was recorded under T₇ (16.5 mg kg⁻¹ soil) followed by T₄ (16.3 mg kg⁻¹ soil). Next were the treatments T₉ (15.5 mg kg⁻¹ soil), T₆ (15.3 mg kg⁻¹ soil) and T₅ (15.1 mg kg⁻¹ soil), which were statistically at par among themselves. Lower LB-P contents were maintained under T₃ (12.2 mg kg⁻¹ soil), T₁ (12.3 mg kg⁻¹ soil) and T₂ (12.5 mg kg⁻¹ soil), which also were responsible for the lower amounts of aluminium- and reductant soluble-P in soil. In case of aluminium-P (Al-P), the highest content was exhibited under T₇ (52.2 mg kg⁻¹ soil). This was followed by the statistically similar treatments T₈, T₄, T₆, T₅ and T₉ in that order, with Al-P contents ranging between 39.4 and 45.0 mg kg⁻¹ soil. The highest iron-P (Fe-P) content of the soil was maintained under T₄ (30.0 mg kg⁻¹ soil), which was at par with T₇ (28.6 mg kg⁻¹ soil) and T₃ (26.8 mg kg⁻¹ soil). The rest of the treatments were similar among themselves in this respect, with a Fe-P range of 23.0 to 24.2 mg kg⁻¹ soil. In case of reductant soluble-P (RS-P) also, the highest content was maintained under T₇ (76.7 mg kg⁻¹ soil), but it was at par with T₄ (71.6 mg kg⁻¹ soil), T₈ (71.2 mg kg⁻¹ soil) and T₆ (70.9 mg kg⁻¹ soil). The treatments T₇ (202 mg kg⁻¹ soil) and T₈ (200 mg kg⁻¹ soil) were statistically at par with each other and superior to the rest of the treatments (range- 178-190 mg kg⁻¹ soil) in terms of Ca-P content of the soil. There was no significant difference among the different treatments in influencing the residual-P (Res-P) content of the soil at the heading stage of wheat.

There was a further increase in all the inorganic P fractions of the soil from the heading to the dough stage of wheat. The treatments T₁, T₂ and T₃ were found to maintain the lowest amounts of LB-P, Al-P, RS-P and Ca-P contents of the soil during the dough stage of wheat (Table 53). In case of LB-P, the highest amount was maintained under T₄ (20.3 mg kg⁻¹ soil), which was statistically at par with T₇ (19.5 mg kg⁻¹ soil). Both treatments applied 100% recommended P to the soil. They were followed by the statistically similar treatments T₈ (16.8 mg kg⁻¹ soil), T₅ (16.5 mg kg⁻¹ soil), T₆ (16.5 mg kg⁻¹ soil) and T₉ (15.3 mg kg⁻¹ soil). The highest values of Al-P were recorded by T₇ (54.1 mg kg⁻¹ soil) and T₄ (52.7 mg kg⁻¹ soil), both of which were at par with each other.

The treatments T_6 and T_8 , with values of 49.7 and 47.9 mg kg⁻¹ soil were the next to follow. None of the treatments were found to influence the Fe-P content of the soil at this stage. The treatments T_7 (74.6 mg kg⁻¹ soil) and T_8 (73.0 mg kg⁻¹ soil) were found to be superior to the rest of the treatments in terms of RS-P content of the soil. In case of Ca-P also, these two treatments performed similarly (224 mg kg⁻¹ soil each under T_7 and T_8), but were at par with T_4 (214 mg kg⁻¹ soil), T_6 (209 mg kg⁻¹ soil) and T_9 (209 mg kg⁻¹ soil). The range of values obtained in case of Res-P was large, with the lowest value of 41.2 mg kg⁻¹ soil being recorded under T_9 and the highest value of 110.4 mg kg⁻¹ soil, recorded under T_3 .

A slight decrease in the LB-P content of soil was observed after the harvest of wheat when compared with that at the dough stage. The decrease might be due to the transformation of LB-P into other, more resistant P fractions. However, the treatments where higher levels of P were applied could still sustain higher amounts of LB-P as compared to the treatments where no or low P was applied. The treatments T_8 (15.8 mg kg⁻¹ soil), T_7 (15.3 mg kg⁻¹ soil), T_4 (15.3 mg kg⁻¹ soil) and T_9 (14.7 mg kg⁻¹ soil) were at par with each other (Table 54). They were superior to T_5 (13.5 mg kg⁻¹ soil) and T_6 (12.9 mg kg⁻¹ soil), while the lowest value in this respect was maintained under T_1 (9.2 mg kg⁻¹ soil). The highest Al-P content of 62.7 mg kg⁻¹ soil was maintained under T_7 . This was followed by the statistically similar treatments T_8 (57.8 mg kg⁻¹ soil), T_4 (56.3 mg kg⁻¹ soil) and T_6 (54.1 mg kg⁻¹ soil). The lowest Al-P value of 38.2 mg kg⁻¹ soil was recorded under control (T_1). The lowest and the highest amount of Fe-P at wheat harvest was maintained under T_1 (23.9 mg kg⁻¹ soil) and T_4 (34.1 mg kg⁻¹ soil), with the rest of the treatments performing similarly in this regard (range 25.2 to 28.5 mg kg⁻¹ soil). The treatment T_1 and T_3 maintained the lowest Ca-P content of the soil (188 mg kg⁻¹ soil), which was at par with the value registered under T_2 (195 mg kg⁻¹ soil). The highest Ca-P value of 228 mg kg⁻¹ soil was recorded under T_8 and T_4 . They were at par with the treatments T_7 (224 mg kg⁻¹ soil) and T_9 (219 mg kg⁻¹ soil). The treatments were divided into two groups with respect to the Res-P values of the soil at wheat harvest. The superior

Table 53. Inorganic P fractions (mg P kg⁻¹ soil) at dough stage of wheat

Treatment	Loosely bound P	Al-P	Fe-P	RS-P	Ca-P	Residual P
T ₁	12.2	37.8	23.0	62.0	185	91.1
T ₂	12.5	38.7	24.9	63.1	190	80.8
T ₃	12.1	39.6	25.9	64.0	187	110.4
T ₄	20.3	52.7	32.9	72.2	214	54.9
T ₅	16.5	45.1	24.9	68.9	194	82.6
T ₆	16.5	49.7	25.4	71.5	209	94.7
T ₇	19.5	54.1	29.5	74.6	224	48.3
T ₈	16.8	47.9	25.2	73.0	224	44.1
T ₉	15.3	42.4	24.9	70.2	209	41.2
Mean	15.7	45.3	26.3	68.8	204	72.9
CD (<i>P</i> = 0.05)	2.5	2.5	NS	2.4	27	42.5

Table 54. Inorganic P fractions (mg P kg⁻¹ soil) after harvest of wheat

Treatment	Loosely bound P	Al-P	Fe-P	RS-P	Ca-P	Residual P
T ₁	9.2	38.2	23.9	62.0	188	56.7
T ₂	10.5	43.2	25.2	63.8	195	60.3
T ₃	11.1	39.6	27.1	64.4	188	51.8
T ₄	15.3	56.3	34.1	71.9	228	18.4
T ₅	13.5	50.3	27.6	70.4	201	59.2
T ₆	12.9	54.1	26.1	73.6	212	37.3
T ₇	15.3	62.7	28.5	73.7	224	11.8
T ₈	15.8	57.8	25.7	73.8	228	8.9
T ₉	14.7	50.6	25.4	69.8	219	6.5
Mean	13.1	50.4	27.1	69.3	209	34.1
CD (<i>P</i> = 0.05)	1.4	4.7	3.9	NS	15	25.4

T₁: control; T₂: FYM; T₃: N₁₂₀; T₄: P₆₀; T₅: N₆₀P₃₀K₃₀; T₆: N₉₀P₄₅K₄₅; T₇: N₁₂₀P₆₀K₆₀; T₈: T₆ + FYM;
T₉: T₅ + FYM

group comprised the treatments T_1 , T_2 , T_3 , T_5 and T_6 , with a range of values between 37.3 and 60.3 mg kg⁻¹ soil. The rest of the treatments, with values between 6.5 and 18.4 mg kg⁻¹ soil, comprised the second group. The treatments did not influence the RS-P content of the soil at this stage. Higher amount of residual P in the plots receiving lower amount of fertilizer P signifies the inability of such plots to meet the quick demand of the crop for P by means of transformation to the easily available fractions, which would result in lower yield and P uptake.

4.2.4.2 Mungbean

The effect of various treatments on the different P fractions at the flowering stage of mungbean is shown in Table 55. The highest amount of LB-P was maintained under T_4 (19.43 mg kg⁻¹ soil), which was at par with T_7 (18.73 mg kg⁻¹ soil). These were followed by T_8 (16.27 mg kg⁻¹ soil). The lowest LB-P content was recorded under T_1 (7.27 mg kg⁻¹ soil), which was at par with T_2 (8.47 mg kg⁻¹ soil), T_3 (8.33 mg kg⁻¹ soil) and T_5 (9.57 mg kg⁻¹ soil). The treatment T_1 also maintained the lowest content of Al-P (34.1 mg kg⁻¹ soil) and Fe-P (21.6 mg kg⁻¹ soil), while the highest amount of both these fractions was exhibited under T_7 (51.3 and 28.5 mg kg⁻¹ soil in case of Al-P and Fe-P, respectively). The treatments T_8 (209 mg kg⁻¹ soil), T_7 (208 mg kg⁻¹ soil) and T_6 (206 mg kg⁻¹ soil) were statistically similar among themselves and superior to the rest of the treatments (range 186 to 197 mg kg⁻¹ soil) in terms of Ca-P content during the flowering stage. None of the treatments influenced the RS-P content. The lowest amount of Res-P was registered under T_8 (2.0 mg kg⁻¹ soil). The rest of the treatments could be divided into two groups, the superior group consisting of T_1 , T_2 , T_3 and T_5 , with the values ranging between 40.7 and 67.3 mg kg⁻¹ soil.

Barring Res-P, the values pertaining to different inorganic P fraction was not found to have changed from flowering stage of mungbean to the stage before its incorporation i.e. maturity. This could be attributed to the fact that no P fertilizer was applied after the wheat crop, and by this time the soil P would have been distributed among different pools. Moreover, P uptake by mungbean would have been more or

less complete by this stage. The treatments applied to wheat did not influence the RS-P and Res-P content of the soil before incorporation of mungbean (Table 56). The treatments T₇ (19.33 mg kg⁻¹ soil), T₆ (18.40 mg kg⁻¹ soil) and T₈ (17.73 mg kg⁻¹ soil) were at par among themselves and superior to the rest of the treatments in terms of LB-P content of the soil. The lowest value of 6.33 mg kg⁻¹ soil in this respect was exhibited under T₁ and T₃. They were at par with T₂ (7.07 mg kg⁻¹ soil). In case of Al-P, the lowest value was again recorded under T₁ (35.5 mg kg⁻¹ soil), which was statistically similar to the value of 36.8 mg kg⁻¹ soil obtained under T₃. The rest of the treatments were at par among themselves and superior to these two treatments, with Al-P values ranging from 38.7 to 44.3 mg kg⁻¹ soil. The treatments T₇, T₈, T₉, T₄ and T₆, with Fe-P values between 25.4 and 28.0 mg kg⁻¹ soil, were superior to the rest of the treatments, which were at par among themselves (range- 23.3 to 24.7 mg kg⁻¹ soil). The lowest Ca-P content of the soil before incorporation of mungbean was maintained under T₁ (184 mg kg⁻¹ soil), with all other treatments, as a group, being superior. The values ranged between 192 and 208 mg kg⁻¹ soil.

4.2.4.3 Maize

Application of mungbean residue to the soil resulted in an increase in the organic P content (Figure 22) and a concomitant decrease in the inorganic P fractions. Barring the Ca-P fraction, all the other P-fractions showed a decrease from their values during mungbean growth to the sowing of maize. As Ca-P was present in abundant quantities in the soil, it appears that the higher activity of Ca relative to Al and Fe in the alkaline soil would have acted as a sink to whatever P was released through the mineralization of organic P. The average contents of LB-P, Al-P, Fe-P, RS-P, Ca-P and Res-P before sowing maize were 6.32, 31.2, 23.5, 65.7, 201 and 7.3 mg kg⁻¹ soil, respectively (Table 57).

Except for RS-P and Res-P, which were not influenced by the subplot factor *i.e.* fertilizer applied to maize, the other four P fractions increased by the increased rate of

Table 55. Inorganic P fractions (mg P kg⁻¹ soil) at flowering stage of mungbean

Treatment	Loosely bound P	Al-P	Fe-P	RS-P	Ca-P	Residual P
T ₁	7.27	34.1	21.6	60.7	186	67.3
T ₂	8.47	35.0	24.0	61.7	197	50.3
T ₃	8.33	38.0	26.0	62.9	186	53.0
T ₄	19.43	49.2	27.0	67.4	187	36.0
T ₅	9.57	38.0	24.9	65.6	195	40.7
T ₆	12.20	37.3	25.7	68.8	206	25.3
T ₇	18.73	51.3	28.5	71.3	208	9.7
T ₈	16.27	46.2	28.0	70.1	209	2.0
T ₉	11.60	44.8	25.1	66.5	195	24.0
Mean	12.43	41.5	25.6	66.1	197	34.3
CD (<i>P</i> = 0.05)	2.62	3.4	2.0	NS	12	27.7

Table 56. Inorganic P fractions (mg P kg⁻¹ soil) before incorporation of mungbean

Treatment	Loosely bound P	Al-P	Fe-P	RS-P	Ca-P	Residual P
T ₁	6.33	35.5	23.3	59.3	184	79.3
T ₂	7.07	42.0	23.3	61.1	192	58.3
T ₃	6.33	36.8	23.7	62.6	193	64.0
T ₄	11.80	44.2	25.7	68.7	202	49.7
T ₅	10.27	38.7	24.7	65.7	195	41.0
T ₆	18.40	40.8	25.4	69.2	204	35.7
T ₇	19.33	50.6	28.0	70.4	207	30.0
T ₈	17.73	44.3	27.6	68.0	208	9.3
T ₉	12.80	42.4	25.7	67.1	207	18.7
Mean	12.23	41.7	25.3	65.8	199	42.9
CD (<i>P</i> = 0.05)	1.89	6.3	2.8	NS	10	NS

T₁: control; T₂: FYM; T₃: N₁₂₀; T₄: P₆₀; T₅: N₆₀P₃₀K₃₀; T₆: N₉₀P₄₅K₄₅; T₇: N₁₂₀P₆₀K₆₀; T₈: T₆ + FYM;
T₉: T₅ + FYM

Table 57. Inorganic P fractions (mg P kg⁻¹ soil) before sowing maize

Treatment	Loosely bound P	Al-P	Fe-P	RS-P	Ca-P	Residual P
T ₁	4.16	30.1	22.1	54.3	206	3.5
T ₂	5.02	31.5	23.5	58.9	207	6.1
T ₃	5.74	30.4	22.1	60.4	193	8.3
T ₄	6.67	32.1	25.7	72.6	202	9.0
T ₅	6.50	28.9	22.1	65.1	193	10.4
T ₆	6.97	28.9	23.5	68.5	202	12.2
T ₇	7.58	32.1	24.2	70.3	212	1.8
T ₈	7.60	35.5	24.7	72.1	200	8.1
T ₉	6.63	31.5	23.3	69.5	193	8.2
Mean	6.32	31.2	23.5	65.7	201	7.3

T₁: control; T₂: FYM; T₃: N₁₂₀; T₄: P₆₀; T₅: N₆₀P₃₀K₃₀; T₆: N₉₀P₄₅K₄₅; T₇: N₁₂₀P₆₀K₆₀; T₈: T₆ + FYM;
T₉: T₅ + FYM

applied fertilizers (i.e., $M_3 > M_2 > M_1$) at the silking stage of maize (Table 58). The values of LB-P, Al-P, Fe-P and Ca-P recorded under M_1 were 6.3, 29.8, 24.9 and 201 mg kg⁻¹ soil, respectively, and that under M_3 were 8.2, 39.0, 30.5 and 210 mg kg⁻¹ soil, respectively. The highest LB-P content was recorded under T_7 (8.32 mg kg⁻¹ soil) followed by T_8 (8.24 mg kg⁻¹ soil), T_6 (8.00 mg kg⁻¹ soil) and T_4 (7.74 mg kg⁻¹ soil), all of which were statistically at par among themselves. The lowest LB-P contents were maintained under the statistically similar T_1 (5.98 mg kg⁻¹ soil), T_2 (6.09 mg kg⁻¹ soil) and T_3 (6.43 mg kg⁻¹ soil), which were also responsible for the lowest amounts of Al-P content of soil (31.4, 31.8 and 31.7 mg kg⁻¹ soil, under T_1 , T_2 and T_3 , respectively). In case of Al-P, the highest content was exhibited under T_7 (38.8 mg kg⁻¹ soil), which was at par with T_4 (37.6 mg kg⁻¹ soil). This was followed by the statistically similar treatments T_8 , T_9 , T_6 and T_5 , with Al-P contents ranging between 35.0 and 36.4 mg kg⁻¹ soil. The highest Fe-P content of the soil was maintained under T_4 (30.5 mg kg⁻¹ soil), which performed similarly as T_7 (30.5 mg kg⁻¹ soil). These were followed by T_9 (28.7 mg kg⁻¹ soil) and T_8 (28.4 mg kg⁻¹ soil), which were at par with each other. The lowest value of 25.7 mg kg⁻¹ soil was maintained under T_2 and T_3 . It needs to be mentioned here that fertilizer P was applied to all the plots except M_1 before sowing of maize. This resulted in higher amounts of LB-P (Figure 25), Fe-P (Figure 27) and Al-P (Figure 26) in the soil during silking stage as compared to the previous stage. The increase was particularly higher in the plots receiving higher doses of P during wheat. Addition of soluble P fertilizer is known to transform Ca-P into LB-P, Fe-P and Al-P fractions in the soil (Jain and Sarkar, 1980). In case of RS-P, the highest content was maintained under T_7 (71.4 mg kg⁻¹ soil), but it was at par with T_4 (68.6 mg kg⁻¹ soil), T_6 (68.0 mg kg⁻¹ soil) and T_5 (67.5 mg kg⁻¹ soil). The lowest RS-P was observed in T_1 (53.8 mg kg⁻¹ soil) followed by statistically similar T_2 (59.0 mg kg⁻¹ soil). The rest of the treatments had values lying in between 60.7 and 64.4 mg kg⁻¹ soil. The lowest amount of Ca-P was maintained under T_3 (197 mg kg⁻¹ soil), which was at par with T_5 (199 mg kg⁻¹ soil) and T_9 (198 mg kg⁻¹ soil). The highest Ca-P content was recorded by T_7 (211 mg kg⁻¹ soil), followed by T_2 (210 mg kg⁻¹ soil), which are

Table 58. Inorganic P fractions (mg P kg⁻¹ soil) at silking stage of maize

Treatment	Loosely bound P				Al-P			
	M ₁	M ₂	M ₃	Mean	M ₁	M ₂	M ₃	Mean
T ₁	5.27	6.03	6.63	5.98	29.0	31.4	33.8	31.4
T ₂	5.47	6.27	5.53	6.09	29.3	31.5	34.5	31.8
T ₃	4.67	7.00	7.63	6.43	31.1	32.0	31.9	31.7
T ₄	7.17	7.53	8.53	7.74	30.8	40.3	41.7	37.6
T ₅	6.50	7.63	8.50	7.54	29.1	36.0	39.3	34.8
T ₆	7.07	8.13	8.80	8.00	29.7	37.3	42.3	36.4
T ₇	7.43	7.83	9.70	8.32	35.5	37.7	43.2	38.8
T ₈	7.43	7.86	9.73	8.24	28.1	34.6	43.3	35.5
T ₉	5.87	7.33	7.90	7.03	25.9	37.9	41.4	35.0
Mean	6.32	7.29	8.22		29.8	35.0	39.0	
CD (P = 0.05)	T : 0.95; M : 0.26; T×M : NS				T : 1.9; M : 1.0; T×M : 2.9			
Treatment	Fe-P				RS-P			
	M ₁	M ₂	M ₃	Mean	M ₁	M ₂	M ₃	Mean
T ₁	25.0	29.3	29.3	27.9	53.6	52.1	55.8	53.8
T ₂	24.3	25.4	27.4	25.7	59.1	60.0	58.0	59.0
T ₃	22.2	25.6	29.5	25.7	61.2	64.5	65.6	63.8
T ₄	28.5	30.6	32.5	30.5	70.4	61.3	74.2	68.6
T ₅	23.4	25.5	29.4	26.1	62.9	68.3	71.2	67.5
T ₆	23.4	25.5	30.6	26.5	64.5	67.1	72.5	68.0
T ₇	27.5	30.6	33.3	30.5	70.1	74.3	69.6	71.4
T ₈	25.5	28.4	31.3	28.4	64.9	53.2	64.0	60.7
T ₉	24.6	30.4	31.3	28.7	68.1	70.1	54.9	64.4
Mean	24.9	27.9	30.5		63.9	63.4	65.1	
CD (P = 0.05)	T : 0.5; M : 0.2; T×M : 0.3				T : 5.9; M : NS; T×M : NS			
Treatment	Ca-P				Residual-P			
	M ₁	M ₂	M ₃	Mean	M ₁	M ₂	M ₃	Mean
T ₁	202	204	210	205	11.1	12.5	36.8	20.1
T ₂	206	208	216	210	18.2	14.2	8.9	13.8
T ₃	199	191	202	197	9.8	18.6	7.4	11.9
T ₄	202	203	213	206	11.8	25.3	26.8	21.2
T ₅	197	195	205	199	27.0	27.6	8.6	21.1
T ₆	200	203	213	205	37.6	17.0	27.5	27.4
T ₇	207	208	217	211	16.1	16.6	4.9	12.5
T ₈	205	201	209	205	9.4	8.7	22.3	13.4
T ₉	195	193	205	198	12.9	4.7	4.9	7.5
Mean	201	201	210		17.1	16.1	16.5	
CD (P = 0.05)	T : 3; M : 5; T×M : NS				T : NS; M : NS; T×M : NS			

T₁: control; T₂: FYM; T₃: N₁₂₀; T₄: P₆₀; T₅: N₆₀P₃₀K₃₀; T₆: N₉₀P₄₅K₄₅; T₇: N₁₂₀P₆₀K₆₀; T₈: T₆ + FYM;

T₉: T₅ + FYM

M₁: N₀P₀K₀; M₂: N₆₀P₃₀K₃₀; M₃: N₉₀P₄₅K₄₅

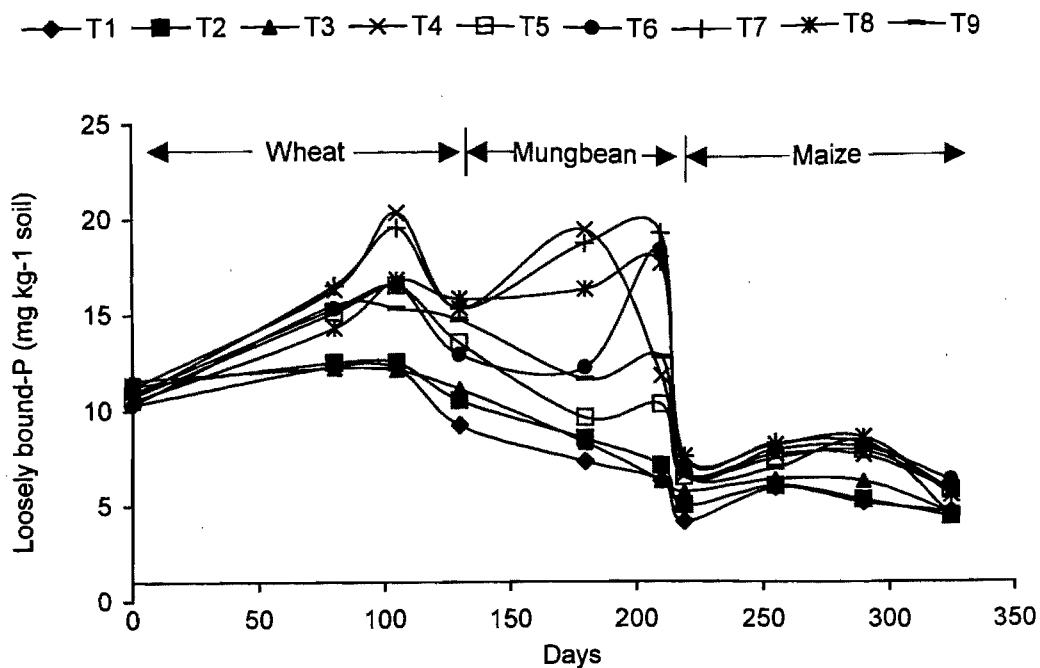


Figure 25. Influence of fertilizer and manurial treatments on loosely bound P contents of soil at different stages of crop growth

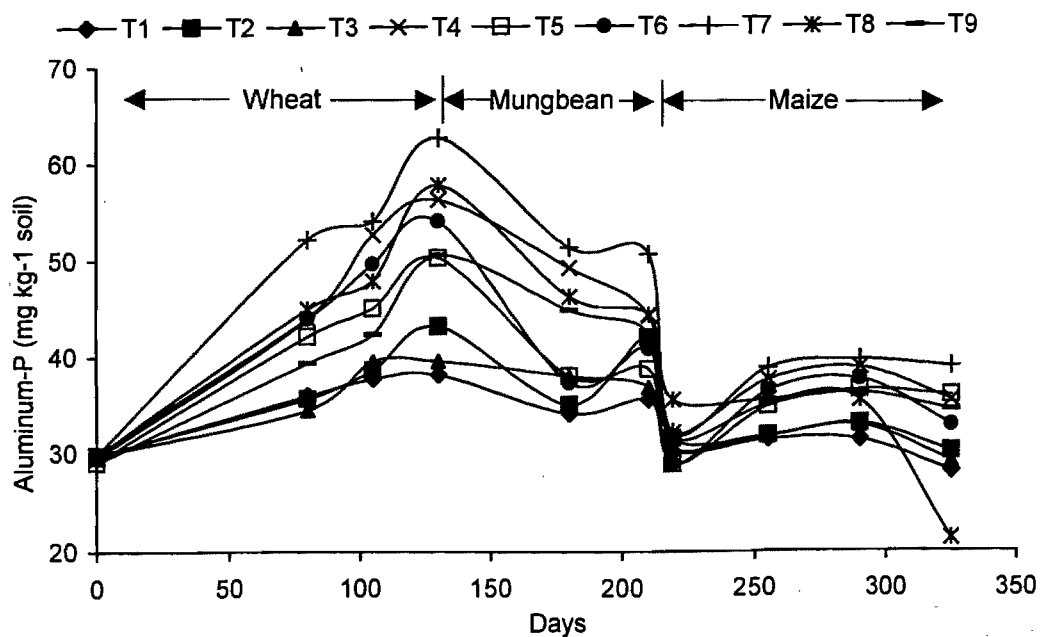


Figure 26. Influence of fertilizer and manurial treatments on the aluminium-P contents of soil at different stages of crop growth

statistically at par. There were no significant differences among the different treatments applied to wheat in influencing the Res-P content of the soil at the silking stage of maize.

The treatments T_8 (8.63 mg kg⁻¹ soil), T_9 (8.43 mg kg⁻¹ soil), T_7 (8.35 mg kg⁻¹ soil), T_6 (8.12 mg kg⁻¹ soil), T_5 (7.94 mg kg⁻¹ soil) and T_4 (7.70 mg kg⁻¹ soil) were at par among themselves and superior to the rest of the treatments in terms of LB-P content of the soil (Figure 25) at the dough stage of maize (Table 59). The lowest value in this respect was exhibited under T_1 (5.21 mg kg⁻¹ soil), which was at par with T_2 (5.34 mg kg⁻¹ soil). In case of Al-P (Figure 26), the lowest value was again recorded under T_1 (31.3 mg kg⁻¹ soil), which was statistically similar to the value of 32.8 mg kg⁻¹ soil obtained under T_3 and 33.0 mg kg⁻¹ soil, under T_2 . The highest Al-P content was maintained under T_7 (39.6 mg kg⁻¹ soil), which was at par with T_4 (38.8 mg kg⁻¹ soil) and T_6 (37.6 mg kg⁻¹ soil). The treatments T_2 , T_3 , T_5 and T_6 , with Fe-P values between 26.5 and 27.1 mg kg⁻¹ soil, performed poorly as compared to the rest of the treatments (Figure 27). The highest Fe-P content was obtained under T_4 (31.3 mg kg⁻¹ soil) followed by statistically similar T_7 (31.2 mg kg⁻¹ soil). The lowest Ca-P content of 203 mg kg⁻¹ soil was maintained under T_9 , which was at par with the values of 206 (under T_1), 205 (under T_3 and T_5) and 207 (under T_6) mg kg⁻¹ soil. The rest of the treatments were superior, with Ca-P (Figure 29) content ranging between 210 (T_2 and T_8) to 214 (T_4) mg kg⁻¹ soil. The treatments applied to wheat did not influence the RS-P (Figure 28) and Res-P content of soil at dough stage of maize. As regards, the treatments applied to maize (subplot treatments), it was observed that the LB-P, Al-P, Fe-P and Ca-P contents of the soil increased as the fertilizer dose increased from 0 (M_1) to 75% (M_3) of the recommended dose. The treatments applied to wheat did not influence the RS-P and Res-P (Figure 30) content of the soil at dough stage of maize. As an example, the LB-P content of the soil increased in the order M_1 (6.22 mg kg⁻¹ soil) < M_2 (7.25 mg kg⁻¹ soil) < M_3 (7.88 mg kg⁻¹ soil). The same was true for all the P fractions after the harvest of maize (Table 60).

From Table 60 it can be seen that the LB-P content of the soil was similar under the treatments T_1 , T_2 , T_3 and T_9 (range 4.45 to 4.67 mg kg⁻¹ soil). The highest value in

Table 59. Inorganic P fractions (mg P kg⁻¹ soil) at dough stage of maize

Treatment	Loosely bound P				Al-P			
	M ₁	M ₂	M ₃	Mean	M ₁	M ₂	M ₃	Mean
T ₁	4.46	5.44	5.74	5.21	28.5	30.9	34.6	31.3
T ₂	5.02	5.51	5.47	5.34	30.9	32.7	35.4	33.0
T ₃	4.69	6.97	7.30	6.32	33.0	32.5	32.8	32.8
T ₄	7.05	7.73	8.33	7.70	32.6	41.4	42.5	38.8
T ₅	6.67	8.17	8.99	7.94	32.9	35.4	41.2	36.5
T ₆	7.49	7.97	8.92	8.12	32.9	37.5	42.3	37.6
T ₇	7.77	8.08	9.20	8.35	36.7	38.4	43.8	39.6
T ₈	7.76	8.78	9.36	8.63	29.7	34.7	41.8	35.4
T ₉	5.08	6.63	7.58	8.43	27.5	38.8	42.3	36.2
Mean	6.22	7.25	7.88		31.6	35.8	39.6	
CD (<i>P</i> = 0.05)	T : 0.97; M : 0.16; T×M : 0.49				T : 2.6; M : 0.9; T×M : 2.7			
	Fe-P				RS-P			
T ₁	26.0	28.6	31.0	28.5	60.7	60.7	58.1	59.8
T ₂	25.7	26.5	28.9	27.0	66.0	62.0	48.1	58.7
T ₃	23.1	26.5	30.0	26.5	65.0	64.9	54.5	61.5
T ₄	30.2	30.9	32.8	31.3	74.4	71.3	61.6	69.1
T ₅	23.5	26.6	29.9	26.7	59.6	66.0	57.0	60.9
T ₆	23.6	26.3	31.4	27.1	69.1	72.2	62.9	68.0
T ₇	28.4	31.5	33.7	31.2	72.8	73.5	66.4	70.9
T ₈	27.3	29.4	32.3	29.7	64.2	54.7	65.3	61.4
T ₉	25.6	31.0	32.6	29.7	60.7	52.3	61.9	58.3
Mean	25.9	28.6	31.4		65.8	64.2	59.5	
CD (<i>P</i> = 0.05)	T : 0.9; M : 0.5; T×M : 1.5				T : NS; M : NS; T×M : NS			
	Ca-P				Residual-P			
T ₁	199	206	214	206	20.4	20.3	16.3	19.0
T ₂	202	213	214	210	16.4	18.3	3.4	12.7
T ₃	194	196	225	205	6.1	15.8	10.8	10.9
T ₄	204	217	220	214	12.7	14.9	5.7	11.1
T ₅	196	213	208	205	9.4	32.1	25.6	22.4
T ₆	201	205	216	207	23.0	17.4	1.2	13.8
T ₇	204	211	222	213	14.7	4.5	9.9	9.7
T ₈	200	206	224	210	7.1	8.8	5.2	7.0
T ₉	196	201	213	203	13.8	1.6	4.3	6.6
Mean	200	208	217		13.7	14.9	9.2	
CD (<i>P</i> = 0.05)	T : 6; M : 3; T×M : 8				T : NS; M : NS; T×M : NS			

T₁: control; T₂: FYM; T₃: N₁₂₀; T₄: P₆₀; T₅: N₆₀P₃₀K₃₀; T₆: N₉₀P₄₅K₄₅; T₇: N₁₂₀P₆₀K₆₀; T₈: T₆ + FYM;
T₉: T₅ + FYM
M₁: N₀P₀K₀; M₂: N₆₀P₃₀K₃₀; M₃: N₉₀P₄₅K₄₅

Table 60. Inorganic P fractions (mg P kg⁻¹ soil) after harvest of maize

Treatment	Loosely bound P				Al-P			
	M ₁	M ₂	M ₃	Mean	M ₁	M ₂	M ₃	Mean
T ₁	4.42	4.79	4.80	4.67	25.4	28.0	30.9	28.1
T ₂	3.96	4.31	5.07	4.45	28.4	30.5	31.5	30.1
T ₃	4.46	4.74	4.68	4.63	28.4	29.2	29.8	29.1
T ₄	4.34	5.50	7.60	5.81	29.6	37.4	39.1	35.4
T ₅	5.00	5.82	6.60	5.81	32.3	35.8	39.8	35.9
T ₆	5.22	6.79	7.01	6.34	21.2	37.2	40.0	32.8
T ₇	4.88	5.93	6.61	5.81	35.7	35.8	45.4	38.9
T ₈	4.88	4.67	7.15	5.57	17.4	21.0	25.6	21.3
T ₉	4.55	4.50	4.50	4.52	25.0	36.0	41.6	34.4
Mean	4.64	5.23	6.00		27.0	32.4	36.0	
CD (<i>P</i> = 0.05)	T : 0.58; M : 0.24; T×M : 0.74				T : NS; M : 2.6; T×M : NS			
Treatment	Fe-P				RS-P			
	M ₁	M ₂	M ₃	Mean	M ₁	M ₂	M ₃	Mean
T ₁	24.1	26.3	28.0	26.1	57.8	66.5	69.8	64.7
T ₂	23.7	25.2	27.0	25.3	70.2	72.6	75.2	72.6
T ₃	22.9	26.5	30.0	26.5	68.5	72.9	69.2	70.2
T ₄	26.6	29.7	33.7	30.0	70.2	77.8	64.0	70.0
T ₅	22.0	28.3	31.2	27.2	66.9	74.7	64.9	68.8
T ₆	23.7	25.7	29.5	26.3	68.9	73.1	69.4	70.4
T ₇	26.9	31.5	34.6	31.0	74.2	76.1	53.0	67.8
T ₈	24.5	28.4	30.3	27.8	71.5	64.0	78.4	71.2
T ₉	23.2	30.3	31.1	28.2	71.2	69.0	75.9	72.0
Mean	24.2	28.0	30.6		68.8	71.8	68.8	
CD (<i>P</i> = 0.05)	T : 2.6; M : 1.0; T×M : NS				T : 3.7; M : 1.8; T×M : 5.4			
Treatment	Ca-P				Residual-P			
	M ₁	M ₂	M ₃	Mean	M ₁	M ₂	M ₃	Mean
T ₁	198	209	214	207	43.3	22.0	21.9	29.1
T ₂	201	216	214	210	29.7	13.1	8.0	16.9
T ₃	193	199	225	206	29.1	27.7	9.3	22.0
T ₄	204	218	221	214	29.2	18.4	10.3	19.3
T ₅	196	207	208	204	24.8	34.4	35.9	31.7
T ₆	200	211	220	210	45.7	14.3	13.5	24.5
T ₇	206	215	223	215	17.9	5.7	17.3	13.5
T ₈	203	208	231	214	35.7	29.2	9.5	24.8
T ₉	199	202	214	205	31.4	12.0	14.5	19.3
Mean	200	209	219		31.9	19.7	17.8	
CD (<i>P</i> = 0.05)	T : 7; M : 3; T×M : 10				T : NS; M : 22.3; T×M : NS			

T₁: control; T₂: FYM; T₃: N₁₂₀; T₄: P₆₀; T₅: N₆₀P₃₀K₃₀; T₆: N₉₀P₄₅K₄₅; T₇: N₁₂₀P₆₀K₆₀; T₈: T₆ + FYM;

T₉: T₅ + FYM

M₁: N₀P₀K₀; M₂: N₆₀P₃₀K₃₀; M₃: N₉₀P₄₅K₄₅

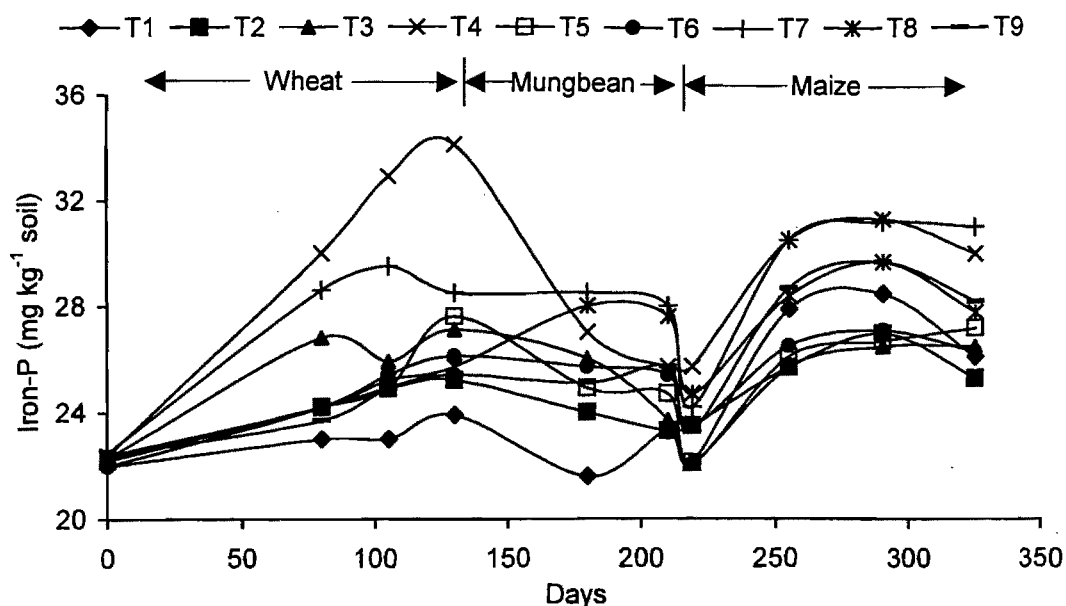


Figure 27. Influence of fertilizer and manurial treatments on the iron-P contents of soil at different stages of crop growth

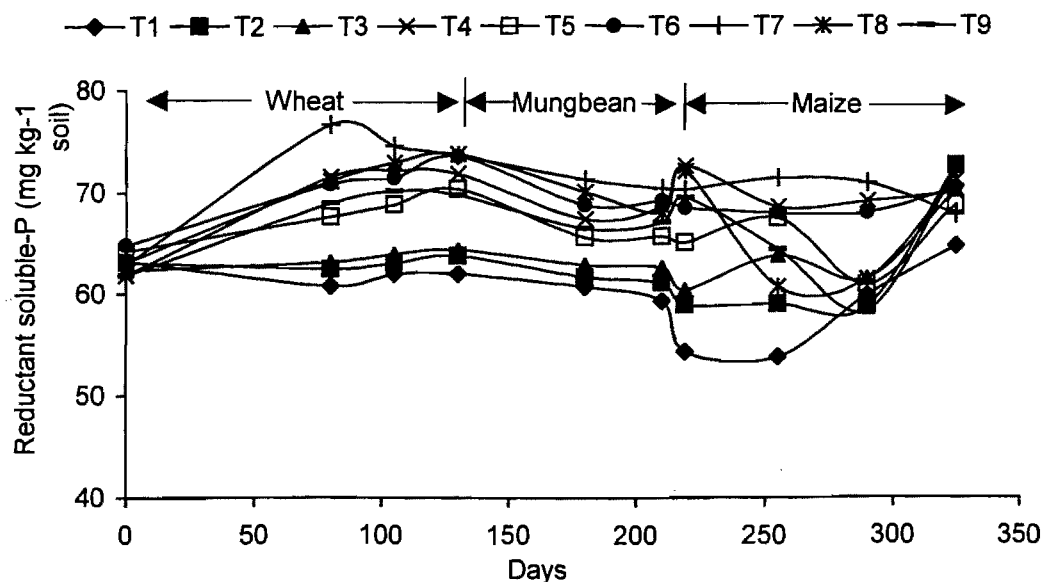


Figure 28. Influence of fertilizer and manurial treatments on the reductant soluble-P contents of soil at different stages of crop growth

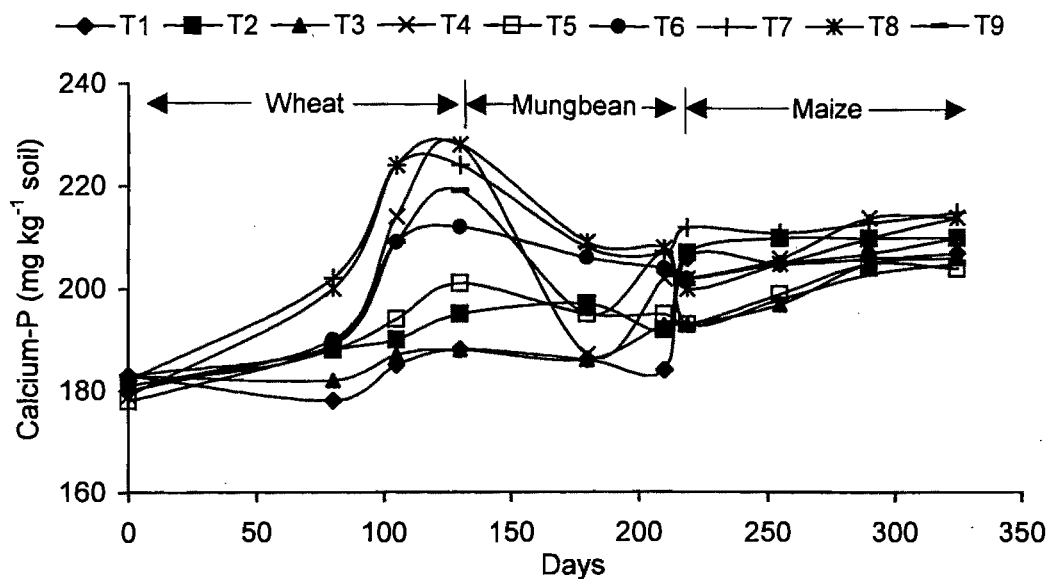


Figure 29. Influence of fertilizer and manurial treatments on the calcium-P contents of soil at different stages of crop growth

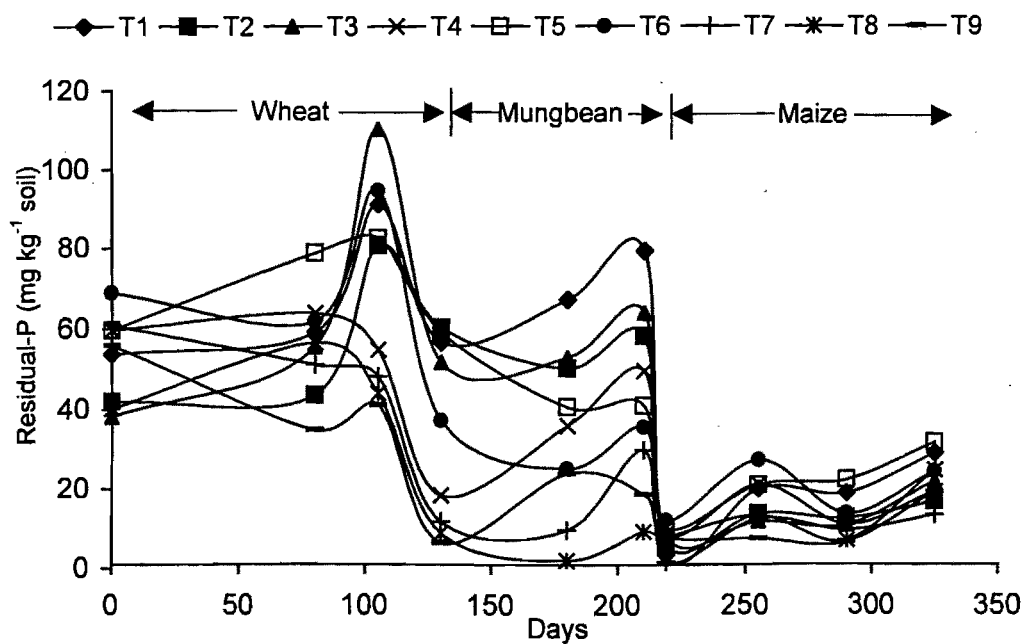


Figure 30. Influence of fertilizer and manurial treatments on the residual-P contents of soil at different stages of crop growth

this respect was maintained under T_6 ($6.34 \text{ mg kg}^{-1} \text{ soil}$), which was at par with the $5.81 \text{ mg kg}^{-1} \text{ soil}$ obtained under T_4 , T_5 and T_7 (Figure 25). The highest Fe-P content of the soil was maintained under T_7 ($31.0 \text{ mg kg}^{-1} \text{ soil}$), which was at par with T_4 ($30.0 \text{ mg kg}^{-1} \text{ soil}$). The lowest content was registered under T_2 ($25.3 \text{ mg kg}^{-1} \text{ soil}$). The rest of the treatments fell in between (range 26.1 to $28.2 \text{ mg kg}^{-1} \text{ soil}$) and were at par among themselves. The lowest RS-P content of the soil was obtained under T_1 ($64.7 \text{ mg kg}^{-1} \text{ soil}$). The treatments T_7 ($67.8 \text{ mg kg}^{-1} \text{ soil}$) and T_5 ($68.8 \text{ mg kg}^{-1} \text{ soil}$), both at par, were superior the rest of the treatments, (similar among themselves) which recorded RS-P contents between 70.0 and $72.6 \text{ mg kg}^{-1} \text{ soil}$. The treatments could be divided into two groups in terms of their influence on the Ca-P content of the soil at the harvest of maize. The superior group comprised of T_7 ($215 \text{ mg kg}^{-1} \text{ soil}$), T_4 ($214 \text{ mg kg}^{-1} \text{ soil}$), T_8 ($214 \text{ mg kg}^{-1} \text{ soil}$), T_2 ($210 \text{ mg kg}^{-1} \text{ soil}$) and T_6 ($210 \text{ mg kg}^{-1} \text{ soil}$). The rest of the treatments exhibited Ca-P values between 204 and $207 \text{ mg kg}^{-1} \text{ soil}$.

The results obtained with respect to different inorganic fractions indicate that these fractions are interdependent, *i.e.* an increase in one fraction causes a decrease in another. Also, these fractions are influenced by the amount of P fertilizers added to the soil. Calcium bound P was found to be the dominant fraction in the experimental soil accounting for 50 to 60% of inorganic P. The next dominant fraction was the RSP, constituting 15 to 19% of inorganic P. Residual P content of the soil was highly variable, with values ranging from 2 to 16%, while the proportion of Al-P, Fe-P and LB-P to the total inorganic P were 8-12, 6-8 and 1-3%, respectively. Dominance of Ca-P in neutral to alkaline soils have been reported by several workers (Tandon, 1987; Paramasivan and Udayasoorian, 1991; Dakshinamurthy and Murugappan, 1996).

As was mentioned earlier, application of P fertilizers was found to increase all the inorganic P fractions. But, while the relative proportion of Ca-P to the total inorganic P decreased, the proportion of LB-P and Al-P increased up to the dough stage of wheat. That the addition of soluble P fertilizers increases the proportion of LB-P and Al-P in the soil was reported earlier by Bhujbal (1989). Jain and Sarkar (1980) and Singh and Sarkar (1986) opined that during the initial stages of crop growth, Ca-P was transformed

to Al-P and Fe-P, while the trend was reversed at crop maturity. Further, increase in LB-P, Al-P and Fe-P were relatively high as compared to Ca-P on addition of water- and citrate-soluble P fertilizers.

There was a decrease in LB-P (Figure 25) fraction after the dough stage of wheat due to the possible conversion into more resistant P fractions. After this stage, it increased under T₄, T₇ and T₈, where higher amounts of P fertilizers had been applied, and decreased in other treatments up to the incorporation of mungbean. After the incorporation of mungbean, LB-P and Al-P were found to decline steeply, due, probably to the immobilization of P by microorganisms. The LB-P (Figure 25), Fe-P (Figure 27) and Al-P (Figure 26) content were found to increase again during the silking stage of maize, due to addition of P fertilizer to the maize crop, and release of P from mungbean residues.

From Figure 28, it can be seen that the RSP fraction did not undergo much change throughout the experimental period. Reductant soluble P represents P in the occluded form in iron and aluminium oxide aggregates or concretions. It is largely insoluble and considered to be not available to plants. The formation of reductant soluble P is a slow process related to soil genesis and is not affected by recent fertilizer application (Bhujbal, 1989)

Calcium P (Figure 29) was found to increase steadily from sowing of maize till its harvest. This could be attributed to the conversion of a part of LB-P, Al-P and Fe-P to the more resistant Ca-P as the crop matures and the requirement for P by the crop is fulfilled.

From the foregoing paragraphs, it appears that LB-P and Al-P are the fractions sensitive to external application of fertilizers, *i.e.* these are in immediate equilibrium with the plant available P. As the crop matures, they get converted to Ca-P, the dominant and most resistant fraction. When required, Ca-P is again transformed to Al-P and LB-P to release P for crop growth. Therefore, more attention should be paid towards these

three fractions for a more meaningful interpretation of P dynamics in this soil. Although Fe-P is also prone to changes through external fertilizers as has been reported by some workers, its content, relative to the total inorganic P did not change appreciably throughout the investigation period. However, in order to confirm these results and develop indices of P availability from among the different P fractions, this experiment should be allowed to continue for a longer period.

4.3. RELATIONSHIPS OF FORMS AND FRACTIONS OF NUTRIENTS WITH CROP YIELD AND NUTRIENT UPTAKE AND THEIR INTERRELATIONSHIPS

The yield potential of any crop is a function of a number of factors. Among them, the capacity of the soil to supply plant nutrients in readily available form, and consequently their uptake assumes great significance. The capacity of soil to supply a particular nutrient depends on the dynamic equilibrium existing among the various pools of that nutrient including the plant available pool. In order to study the interrelationships between the yield, nutrient uptake and different soil N and P fractions that existed throughout the experimental period and also among the different fractions, correlation, regression and path analysis studies were carried out, the results of which are described in the following sections.

4.3.1. Correlation Analysis

4.3.1.1. Relationships of forms and fractions of nitrogen with crop yield and N uptake

4.3.1.1.1. Wheat

Total-N, alkaline potassium permanganate oxidizable N ($\text{KMnO}_4\text{-N}$), $\text{NH}_4\text{-N}$ and $\text{NO}_3\text{-N}$ content of the soil at heading and dough stage of wheat positively and strongly affected wheat yield and N uptake at maturity (Table 61). Similarly, wheat yield (grain, straw and grain + straw) and N uptakes were highly correlated with total and $\text{KMnO}_4\text{-N}$ of soil at harvest. The grain yield ($r = 0.44^*$) and total yield ($r = 0.41^*$) and total N uptake by grain ($r = 0.49^{**}$) exhibited significant correlations with $\text{NO}_3\text{-N}$ content of the soil at that stage. However, neither yield nor N uptake by wheat was influenced by $\text{NH}_4\text{-N}$ content of the soil at wheat harvest (except straw N uptake, $r = 0.42^*$).

Table 61. Relationship (r-value) of soil nitrogen (N) with wheat yield and N uptake

Heading stage				
	Total N	Available N ^a	Ammoniacal-N	Nitrate-N
Grain yield (G)	0.60**	0.60**	0.58**	0.54**
Straw yield (S)	0.54**	0.61**	0.44*	0.51**
Total (G+S)	0.60**	0.67**	0.51**	0.57**
Grain N uptake	0.56**	0.57**	0.57**	0.49**
Straw N uptake	0.70**	0.59**	0.55**	0.67**
Total N uptake	0.69**	0.64**	0.61**	0.63**
Dough stage				
	Total N	Available N ^a	Ammoniacal-N	Nitrate-N
Grain yield (G)	0.60**	0.70**	0.52**	0.51**
Straw yield (S)	0.41*	0.49**	0.47*	0.51**
Total (G+S)	0.49**	0.58**	0.52**	0.56**
Grain N uptake	0.54**	0.74**	0.45*	0.46*
Straw N uptake	0.62**	0.63**	0.68**	0.65**
Total N uptake	0.64**	0.76**	0.61**	0.60**
After harvest				
	Total N	Available N ^a	Ammoniacal-N	Nitrate-N
Grain yield (G)	0.53**	0.54**	0.28	0.44*
Straw yield (S)	0.48**	0.60**	0.25	0.36
Total (G+S)	0.54**	0.64**	0.28	0.41*
Grain N uptake	0.50**	0.60**	0.20	0.38*
Straw N uptake	0.52**	0.59**	0.42*	0.52**
Total N uptake	0.56**	0.65**	0.34	0.49**

^a Alkaline potassium permanganate oxidisable nitrogen

* Significant at 5% level

** Significant at 1% level

No significant relationship could be obtained between organic N at the heading stage, and yield and N uptake by wheat (Table 62). Organic N content of soil at the dough stage could significantly relate with grain yield ($r = 0.45^*$), grain N uptake ($r = 0.41^*$) and total N uptake ($r = 0.43^*$). Barring straw N uptake, the yield and N uptake were related with the organic N values obtained from the samples collected at the harvest of wheat. All the hydrolysable N fractions strongly and positively influenced the wheat yield and nitrogen uptake during all the stages, particularly AAN, ASN and NHN fractions. Yield and N-uptake were significantly and negatively related to AIN at the heading stage of wheat; while its impact at dough stage was minimal and completely disappeared by the harvesting stage of wheat crop. UIN fraction of soil organic N was found to be correlated with both yield (except grain yield at heading and dough stage) and nutrient uptake at all the stages, but the relationship was negative. There was a general decline in the 'r' values of ASN with yield and nutrient uptake as the crop advanced from heading to harvesting stage, while the r values with respect to AAN and NHN fractions remained more or less similar at all stages.

The correlation tables 61 and 62 suggest that the different forms and fractions determined at the heading stage of wheat correlated best with the yield and N uptake.

4.3.1.1.2. Mungbean

Barring a few cases, none of the N forms influenced yield and nutrient uptake by mungbean (Table 63). While the total N uptake was related to total N, $\text{NH}_4\text{-N}$ and $\text{NO}_3\text{-N}$ of the soil at flowering stage (r values of 0.42^* , 0.38^* and 0.38^* , respectively), it was related only to $\text{NH}_4\text{-N}$ of soil before incorporation ($r = 0.38^*$). $\text{KMnO}_4\text{-N}$ content of soil at flowering stage influenced the grain ($r = 0.41^*$) and total ($r = 0.38^*$) yield.

Among the hydrolysable N fractions (Table 64) AAN and UIN exhibited significant correlation with stover, root and total N uptake at flowering stage (r values were 0.41^* , 0.40^* and 0.44^* , respectively in case of AAN, and -0.38^* , -0.44^* and -0.41^* , respectively in case of UIN). Total N uptake was also a function of NHN at flowering stage ($r = 0.40^*$). Both AAN and UIN were significantly correlated with total N uptake

Table 62. Relationship (r-value) of organic nitrogen (N) fractions of soil at different stages with wheat yield and N uptake at maturity

Heading stage							
	Org. N	Hyd. N	AIN	AAN	ASN	NHN	UIN
Grain yield (G)	0.31	0.64**	-0.54**	0.53**	0.62**	0.57**	-0.34
Straw yield (S)	0.29	0.59**	-0.50**	0.57**	0.61**	0.63**	-0.48**
Total (G+S)	0.32	0.66**	-0.56**	0.62**	0.67**	0.68**	-0.50**
Grain N uptake	0.30	0.68**	-0.58**	0.51**	0.58**	0.55**	-0.26
Straw N uptake	0.36	0.70**	-0.59**	0.73**	0.72**	0.73**	-0.57**
Total N uptake	0.37	0.76**	-0.65**	0.67**	0.71**	0.70**	-0.44*
Dough stage							
	Org. N	Hyd. N	AIN	AAN	ASN	NHN	UIN
Grain yield (G)	0.45*	0.48*	-0.28	0.53**	0.57**	0.55**	-0.45*
Straw yield (S)	0.19	0.58**	-0.57**	0.57**	0.53**	0.62**	-0.41*
Total (G+S)	0.26	0.61**	-0.56**	0.62**	0.59**	0.67**	-0.46*
Grain N uptake	0.41*	0.47*	-0.30	0.51**	0.52**	0.53**	-0.40*
Straw N uptake	0.35	0.69**	-0.61**	0.73**	0.67**	0.71**	-0.49**
Total N uptake	0.43*	0.64**	-0.49**	0.67**	0.65**	0.68**	-0.49**
After harvest							
	Org. N	Hyd. N	AIN	AAN	ASN	NHN	UIN
Grain yield (G)	0.40*	0.51**	-0.13	0.53**	0.54**	0.55**	-0.49**
Straw yield (S)	0.43*	0.62**	-0.21	0.57**	0.48*	0.62**	-0.47*
Total (G+S)	0.47*	0.65**	-0.20	0.62**	0.54**	0.67**	-0.52**
Grain N uptake	0.41*	0.48*	-0.10	0.51**	0.51**	0.53**	-0.46*
Straw N uptake	0.36	0.66**	-0.30	0.73**	0.61**	0.71**	-0.63**
Total N uptake	0.42*	0.63**	-0.22	0.67**	0.61**	0.68**	-0.60**

Org. N: Organic N; Hyd. N: Hydrolysable N; AIN: Acid insoluble N; AAN: Amino acid N;

ASN: Amino sugar N; NHN: Ammonia N; UIN: Unidentified N

* Significant at 5% level

** Significant at 1% level

Table 63. Relationship (r-value) of soil nitrogen (N) with mungbean yield and N uptake

Flowering stage				
	Total N	Available N ^a	Ammoniacal-N	Nitrate-N
Grain yield (G)	0.32	0.41*	0.37	0.26
Straw yield (S)	0.27	0.35	0.17	0.13
Root yield (R)	0.16	0.16	0.12	0.11
Total (G+S+R)	0.30	0.38*	0.21	0.17
Grain N uptake	0.21	0.36	0.32	0.20
Stover N uptake	0.39*	-0.03	0.31	0.33
Root N uptake	0.26	0.16	0.24	0.32
Total N uptake	0.42*	0.07	0.38*	0.38*
Before incorporation				
	Total N	Available N ^a	Ammoniacal-N	Nitrate-N
Grain yield (G)	0.30	0.20	0.27	0.05
Straw yield (S)	0.13	0.11	0.27	-0.14
Root yield (R)	0.05	0.21	0.32	0.20
Total (G+S+R)	0.16	0.15	0.32	-0.08
Grain N uptake	0.21	0.12	0.22	-0.01
Stover N uptake	0.25	0.22	0.31	0.20
Root N uptake	0.18	0.37	0.52**	0.31
Total N uptake	0.30	0.26	0.38*	0.20

^a Alkaline potassium permanganate oxidisable nitrogen

* Significant at 5% level

** Significant at 1% level

Table 64. Relationship (r-value) of organic nitrogen (N) fractions of soil at different stages with mungbean yield and N uptake at maturity

Flowering stage							
	Org. N	Hyd. N	AIN	AAN	ASN	NHN	UIN
Grain yield (G)	0.20	0.28	-0.07	0.23	0.30	0.24	-0.19
Stover yield (S)	0.25	0.15	0.11	0.08	0.09	0.09	-0.03
Root yield (R)	0.12	0.11	0.02	0.23	0.12	0.16	-0.23
Total (G+S+R)	0.26	0.18	0.09	0.13	0.14	0.13	-0.09
Grain N uptake	0.11	0.22	-0.11	0.15	0.21	0.18	-0.12
Stover N uptake	0.30	0.32	-0.01	0.41*	0.30	0.35	-0.38*
Root N uptake	0.16	0.23	-0.07	0.40*	0.31	0.37	-0.44*
Total N uptake	0.32	0.37	-0.05	0.44*	0.36	0.40*	-0.41*
Before incorporation							
	Org. N	Hyd. N	AIN	AAN	ASN	NHN	UIN
Grain yield (G)	0.30	0.23	0.07	0.18	0.30	0.25	-0.17
Stover yield (S)	0.14	0.11	0.03	0.08	0.09	0.02	-0.02
Root yield (R)	-0.06	0.17	-0.23	0.26	0.12	0.11	-0.18
Total (G+S+R)	0.15	0.15	-0.01	0.14	0.14	0.07	-0.07
Grain N uptake	0.21	0.17	0.04	0.10	0.21	0.21	-0.10
Stover N uptake	0.17	0.34	-0.18	0.45*	0.30	0.31	-0.36
Root N uptake	0.03	0.35	-0.34	0.45*	0.31	0.31	-0.36
Total N uptake	0.21	0.38*	-0.18	0.47*	0.36	0.35	-0.38*

Org. N: Organic N; Hyd. N: Hydrolysable N; AIN: Acid insoluble N; AAN: Amino acid N; ASN: Amino sugar N; NHN: Ammonia N; UIN: Unidentified N

* Significant at 5% level

** Significant at 1% level

by mungbean before its incorporation (r values were 0.47* and -0.38*, respectively). AAN values before incorporation also correlated with stover N uptake ($r = 0.45^*$) and root N uptake ($r = 0.45^*$). Mungbean, like other leguminous crops in rotation tends to immobilize more of N in amino acid form (Stevenson, 1956). This could be the possible reason of AAN correlating with the N uptake by mungbean.

4.3.1.1.3. Maize

There was a highly significant correlation of maize yield (grain, straw, grain+straw) with total N, $\text{KMnO}_4\text{-N}$ and $\text{NH}_4\text{-N}$ contents of soil at all the stages of maize growth barring the first stage, i.e. before sowing (Table 65). Both yield and uptake correlated significantly with $\text{KMnO}_4\text{-N}$ before sowing of maize. Similar results were obtained by Duraisami *et al.* (2001). Highly significant correlation with yield values and $\text{NH}_4\text{-N}$ content of soil before sowing of maize was observed with ' r ' values for grain, straw and total yield computed as 0.81**, 0.86** and 0.85** respectively. Significant correlation of grain ($r = 0.75^*$) and total ($r = 0.67^*$) N uptake with $\text{NH}_4\text{-N}$ was also observed. Nitrate-N content of soil before sowing of maize, however, was not found to correlate with yield and N uptake (Table 65), but strong correlation was observed at silking and dough stages, and after harvest.

Organic N content of soil before sowing of maize was found to correlate significantly with yield and N uptake, but at the subsequent stages, it correlated even more strongly at 1% level of significance. All the organic N fractions determined at silking stage of maize strongly influenced yield and N uptake as is evident from Table 66. During all other stages, only the hydrolysable N (Hyd. N) fractions, viz. AAN, ASN, NHN and UIN were found to correlate significantly with yield and N uptake by maize, with UIN exhibiting negative values of ' r '. Nitrogen uptake of maize was found to correlate negatively with the AIN fraction of organic N at the dough stage.

Considering the number of variables that strongly correlate with yield and N uptake by maize, and also the ' r ' values, silking stage of maize could be considered as best in order to go for correlation studies.

Table 65. Relationship (r-value) of soil nitrogen (N) with maize yield and N uptake

Before sowing				
	Total N	Available N ^a	Ammoniacal-N	Nitrate-N
Grain yield (G)	0.82**	0.76*	0.81**	0.63
Straw yield (S)	0.81**	0.77*	0.86**	0.65
Total (G+S)	0.81**	0.77*	0.85**	0.65
Grain N uptake	0.77*	0.72*	0.75*	0.62
Straw N uptake	0.69*	0.79*	0.58	0.52
Total N uptake	0.74*	0.77*	0.67*	0.58
Silking stage				
	Total N	Available N ^a	Ammoniacal-N	Nitrate-N
Grain yield (G)	0.76**	0.77**	0.62**	0.66**
Straw yield (S)	0.69**	0.65**	0.53**	0.55**
Total (G+S)	0.74**	0.72**	0.58**	0.61**
Grain N uptake	0.68**	0.79**	0.60**	0.68**
Straw N uptake	0.55**	0.77**	0.48**	0.57**
Total N uptake	0.63**	0.81**	0.56**	0.64**
Dough stage				
	Total N	Available N ^a	Ammoniacal-N	Nitrate-N
Grain yield (G)	0.77**	0.78**	0.68**	0.56**
Straw yield (S)	0.69**	0.62**	0.62**	0.48**
Total (G+S)	0.75**	0.70**	0.67**	0.53**
Grain N uptake	0.70**	0.76**	0.62**	0.59**
Straw N uptake	0.54**	0.70**	0.54**	0.54**
Total N uptake	0.58**	0.74**	0.57**	0.54**
After harvest				
	Total N	Available N ^a	Ammoniacal-N	Nitrate-N
Grain yield (G)	0.75**	0.69**	0.65**	0.63**
Straw yield (S)	0.65**	0.56**	0.57**	0.50**
Total (G+S)	0.71**	0.63**	0.62**	0.56**
Grain N uptake	0.69**	0.72**	0.63**	0.63**
Straw N uptake	0.52**	0.67**	0.61**	0.61**
Total N uptake	0.62**	0.68**	0.62**	0.62**

^a Alkaline potassium permanganate oxidisable nitrogen

* Significant at 5% level

** Significant at 1% level

Table 66. Relationship (r-value) of organic nitrogen (N) fractions of soil at different stages with maize yield and N uptake at maturity

Before sowing							
	Org. N	Hyd. N	AIN	AAN	ASN	NHN	UIN
Grain yield (G)	0.80**	0.79*	0.25	0.92**	0.88**	0.79*	-0.93**
Straw yield (S)	0.75*	0.77*	0.20	0.88**	0.90**	0.76*	-0.89**
Total (G+S)	0.77*	0.78*	0.22	0.90**	0.89**	0.77*	-0.91**
Grain N uptake	0.77*	0.76*	0.24	0.92**	0.84**	0.80**	-0.96**
Stover N uptake	0.68*	0.69*	0.19	0.85**	0.76*	0.58	-0.82**
Total N uptake	0.74*	0.74*	0.22	0.90**	0.81**	0.70*	-0.90**
Silking stage							
	Org. N	Hyd. N	AIN	AAN	ASN	NHN	UIN
Grain yield (G)	0.51**	0.77**	-0.43**	0.77**	0.79**	0.81**	-0.74**
Straw yield (S)	0.51**	0.62**	-0.27*	0.54**	0.64**	0.71**	-0.57**
Total (G+S)	0.53**	0.70**	-0.33**	0.64**	0.72**	0.77**	-0.65**
Grain N uptake	0.39**	0.77**	-0.52**	0.85**	0.84**	0.85**	-0.84**
Stover N uptake	0.31**	0.65**	-0.45**	0.70**	0.68**	0.72**	-0.69**
Total N uptake	0.36**	0.73**	-0.50**	0.80**	0.78**	0.81**	-0.79**
Dough stage							
	Org. N	Hyd. N	AIN	AAN	ASN	NHN	UIN
Grain yield (G)	0.62**	0.73**	-0.12	0.75**	0.77**	0.77**	-0.70**
Straw yield (S)	0.56**	0.57**	-0.02	0.57**	0.68**	0.65**	-0.57**
Total (G+S)	0.60**	0.65**	-0.06	0.65**	0.74**	0.72**	-0.64**
Grain N uptake	0.53**	0.75**	-0.23*	0.83**	0.80**	0.80**	-0.78**
Stover N uptake	0.34**	0.70**	-0.36**	0.64**	0.62**	0.71**	-0.58**
Total N uptake	0.38**	0.70**	-0.32**	0.69**	0.70**	0.71**	-0.64**
After harvest							
	Org. N	Hyd. N	AIN	AAN	ASN	NHN	UIN
Grain yield (G)	0.57**	0.79**	-0.15	0.77**	0.75**	0.75**	-0.68**
Straw yield (S)	0.52**	0.66**	-0.08	0.54**	0.67**	0.62**	-0.48**
Total (G+S)	0.56**	0.73**	-0.11	0.64**	0.72**	0.69**	-0.57**
Grain N uptake	0.51**	0.79**	-0.21	0.84**	0.76**	0.79**	-0.76**
Stover N uptake	0.31**	0.71**	-0.33	0.66**	0.57**	0.66**	-0.55**
Total N uptake	0.43**	0.73**	-0.24	0.74**	0.66**	0.71**	-0.65**

Org. N: Organic N; Hyd. N: Hydrolysable N; AIN: Acid insoluble N; AAN: Amino acid N; ASN: Amino sugar N; NHN: Ammonia N; UIN: Unidentified N

*. Significant at 5% level

** Significant at 1% level

4.3.1.2. Relationships of forms and fractions of phosphorus with crop yield and nutrient uptake

4.3.1.2.1. Wheat

Both organic and inorganic P at any of the growth stages, were not found to correlate with wheat yield in soil (Table 67). While inorganic P content of soil at heading stage of wheat correlated significantly with straw P ($r = 0.42^*$) and total P uptake ($r = 0.43^*$), organic P content of soil at harvest of wheat correlated with straw P ($r = 0.45^*$) and total P uptake ($r = 0.38^*$). Total P content of the soil at all the growth stages of wheat was found to significantly influence P uptake. Olsen P content of the soil at all the growth stages of wheat, influenced positively and significantly both yield and P uptake.

Among the various inorganic P fractions, Fe-P and Res-P at any of the stages did not correlate significantly with yield and P uptake by wheat barring straw P uptake which was negatively related with Res-P at dough stage (Table 68) with 'r' value of 0.38^* . The same was true with respect to Ca-P during heading stage (except for total P uptake, where $r = 0.39^*$) and RS-P at harvest of wheat. During all the growth stages LB-P and Al-P influenced P uptake by wheat. Both yield and P uptake were significantly correlated with RS-P during the heading and dough stages. Except grain yield, which was not correlated with Ca-P at dough stage ($r = 0.34$), straw, total drymatter yield and P uptake were influenced by this fraction at that stage. The total P uptake by wheat was found to be significantly correlated with Ca-P fraction at the heading ($r=0.39^*$) and dough stages ($r=0.48^*$). Correlation of P uptake with LB-P, Al-P and Ca-P determined at all the stages of wheat shows that these three fractions should be closely monitored for a longer period.

4.3.1.2.2. Mungbean

Total, organic and inorganic P content of the soil at both flowering stage and before incorporation of mungbean were not found to influence mungbean yield and P uptake (Table 69). Olsen P at both the stages correlated significantly with yield and P uptake by mungbean (except root yield and uptake).

Table 67. Relationship (r-value) of soil phosphorus (P) with wheat yield and P uptake

Heading stage				
	Total P	Organic P	Inorganic P	Olsen P
Grain yield (G)	0.15	-0.10	0.24	0.41*
Straw yield (S)	0.10	-0.05	0.15	0.44*
Total (G+S)	0.12	-0.07	0.18	0.48*
Grain P uptake	0.42*	0.05	0.36	0.55**
Straw P uptake	0.43*	-0.01	0.42*	0.65**
Total P uptake	0.48*	0.03	0.43*	0.66**
Dough stage				
	Total P	Organic P	Inorganic P	Olsen P
Grain yield (G)	0.30	-0.01	0.27	0.54**
Straw yield (S)	0.26	0.07	0.16	0.42*
Total (G+S)	0.29	0.06	0.19	0.49**
Grain P uptake	0.49*	0.12	0.30	0.66**
Straw P uptake	0.51**	0.21	0.23	0.62**
Total P uptake	0.56**	0.17	0.30	0.72**
After harvest				
	Total P	Organic P	Inorganic P	Olsen P
Grain yield (G)	0.29	0.25	-0.05	0.58**
Straw yield (S)	0.26	0.21	-0.03	0.40*
Total (G+S)	0.29	0.24	-0.03	0.48*
Grain P uptake	0.47*	0.27	0.07	0.69**
Straw P uptake	0.46*	0.45*	-0.14	0.60**
Total P uptake	0.51**	0.38*	-0.02	0.73**

* Significant at 5% level

** Significant at 1% level

Table 68. Relationship (r-value) of inorganic phosphorus (P) fractions of soil at different stages with wheat yield and P uptake at maturity

Heading stage						
	Lb.P	FeP	AlP	RSP	CaP	Res.P
Grain yield (G)	0.39*	0.21	0.32	0.49**	0.12	-0.03
Straw yield (S)	0.10	0.07	0.10	0.42*	0.18	-0.08
Total (G+S)	0.18	0.10	0.16	0.48*	0.18	-0.08
Grain P uptake	0.55**	0.12	0.57**	0.55**	0.36	-0.15
Straw P uptake	0.41*	0.18	0.47*	0.74**	0.33	-0.08
Total P uptake	0.55**	0.16	0.60**	0.71**	0.39*	-0.14
Dough stage						
	Lb.P	FeP	AlP	RSP	CaP	Res.P
Grain yield (G)	0.38*	0.23	0.45*	0.52**	0.34	-0.21
Straw yield (S)	0.15	0.17	0.29	0.39*	0.56**	-0.36
Total (G+S)	0.21	0.20	0.36	0.46*	0.58**	-0.37
Grain P uptake	0.55**	0.20	0.63**	0.66**	0.41*	-0.30
Straw P uptake	0.34	0.16	0.54**	0.62**	0.53**	-0.38*
Total P uptake	0.52**	0.20	0.66**	0.72**	0.51**	-0.37
After harvest						
	Lb.P	FeP	AlP	RSP	CaP	Res.P
Grain yield (G)	0.34	0.23	0.41*	0.09	0.33	-0.02
Straw yield (S)	0.33	-0.08	0.32	0.01	0.29	0.01
Total (G+S)	0.37	-0.02	0.38*	0.03	0.33	0.01
Grain P uptake	0.37	0.23	0.56**	0.20	0.48*	-0.13
Straw P uptake	0.45*	-0.07	0.50**	-0.01	0.36	0.24
Total P uptake	0.45*	0.12	0.60**	0.12	0.48*	0.03

Lb.P: Loosely bound P; FeP: Iron-P; AlP: Aluminum-P; RSP: Reductant-soluble P; CaP: Calcium-P;

Res.P: Residual P

* Significant at 5% level

** Significant at 1% level

Table 69. Relationship (r-value) of soil phosphorus (P) with mungbean yield and P uptake

Flowering stage				
	Total P	Organic P	Inorganic P	Olsen P
Grain yield (G)	0.14	0.12	0.04	0.44*
Stover yield (S)	0.26	0.26	0.01	0.52**
Root yield (R)	-0.26	-0.23	-0.07	0.10
Total (G+S+R)	0.20	0.20	-0.01	0.52**
Grain P uptake	0.22	0.16	0.14	0.53**
Stover P uptake	0.34	0.34	0.01	0.59**
Root P uptake	-0.18	-0.19	0.04	0.06
Total P uptake	0.32	0.31	0.03	0.62**
Before incorporation				
	Total P	Organic P	Inorganic P	Olsen P
Grain yield (G)	0.22	0.17	-0.01	0.36
Stover yield (S)	0.33	0.12	0.19	0.41*
Root yield (R)	0.03	-0.14	0.22	0.11
Total (G+S+R)	0.31	0.10	0.18	0.41*
Grain P uptake	0.26	0.17	0.03	0.44*
Stover P uptake	0.35	0.32	-0.08	0.50**
Root P uptake	0.06	-0.10	0.20	0.07
Total P uptake	0.36	0.31	-0.05	0.52**

* Significant at 5% level

** Significant at 1% level

Phosphorus uptake by both grain and stover was significantly influenced by LB-P at flowering stage as well as before incorporation of mungbean and with Al-P at the flowering stage. LB-P also influenced the stover ($r = 0.46^*$) and total yield ($r = 0.45^*$) at the flowering stage. Unlike wheat, Fe-P at the flowering stage was found to influence the grain yield and grain N uptake. Ca-P status of soil prior to incorporation of mungbean was found to have significant correlation with P uptake values. Negative correlation was observed of Res-P at both the stages with the stover and total P uptake. These results are depicted in Table 70.

4.3.1.2.3. Maize

Both yield and P uptake by maize were direct functions of total and Olsen P at silking, dough and at harvesting of maize (Table 71). However, the values of Olsen P determined at silking stage correlated better with both yield and uptake. Phosphorus uptake values were also found to bear significant relationship with the above two soil P parameters before sowing of maize. Organic P was not found to significantly influence these parameters while inorganic P at harvest of maize correlated with both yield and P uptake. Inorganic P during the silking stage significantly correlated with grain yield and P uptake by both grain and stover. Correlation could also be established between stover and total P uptake and total inorganic P values obtained before sowing and dough stage of maize.

As can be seen from Table 72, LB-P during all the growth stages of maize was found to influence both yield and P uptake. In contrast, Res-P of the soil at any of the growth stages did not influence these parameters. Leaving aside the first stage i.e. before sowing, Fe-P content of soil had highly significant correlation with all the yield parameters under study. Same was true for Al-P at silking and dough stages. Ca-P during dough stage and at harvest of maize was found to significantly correlate with both yield and P uptake. There was no consistency with respect to RS-P in influencing yield and P uptake by maize.

Table 70. Relationship (r-value) of inorganic phosphorus (P) fractions of soil at different stages with mungbean yield and P uptake at maturity

Flowering stage						
	Lb.P	FeP	AlP	RSP	CaP	Res.P
Grain yield (G)	0.34	0.49**	0.36	0.06	0.35	-0.35
Stover yield (S)	0.46*	0.28	0.34	0.10	0.22	-0.33
Root yield (R)	0.04	0.05	-0.08	-0.02	0.09	-0.07
Total (G+S+R)	0.45*	0.32	0.33	0.09	0.25	-0.34
Grain P uptake	0.47*	0.48*	0.43*	0.11	0.40*	-0.37
Stover P uptake	0.58**	0.30	0.53**	0.33	0.22	-0.46*
Root P uptake	0.15	-0.06	0.01	0.05	0.06	-0.04
Total P uptake	0.61**	0.34	0.54**	0.32	0.27	-0.47*
Before incorporation						
	Lb.P	FeP	AlP	RSP	CaP	Res.P
Grain yield (G)	0.32	0.26	0.31	0.15	0.46*	-0.31
Stover yield (S)	0.36	0.28	0.29	0.12	0.32	-0.13
Root yield (R)	0.10	-0.11	0.19	-0.07	-0.07	0.15
Total (G+S+R)	0.36	0.26	0.33	0.12	0.32	-0.14
Grain P uptake	0.39*	0.34	0.35	0.18	0.44*	-0.32
Stover P uptake	0.40*	0.29	0.37	0.34	0.38*	-0.41*
Root P uptake	0.07	-0.08	0.27	-0.06	-0.25	0.18
Total P uptake	0.43*	0.31	0.40*	0.33	0.40*	-0.41*

Lb.P: Loosely bound P; FeP: Iron-P; AlP: Aluminum-P; RSP: Reductant-soluble P; CaP: Calcium-P; Res.P: Residual P

* Significant at 5% level

** Significant at 1% level

Table 71. Relationship (r-value) of soil phosphorus (P) with maize yield and P uptake

Before sowing				
	Total P	Organic P	Inorganic P	Olsen P
Grain yield (G)	0.66	0.42	0.47	0.64
Straw yield (S)	0.70*	0.46	0.49	0.67*
Total (G+S)	0.69*	0.45	0.48	0.66
Grain P uptake	0.70*	0.40	0.53	0.69*
Straw P uptake	0.82**	0.23	0.81**	0.84**
Total P uptake	0.83**	0.38	0.70*	0.83**
Silking stage				
	Total P	Organic P	Inorganic P	Olsen P
Grain yield (G)	0.53**	0.03	0.28*	0.72**
Straw yield (S)	0.54**	0.16	0.16	0.62**
Total (G+S)	0.56**	0.12	0.21	0.68**
Grain P uptake	0.49**	-0.01	0.30**	0.66**
Straw P uptake	0.56**	-0.30**	0.51**	0.72**
Total P uptake	0.60**	-0.20	0.48**	0.79**
Dough stage				
	Total P	Organic P	Inorganic P	Olsen P
Grain yield (G)	0.50**	0.08	0.14	0.66**
Straw yield (S)	0.53**	0.09	0.14	0.54**
Total (G+S)	0.54**	0.09	0.15	0.60**
Grain P uptake	0.46**	0.07	0.13	0.63**
Straw P uptake	0.50**	-0.14	0.36**	0.70**
Total P uptake	0.54**	-0.06	0.30**	0.75**
After harvest				
	Total P	Organic P	Inorganic P	Olsen P
Grain yield (G)	0.49**	0.12	0.25*	0.67**
Straw yield (S)	0.53**	0.07	0.26*	0.57**
Total (G+S)	0.53**	0.09	0.27*	0.63**
Grain P uptake	0.44**	0.11	0.26*	0.64**
Straw P uptake	0.52**	0.03	0.45**	0.69**
Total P uptake	0.55**	0.08	0.41**	0.75**

* Significant at 5% level

** Significant at 1% level

Table 72. Relationship (r-value) of inorganic phosphorus (P) fractions of soil at different stages with maize yield and P uptake at maturity

Before sowing						
	Lb.P	FeP	AlP	RSP	CaP	Res.P
Grain yield (G)	0.75*	0.28	0.56	0.63	-0.19	0.11
Straw yield (S)	0.79*	0.31	0.61	0.66	-0.23	0.14
Total (G+S)	0.78*	0.30	0.59	0.65	-0.22	0.13
Grain P uptake	0.81**	0.41	0.59	0.77*	-0.33	0.27
Stover P uptake	0.82**	0.58	0.33	0.79*	-0.28	0.03
Total P uptake	0.89**	0.47	0.47	0.81**	0.01	0.12
Silking stage						
	Lb.P	FeP	AlP	RSP	CaP	Res.P
Grain yield (G)	0.60**	0.49**	0.54**	0.20	0.14	-0.14
Straw yield (S)	0.46**	0.31**	0.37**	0.23*	0.07	-0.17
Total (G+S)	0.53**	0.39**	0.45**	0.22*	0.09	-0.16
Grain P uptake	0.58**	0.51**	0.56**	0.10	0.22*	-0.11
Stover P uptake	0.62**	0.53**	0.63**	0.37**	0.22*	0.13
Total P uptake	0.68**	0.59**	0.68**	0.29**	0.25*	0.03
Dough stage						
	Lb.P	FeP	AlP	RSP	CaP	Res.P
Grain yield (G)	0.57**	0.51**	0.51**	-0.16	0.35**	-0.19
Straw yield (S)	0.48**	0.31**	0.35**	-0.07	0.26*	-0.09
Total (G+S)	0.53**	0.39**	0.42**	-0.11	0.30**	-0.13
Grain P uptake	0.55**	0.51**	0.51**	-0.18	0.38**	-0.20
Stover P uptake	0.61**	0.51**	0.63**	0.04	0.42**	-0.06
Total P uptake	0.66**	0.58**	0.66**	-0.06	0.46**	-0.13
After harvest						
	Lb.P	FeP	AlP	RSP	CaP	Res.P
Grain yield (G)	0.35**	0.47**	0.17	0.13	0.38**	-0.19
Straw yield (S)	0.22*	0.32**	0.04	0.14	0.30**	-0.05
Total (G+S)	0.28*	0.38**	0.09	0.14	0.34**	-0.10
Grain P uptake	0.37**	0.42**	0.19	0.19	0.40**	-0.18
Stover P uptake	0.56**	0.48**	0.43**	-0.07	0.43**	-0.09
Total P uptake	0.54**	0.52**	0.38**	0.04	0.46**	-0.15

Lb.P: Loosely bound P; FeP: Iron-P; AlP: Aluminum-P; RSP: Reductant-soluble P; CaP: Calcium-;

Res.P: Residual P

* Significant at 5% level

** Significant at 1% level

From Tables 68, 70 and 72, it can be seen that P uptake was consistently and positively correlated with LB-P fraction, followed by the Al-P fractions for the three crops. Hence, it can be suggested that these two fractions could be used as indicators of P availability in soil and P uptake by crops.

4.3.1.3. Interrelationship among different fractions of nitrogen and phosphorus in soil

4.3.1.3.1. Nitrogen

Wheat

Total N was found to be highly correlated with all the forms and fractions of N in soil at all the stages of wheat growth (Table 73), thereby pointing to a dynamic equilibrium among these forms. While some of the fractions (AIN and UIN) had an inverse relationship with total N, other forms were linked positively with total N. Acid insoluble N and UIN fraction of hydrolysable N were negatively correlated with all other forms of N in soils. All the hydrolysable N fractions were found to be significantly interdependent on each other.

Mungbean

As in case of wheat, all the hydrolysable N fractions were strongly correlated with one another during mungbean growth (Table 74). But AIN did not correlate with any of the hydrolysable N fractions and also with total N and $\text{KMnO}_4\text{-N}$. Both the mineral N fractions *viz.* $\text{NH}_4\text{-N}$ and $\text{NO}_3\text{-N}$, were found to be related to each other, and also to the total N, AIN and hydrolysable N fractions. Barring AIN, there existed a highly significant correlation between $\text{KMnO}_4\text{-N}$ and all other forms of N in soil during flowering stage and before incorporation of mungbean, the dependence on UIN being negative.

Maize

Before sowing of maize (Table 75) $\text{KMnO}_4\text{-N}$ was found to be a function of only the hydrolysable N fractions. The $\text{NH}_4\text{-N}$ fraction of mineral N was dependent on total

Table 73. Relationships (r-values) among nitrogen forms and fractions in soil during wheat growth

Heading stage										
	Av.N	NH ₄ -N	NO ₃ -N	Org.N	Hyd.N	AIN	AAN	ASN	NHN	UIN
Tot.N	0.75**	0.73**	0.82**	0.68**	0.82**	-0.56**	0.74**	0.81**	0.83**	-0.58**
Av.N	1.00	0.70**	0.73**	0.31	0.83**	-0.74**	0.79**	0.88**	0.81**	-0.59**
NH ₄ -N		1.00	0.73**	0.16	0.73**	-0.72**	0.80**	0.79**	0.77**	-0.63**
NO ₃ -N			1.00	0.18	0.79**	-0.76**	0.80**	0.84**	0.87**	-0.68**
Org.N				1.00	0.38*	0.07	0.18	0.27	0.29	-0.07
Hyd.N					1.00	-0.90**	0.81**	0.88**	0.85**	-0.46*
AIN						1.00	-0.78**	-0.81**	-0.77**	0.46*
AAN							1.00	0.93**	0.91**	-0.83**
ASN								1.00	0.92**	-0.75**
NHN									1.00	-0.84**
UIN										1.00
Dough stage										
	Av.N	NH ₄ -N	NO ₃ -N	Org.N	Hyd.N	AIN	AAN	ASN	NHN	UIN
Tot.N	0.61**	0.70**	0.76**	0.85**	0.80**	-0.42*	0.67**	0.76**	0.76**	-0.40*
Av.N	1.00	0.56**	0.43*	0.51**	0.71**	-0.52**	0.72**	0.67**	0.70**	-0.46*
NH ₄ -N		1.00	0.70**	0.34	0.82**	-0.77**	0.74**	0.63**	0.68**	-0.31
NO ₃ -N			1.00	0.33	0.68**	-0.61**	0.70**	0.67**	0.73**	-0.51**
Org.N				1.00	0.57**	-0.03	0.38*	0.57**	0.51**	-0.21
Hyd.N					1.00	-0.84**	0.84**	0.78**	0.82**	-0.33
AIN						1.00	-0.77**	-0.57**	-0.65**	0.26
AAN							1.00	0.91**	0.91**	-0.73**
ASN								1.00	0.88**	-0.74**
NHN									1.00	-0.79**
UIN										1.00
After harvest										
	Av.N	NH ₄ -N	NO ₃ -N	Org.N	Hyd.N	AIN	AAN	ASN	NHN	UIN
Tot.N	0.65**	0.35	0.59**	0.89**	0.57**	0.22	0.63**	0.62**	0.74**	-0.67**
Av.N	1.00	0.47*	0.54**	0.48*	0.64**	-0.18	0.73**	0.69**	0.81**	-0.74**
NH ₄ -N		1.00	0.65**	0.01	0.45*	-0.41*	0.66**	0.64**	0.58**	-0.62**
NO ₃ -N			1.00	0.18	0.67**	-0.45*	0.71**	0.84**	0.71**	-0.65**
Org.N				1.00	0.33	0.53**	0.36	0.29	0.51**	-0.44*
Hyd.N					1.00	-0.63**	0.83**	0.82**	0.79**	-0.54**
AIN						1.00	-0.45*	-0.50**	-0.29	0.12
AAN							1.00	0.90**	0.91**	-0.87**
ASN								1.00	0.87**	-0.81**
NHN									1.00	-0.93**
UIN										1.00

Tot. N: Total N; Av.N: Alkaline potassium permanganate oxidisable N; NH₄-N: Ammoniacal-N; NO₃-N: Nitrate-N; Org.N: Organic N; Hyd. N: Hydrolysable N; AIN: Acid insoluble N; AAN: Amino acid N; ASN: Amino sugar N; NHN: Ammonia N; UIN: Unidentified N

* Significant at 5% level

** Significant at 1% level

Table 74. Relationships (r-values) among nitrogen forms and fractions in soil during mungbean growth

Flowering stage										
	Av.N	NH ₄ -N	NO ₃ -N	Org.N	Hyd.N	AIN	AAN	ASN	NHN	UIN
Tot.N	0.66**	0.62**	0.67**	0.90**	0.77**	0.16	0.80**	0.79**	0.73**	-0.70**
Av.N	1.00	0.63**	0.54**	0.51**	0.63**	-0.12	0.67**	0.66**	0.72**	-0.65**
NH ₄ -N		1.00	0.87**	0.25	0.72**	-0.49**	0.61**	0.67**	0.68**	-0.53**
NO ₃ -N			1.00	0.31	0.72**	-0.43*	0.71**	0.77**	0.73**	-0.66**
Org.N				1.00	0.55**	0.49**	0.63**	0.58**	0.52**	-0.55**
Hyd.N					1.00	-0.46*	0.81**	0.85**	0.83**	-0.62**
AIN						1.00	-0.17	-0.27	-0.31	0.06
AAN							1.00	0.88**	0.88**	-0.94**
ASN								1.00	0.89**	-0.84**
NHN									1.00	-0.88**
UIN										1.00
Before incorporation										
	Av.N	NH ₄ -N	NO ₃ -N	Org.N	Hyd.N	AIN	AAN	ASN	NHN	UIN
Tot.N	0.66**	0.59**	0.47*	0.93**	0.74**	0.20	0.81**	0.85**	0.66**	-0.68**
Av.N	1.00	0.58**	0.53**	0.50**	0.76**	-0.27	0.78**	0.65**	0.66**	0.58**
NH ₄ -N		1.00	0.52**	0.34	0.71**	-0.38*	0.69**	0.71**	0.67**	-0.57**
NO ₃ -N			1.00	0.13	0.65**	-0.54**	0.57**	0.62**	0.51**	-0.40*
Org.N				1.00	0.53**	0.48*	0.65**	0.68**	0.49**	-0.58**
Hyd.N					1.00	-0.48*	0.79**	0.82**	0.77**	-0.49**
AIN						1.00	-0.14	-0.15	-0.29	-0.09
AAN							1.00	0.82**	0.79**	-0.86**
ASN								1.00	0.86**	-0.76**
NHN									1.00	-0.82**
UIN										1.00

N: Total N; Av.N: Alkaline potassium permanganate oxidisable N; NH₄-N: Ammoniacal-N; NO₃-N: Nitrate-N; Org.N: Organic N;
 N: Hydrolysable N; AIN: Acid insoluble N; AAN: Amino acid N; ASN: Amino sugar N; NHN: Ammonia N; UIN: Unidentified N
 Significant at 5% level
 Significant at 1% level

Table 75. Relationships (r-values) among nitrogen forms and fractions in soil during maize growth

Before sowing										
	Av.N	NH ₄ -N	NO ₃ -N	Org.N	Hyd.N	AIN	AAN	ASN	NHN	UIN
Tot.N	0.56	0.76*	0.59	0.98**	0.86**	0.49	0.87**	0.78*	0.59	-0.77*
Av.N	1.00	0.60	0.50	0.53	0.75*	-0.21	0.75*	0.88**	0.69*	-0.72*
NH ₄ -N		1.00	0.70*	0.67*	0.67*	0.19	0.72*	0.86**	0.74*	-0.75*
NO ₃ -N			1.00	0.53	0.73*	-0.18	0.76*	0.78*	0.50	-0.68*
Org.N				1.00	0.86**	0.53	0.88**	0.73*	0.59	-0.79*
Hyd.N					1.00	0.03	0.93**	0.90**	0.73*	-0.84**
AIN						1.00	0.18	-0.07	-0.07	-0.16
AAN							1.00	0.90**	0.74*	-0.95**
ASN								1.00	0.83**	-0.88**
NHN									1.00	-0.88**
UIN										1.00
Silking stage										
	Av.N	NH ₄ -N	NO ₃ -N	Org.N	Hyd.N	AIN	AAN	ASN	NHN	UIN
Tot.N	0.64**	0.74**	0.62**	0.84**	0.75**	-0.16	0.57**	0.68**	0.68**	-0.50**
Av.N	1.00	0.50**	0.74**	0.34**	0.81**	-0.60**	0.77**	0.79**	0.78**	-0.71**
NH ₄ -N		1.00	0.55**	0.38**	0.66**	-0.41**	0.55**	0.63**	0.66**	-0.52**
NO ₃ -N			1.00	0.16	0.76**	-0.68**	0.74**	0.72**	0.71**	-0.67**
Org.N				1.00	0.42**	0.30**	0.21	0.35**	0.35**	-0.17
Hyd.N					1.00	-0.74**	0.81**	0.88**	0.85**	-0.68**
AIN						1.00	-0.69**	-0.66**	-0.63**	0.59**
AAN							1.00	0.90**	0.82**	-0.96**
ASN								1.00	0.88**	-0.87**
NHN									1.00	-0.85**
UIN										1.00

N: Total N; Av.N: Alkaline potassium permanganate oxidisable N; NH₄-N: Ammoniacal-N; NO₃-N: Nitrate-N; Org.N: Organic N;
 .N: Hydrolysable N; AIN: Acid insoluble N; AAN: Amino acid N; ASN: Amino sugar N; NHN: Ammonia N; UIN: Unidentified N
 Significant at 5% level
 Significant at 1% level

N, NO₃-N, organic N and hydrolysable N fractions in the soil, whereas NO₃-N was dependent only on AAN, ASN and UIN fractions of hydrolysable N, with UIN being negatively correlated with NO₃-N. Similar to the growth stages of wheat and mungbean, the various hydrolysable N fractions were significantly correlated among one another. With a very few exceptions of total organic N and AIN all the forms and fractions of N were found to be interdependent in the remaining growth stages of maize *viz.* silking, dough stage and after harvest as can be seen from Tables 75 and 76.

4.3.1.3.2. Phosphorus

Wheat

At heading stage of wheat, total P was significantly correlated with organic P ($r = 0.47^*$), Olsen P ($r = 0.51^{**}$) and inorganic P fractions excluding Fe-P, Al-P and Res-P, as can be seen from Table 77. Organic P was found to bear a positive relationship with Ca-P ($r = 0.44^*$) and a negative relationship with Res-P ($r = -0.65^{**}$). Olsen P was a direct function of total P, total inorganic P and its fractions excluding Fe-P and Res-P. LB-P was a function of Olsen P ($r = 0.64^{**}$), Al-P ($r = 0.68^{**}$), RS-P ($r = 0.73^{**}$) and Ca-P ($r = 0.41^*$). Iron-P was only related with RS-P fraction ($r = 0.39^*$).

During dough stage, Olsen P was significantly correlated with all the forms and fractions of P, excluding organic P. Similar was the case with loosely bound P. Although inorganic P was negatively related to organic P, none of its fractions (with the lone exception of residual P, $r = -0.64^{**}$) were significantly related to the latter. Except RS-P and Res-P, all the other inorganic P fractions were significantly correlated with one another. At the harvesting stage, LB-P was directly and significantly related to total P, Olsen P, Al-P, Fe-P and Ca-P with the 'r' values of 0.49**, 0.86**, 0.82**, 0.47** and 0.85** respectively. Olsen P was related to Al-P ($r = 0.86^{**}$), Ca-P ($r = 0.82^{**}$) and total P ($r = 0.57^{**}$), other than LB-P. Aluminium bound P was related to all other inorganic P fractions with the exception of Res-P, which was found to bear a significant indirect relationship with RS-P alone ($r = -0.50^{**}$). Calcium bound P behaved similarly as Al-P at that stage.

Table 76. Relationships (r-values) among nitrogen forms and fractions in soil during maize growth

Dough stage										
	Av.N	NH ₄ -N	NO ₃ -N	Org.N	Hyd.N	AIN	AAN	ASN	NHN	UIN
Tot.N	0.65**	0.80**	0.63**	0.87**	0.68**	0.19	0.62**	0.75**	0.60**	-0.55**
Av.N	1.00	0.59**	0.55**	0.48**	0.75**	-0.27*	0.69**	0.69**	0.69**	-0.59**
NH ₄ -N		1.00	0.69**	0.47**	0.59**	-0.12	0.59**	0.71**	0.59**	-0.56**
NO ₃ -N			1.00	0.22*	0.59**	-0.37**	0.66**	0.63**	0.59**	-0.61**
Org.N				1.00	0.50**	0.49**	0.39**	0.53**	0.39**	-0.32**
Hyd.N					1.00	-0.51**	0.74**	0.74**	0.78**	-0.56**
AIN						1.00	-0.35**	-0.21	-0.39**	0.23*
AAN							1.00	0.86**	0.80**	-0.94**
ASN								1.00	0.81**	-0.85**
NHN									1.00	-0.82**
UIN										1.00
After harvest										
	Av.N	NH ₄ -N	NO ₃ -N	Org.N	Hyd.N	AIN	AAN	ASN	NHN	UIN
Tot.N	0.56**	0.60**	0.55**	0.92**	0.65**	0.32**	0.63**	0.70**	0.55**	-0.55**
Av.N	1.00	0.65**	0.55**	0.37**	0.76**	-0.33**	0.71**	0.57**	0.68**	-0.59**
NH ₄ -N		1.00	0.62**	0.32**	0.69**	-0.31**	0.62**	0.61**	0.70**	-0.55**
NO ₃ -N			1.00	0.21	0.61**	-0.34**	0.64**	0.55**	0.62**	-0.58**
Org.N				1.00	0.45**	0.59**	0.43**	0.55**	0.32**	-0.36**
Hyd.N					1.00	-0.46**	0.74**	0.73**	0.79**	-0.54**
AIN						1.00	-0.24*	-0.12	-0.40**	0.13
AAN							1.00	0.75**	0.75**	-0.93**
ASN								1.00	0.76**	-0.75**
NHN									1.00	-0.76**
UIN										1.00

N: Total N; Av.N: Alkaline potassium permanganate oxidisable N; NH₄-N: Ammoniacal-N; NO₃-N: Nitrate-N; Org.N: Organic N;
 N: Hydrolysable N; AIN: Acid insoluble N; AAN: Amino acid N; ASN: Amino sugar N; NHN: Ammonia N; UIN: Unidentified N
 Significant at 5% level
 Significant at 1% level

Table 77. Relationships (r-values) among phosphorus forms and fractions in soil during wheat growth

Heading stage										
	Tot.P	Org.P	Inorg.P	Ol.P	Lb.P	FeP	AlP	RSP	CaP	ResP
Tot.P	1.00	0.47*	0.51**	0.51**	0.46**	0.18	0.37	0.41*	0.52**	-0.08
Org.P		1.00	-0.52**	0.01	-0.07	-0.29	-0.21	-0.26	0.44*	-0.65**
Inorg.P			1.00	0.49**	0.51**	0.46**	0.56**	0.65**	0.07	0.56**
Ol.P				1.00	0.64**	0.27	0.71**	0.68**	0.52**	-0.21
Lb.P					1.00	0.34	0.68**	0.73**	0.41*	-0.13
FeP						1.00	0.21	0.39*	0.08	0.15
AlP							1.00	0.69**	0.36	-0.07
RSP								1.00	0.28	0.04
CaP									1.00	-0.75**
ResP										1.00
Dough stage										
	Tot.P	Org.P	Inorg.P	Ol.P	Lb.P	FeP	AlP	RSP	CaP	ResP
Tot.P	1.00	0.55**	0.27	0.59**	0.55**	0.48*	0.56**	0.59**	0.47*	-0.37
Org.P		1.00	-0.66**	0.06	0.08	0.07	-0.10	0.15	0.16	-0.64**
Inorg.P			1.00	0.45*	0.40*	0.35	0.62**	0.36	0.23	0.40*
Ol.P				1.00	0.83**	0.50**	0.91**	0.90**	0.74**	-0.53**
Lb.P					1.00	0.48*	0.86**	0.83**	0.60**	-0.49**
FeP						1.00	0.50**	0.36	0.54**	-0.37
AlP							1.00	0.85**	0.60**	-0.33
RSP								1.00	0.71**	-0.57**
CaP									1.00	-0.76**
ResP										1.00
After harvest										
	Tot.P	Org.P	Inorg.P	Ol.P	Lb.P	FeP	AlP	RSP	CaP	ResP
Tot.P	1.00	0.50**	0.24	0.57**	0.49**	0.19	0.53**	0.36	0.36	-0.25
Org.P		1.00	-0.72**	0.11	0.01	-0.17	-0.17	-0.33	-0.23	0.03
Inorg.P			1.00	0.33	0.39*	0.37	0.61**	0.65**	0.55**	-0.23
Ol.P				1.00	0.86**	0.37	0.86**	0.36	0.82**	-0.11
Lb.P					1.00	0.47*	0.82**	0.27	0.85**	-0.12
FeP						1.00	0.42*	0.09	0.44*	-0.03
AlP							1.00	0.39*	0.88**	-0.04
RSP								1.00	0.40*	-0.50**
CaP									1.00	-0.31
ResP										1.00

Tot. P: Total P; Org.P: Organic P; Inorg.P: Inorganic P; Ol.P: Olsen P; Lb.P: Loosely bound P; FeP: Iron-P;

AlP: Aluminum-P; RSP: Reductant-soluble P; CaP: Calcium-P; Res.P: Residual P

* Significant at 5% level

** Significant at 1% level

Mungbean

At the flowering stage of mungbean (Table 78) both Olsen P and loosely bound P were found to correlate significantly with all the forms and fractions of P except total inorganic P. LB-P, Fe-P and Al-P correlated significantly among themselves and all other inorganic P fractions. The same was the case with Res-P, which exhibited negative relationship with other P fractions. Ca-P was related only with Olsen P ($r = 0.57^{**}$), LB-P ($r = 0.38^*$) and Fe-P ($r = 0.46^{**}$).

Before incorporation of mungbean, Olsen P was significantly correlated with all the inorganic P fractions, besides total P ($r = 0.63^{**}$). The same was true with LB-P. Leaving aside RS-P, both Al-P and Fe-P were significantly correlated with the other inorganic P fractions. At this stage, Ca-P was found to be significantly related with all the inorganic P fractions.

Maize

Before sowing of maize (Table 79), Ca-P and Res-P did not exhibit any correlation with any of the forms and fractions of P, Olsen P was directly related to total P ($r = 0.95^{**}$), inorganic P ($r = 0.90^{**}$), LB-P ($r = 0.94^{**}$), Al-P ($r = 0.70^*$) and RS-P ($r = 0.91^{**}$). Iron bound P correlated significantly with Al-P ($r = 0.67^*$) and RS-P ($r = 0.76^*$). During silking stage, Olsen P and LB-P were found to correlate with all the forms and fractions of P barring Res-P. Phosphorus bound to Fe, Al and Ca were found to be interrelated to one another and also with other inorganic P fractions except RS-P and Res-P (in case of Fe-P and Al-P only). Inorganic P was significantly related with all the P forms and fractions. The behaviour of Al-P, Fe-P and Ca-P during dough stage of maize (Table 80) with respect to their relationships with all other forms and fractions of P was similar to that during silking stage. While Olsen P and LB-P did not correlate significantly with RS-P during the dough stage, they correlated with the same fractions at the silking stage. Olsen P and LB-P content of soil analyzed after the harvest of maize behaved almost similarly as that in the dough stage with respect to different forms and

Table 78. Relationships (r-values) among phosphorus forms and fractions in soil during mungbean growth

Flowering stage										
	Tot.P	Org.P	Inorg.P	Ol.P	Lb.P	FeP	AlP	RSP	CaP	ResP
Tot.P	1.00	0.91**	0.20	0.55**	0.50**	0.35	0.48*	0.27	0.31	-0.34
Org.P		1.00	-0.22	0.48*	0.40*	0.30	0.38*	0.21	0.31	-0.51**
Inorg.P			1.00	0.17	0.22	0.13	0.23	0.13	-0.01	0.41*
Ol.P				1.00	0.86**	0.70**	0.78**	0.55**	0.57**	-0.73**
Lb.P					1.00	0.70**	0.84**	0.43*	0.38*	-0.63**
FeP						1.00	0.73**	0.52**	0.46*	-0.68**
AlP							1.00	0.46*	0.34	-0.62**
RSP								1.00	0.18	-0.52**
CaP									1.00	-0.68**
ResP										1.00
Before incorporation										
	Tot.P	Org.P	Inorg.P	Ol.P	Lb.P	FeP	AlP	RSP	CaP	ResP
Tot.P	1.00	0.68**	0.09	0.63**	0.68**	0.59**	0.41*	0.30	0.52**	-0.40*
Org.P		1.00	-0.67**	0.32	0.44*	0.41*	0.07	0.17	0.46*	-0.77**
Inorg.P			1.00	0.20	0.08	0.05	0.32	0.07	-0.11	0.64**
Ol.P				1.00	0.94**	0.72**	0.66**	0.57**	0.78**	-0.57**
Lb.P					1.00	0.72**	0.60**	0.50**	0.78**	-0.63**
FeP						1.00	0.57**	0.20	0.68**	-0.53**
AlP							1.00	0.33	0.55**	-0.35
RSP								1.00	0.40*	-0.45*
CaP									1.00	-0.76**
ResP										1.00

Tot. P: Total P; Org.P: Organic P; Inorg.P: Inorganic P; Ol.P: Olsen P; Lb.P: Loosely bound P; FeP: Iron-P; AlP: Aluminum-P; RSP: Reductant-soluble P; CaP: Calcium-P; Res.P: Residual P

* Significant at 5% level

** Significant at 1% level

Table 79. Relationships (r-values) among phosphorus forms and fractions in soil during maize growth

Before sowing										
	Tot.P	Org.P	Inorg.P	Ol.P	Lb.P	FeP	AlP	RSP	CaP	ResP
Tot.P	1.00	0.53	0.79*	0.95**	0.95**	0.43	0.57	0.89**	0.07	0.12
Org.P		1.00	-0.09	0.31	0.46	-0.10	-0.33	0.27	-0.47	0.15
Inorg.P			1.00	0.90**	0.78*	0.58	0.92**	0.85**	0.42	0.03
Ol.P				1.00	0.94**	0.44	0.70*	0.91**	0.16	0.21
Lb.P					1.00	0.41	0.58	0.94**	-0.07	0.26
FeP						1.00	0.67*	0.76*	0.37	0.01
AlP							1.00	0.46	0.21	-0.29
RSP								1.00	-0.08	0.31
CaP									1.00	-0.68*
ResP										1.00
Silking stage										
	Tot.P	Org.P	Inorg.P	Ol.P	Lb.P	FeP	AlP	RSP	CaP	ResP
Tot.P	1.00	0.15	0.37**	0.85**	0.66**	0.38**	0.46**	0.38**	0.08	0.03
Org.P		1.00	-0.80**	-0.04	-0.25*	-0.34**	-0.35**	-0.30**	-0.29**	-0.67**
Inorg.P			1.00	0.44**	0.54**	0.45**	0.52**	0.45**	0.28*	0.62**
Ol.P				1.00	0.81**	0.63**	0.66**	0.36**	0.24*	-0.03
Lb.P					1.00	0.64**	0.73**	0.36**	0.25*	0.05
FeP						1.00	0.71**	0.21	0.33**	-0.04
AlP							1.00	0.20	0.34**	-0.02
RSP								1.00	-0.12	0.07
CaP									1.00	-0.23*
ResP										1.00

Tot. P: Total P; Org.P: Organic P; Inorg.P: Inorganic P; Ol.P: Olsen P; Lb.P: Loosely bound P; FeP: Iron-P; AlP: Aluminum-P; RSP: Reductant-soluble P; CaP: Calcium-P; Res.P: Residual P

* Significant at 5% level

** Significant at 1% level

Table 80. Relationships (r-values) among phosphorus forms and fractions in soil during maize growth

Dough stage										
	Tot.P	Org.P	Inorg.P	Ol.P	Lb.P	FeP	AlP	RSP	CaP	ResP
Tot.P	1.00	0.25*	0.20	0.72**	0.74**	0.33**	0.43**	0.21	0.13	-0.15
Org.P		1.00	-0.90**	-0.03	-0.05	-0.25*	-0.23*	-0.56**	-0.40**	-0.69**
Inorg.P			1.00	0.35**	0.38**	0.40**	0.42**	0.67**	0.46**	0.63**
Ol.P				1.00	0.80**	0.58**	0.71**	0.07	0.38**	-0.12
Lb.P					1.00	0.49**	0.68**	0.09	0.38**	-0.08
FeP						1.00	0.65**	0.01	0.66**	-0.21
AlP							1.00	0.07	0.45**	-0.15
RSP								1.00	0.03	0.35**
CaP									1.00	-0.21
ResP										1.00
After harvest										
	Tot.P	Org.P	Inorg.P	Ol.P	Lb.P	FeP	AlP	RSP	CaP	ResP
Tot.P	1.00	0.27*	0.23*	0.82**	0.47**	0.25*	0.15	0.02	0.21	-0.01
Org.P		1.00	-0.47**	0.16	0.03	-0.03	-0.11	-0.33**	-0.22*	-0.19
Inorg.P			1.00	0.33**	0.32**	0.30**	0.31**	0.12	0.40**	0.57**
Ol.P				1.00	0.55**	0.35**	0.36**	0.09	0.33**	-0.09
Lb.P					1.00	0.30**	0.37**	-0.06	0.54**	-0.18
FeP						1.00	0.59**	-0.12	0.19	-0.19
AlP							1.00	-0.12	0.14	-0.22*
RSP								1.00	0.09	-0.16
CaP									1.00	-0.29**
ResP										1.00

Tot. P: Total P; Org.P: Organic P; Inorg.P: Inorganic P; Ol.P: Olsen P; Lb.P: Loosely bound P; FeP: Iron-P; AlP: Aluminum-P; RSP: Reductant-soluble P; CaP: Calcium-P; Res.P: Residual P

* Significant at 5% level

** Significant at 1% level

fractions of P in soil. Unlike dough stage, Al-P and Fe-P after harvest of maize did not correlate with organic P and Ca-P, rest of the relationship remaining the same.

4.3.2. Regression analysis

4.3.2.1. Nitrogen

4.3.2.1.1. Wheat

Ammoniacal-N, ASN and UIN contents of soil at heading stage of wheat could explain the variation in wheat yield to the extent of 45.2%, as could be inferred from the R^2 value in Table 81. Ammonia-N was the only fraction that was found to influence straw and total yield of wheat to the extent of 40.0% and 46.0%, respectively. The same fraction determined at harvest of wheat was found to influence the grain, straw and total yield to the extent of 30.6, 38.6 and 44.3%, respectively. At the same stage, inclusion of UIN fraction in the regression equation increased the predictability of straw and total yield to 46.1 and 50.5%, respectively. At the dough stage of wheat ASN fractions of soil organic N could predict the grain yield to the extent of 33.1%, which was increased to 42.9% by the inclusion of $\text{NH}_4\text{-N}$ and AIN fractions. Like the other two stages NHN explained the straw and total yield of wheat upto 38.6% and 44.3% respectively.

The amount of N taken up by wheat could be better explained by the soil nitrogen pools determined at the heading stage as compared to dough stage or at harvest (Table 82). Nitrogen uptake by wheat grain was explained to the tune of 34.0% by the AIN fraction, while the predictability increased to 38.5% by the inclusion of $\text{NH}_4\text{-N}$. In case of straw, NHN, AAN, UIN and AIN, together accounted for 59.9% variability in N uptake. Only ASN could predict total N uptake by wheat to the extent of 50.7%.

Fluctuation in $\text{KMnO}_4\text{-N}$ of soil could be better explained by the N pools determined at heading stage of wheat (Table 83). During this stage, ASN could predict $\text{KMnO}_4\text{-N}$ variation to the extent of 77.8%, which went slightly up to 78.9% on including UIN. During the dough stage, only AAN was found to influence $\text{KMnO}_4\text{-N}$ ($R^2 = 0.512^{**}$), while only NHN could explain the variability in $\text{KMnO}_4\text{-N}$ after the harvest of wheat ($R^2 = 0.663^{**}$).

Table 81. Stepwise linear regression equations of wheat yield at maturity with soil nitrogen fractions at different stages of crop growth

Stage	Regression equation	R ²
Heading		
Grain (G):	$Y = 35.179 + 1.333X_5$	0.388**
	$Y = 8.910 + 1.806X_5 + 0.135X_7$	0.425**
	$Y = 8.575 + 1.381X_5 + 0.145X_7 + 0.596X_1$	0.452**
Straw (S):	$Y = -46.987 + 1.200X_6$	0.400**
Total (G + S):	$Y = -21.424 + 1.455X_6$	0.460**
Dough		
Grain (G):	$Y = 35.568 + 1.397X_5$	0.331**
	$Y = 36.115 + 0.993X_5 + 0.638X_1$	0.372**
	$Y = 3.753 + 1.123X_5 + 1.264X_1 + 0.191X_3$	0.429**
Straw (S)	$Y = -48.826 + 1.177X_6$	0.386**
	$Y = 77.636 + 0.813X_6 - 0.606X_3$	0.435**
Total (G + S):	$Y = -23.312 + 1.425X_6$	0.443**
	$Y = 85.532 + 1.111X_6 - 0.521X_3$	0.472**
After harvest		
Grain (G):	$Y = 25.239 + 0.256X_6$	0.306**
Straw (S):	$Y = -44.116 + 1.177X_6$	0.386**
	$Y = -363.601 + 2.445X_6 + 1.181X_7$	0.461**
Total (G + S):	$Y = -17.612 + 1.425X_6$	0.443**
	$Y = -346.729 + 2.731 X_6 + 1.216 X_7$	0.505**

X₁ = Ammonium-N, X₂ = Nitrate-N, X₃ = Acid insoluble-N, X₄ = Amino acid-N, X₅ = Amino sugar-N, X₆ = Ammonia-N and X₇ = Unidentified hydrolysable-N

* Significant at 5% level

** Significant at 1% level

Table 82. Stepwise linear regression equations of nitrogen uptake by wheat at maturity with soil nitrogen fractions at different stages of crop growth

Stage	Regression equation	R ²
Heading		
Grain (G):	$Y = 177.009 - 0.590X_3$	0.340**
	$Y = 133.194 - 0.370X_3 + 1.406X_1$	0.385**
Straw (S):	$Y = -56.717 + 0.649X_6$	0.531**
	$Y = -97.650 + 0.349X_6 + 0.582X_4$	0.556**
	$Y = -168.387 + 0.456X_6 + 0.762X_4 + 0.238X_7$	0.575**
	$Y = -342.654 + 0.690X_6 + 1.232X_4 + 0.506X_7 + 0.337X_3$	0.599**
Total (G + S):	$Y = 32.010 + 5.551X_5$	0.507**
Dough		
Grain (G):	$Y = 31.983 - 0.512X_6$	0.277**
Straw (S):	$Y = -132.691 + 1.138X_4$	0.528**
	$Y = -94.970 + 0.773X_4 + 1.473X_1$	0.574**
Total (G + S):	$Y = -24.525 + 1.141X_6$	0.459**
	$Y = -4.374 + 0.814X_6 + 2.522X_2$	0.503**
After harvest		
Grain (G):	$Y = 34.033 + 0.512X_6$	0.277**
Straw (S):	$Y = -129.277 + 1.138X_4$	0.528**
Total (G + S):	$Y = -19.961 + 1.141X_6$	0.459**

X₁ = Ammonium-N, X₂ = Nitrate-N, X₃ = Acid insoluble-N, X₄ = Amino acid-N, X₅ = Amino sugar-N, X₆ = Ammonia-N and X₇ = Unidentified hydrolysable-N

* Significant at 5% level

** Significant at 1% level

Table 83. Stepwise linear regression equations of alkaline potassium permanganate (KMnO₄) oxidisable nitrogen of soil with nitrogen fractions at different stages of wheat growth

Stage	Regression equation	R ²
<i>Heading</i>		
	$Y = 36.293 + 3.388X_5$	0.778**
	$Y = 10.844 + 3.846X_5 + 0.131X_7$	0.789**
<i>Dough</i>		
	$Y = -25.110 + 0.779X_4$	0.512**
<i>After harvest</i>		
	$Y = 51.940 + 0.212X_6$	0.663**

X₁ = Ammonium-N, X₂ = Nitrate-N, X₃ = Acid insoluble-N, X₄ = Amino acid-N, X₅ = Amino sugar-N, X₆ = Ammonia-N and X₇ = Unidentified hydrolysable-N, Y = Alkaline potassium permanganate (KMnO₄) oxidisable nitrogen

* Significant at 5% level

** Significant at 1% level

4.3.2.1.2 Mungbean

None of the nitrogen pools were found to predict mungbean yield, which could be explained by the fact that mungbean, being a legume fixes nitrogen, and does not entirely depend on soil N for fulfilling its N demands. Nitrogen uptake was dependent on a few soil N fractions, but the R^2 values were significant only for stover and root N uptake (Table 84). Better prediction could be made with respect to N uptake with the soil nitrogen pools determined before incorporation of mungbean. Only 20.3 and 22.5% variability in stover and total N uptake, respectively could be explained by AAN fraction of hydrolysable organic N. Root N uptake could be predicted with the help of $\text{NH}_4\text{-N}$ only ($R^2 = 0.267^{**}$) before incorporation of mungbean.

During the flowering stage of mungbean, NHN could explain the fluctuation in $\text{KMnO}_4\text{-N}$ to the extent of 51.7%, as is evident from Table 85. Inclusion of $\text{NH}_4\text{-N}$, AIN and $\text{NO}_3\text{-N}$ increased the predictability to 61.7%. The variability in $\text{KMnO}_4\text{-N}$ was predicted better when the regression was carried out with the soil N pools before incorporation of mungbean. Three N fractions, viz. AAN, UIN and NHN could explain the variability to the tune of 66.4%.

4.3.2.1.3 Maize

Table 86 shows the equations regressing maize yield with soil nitrogen pools before sowing of maize and during the silking stage. The R^2 values obtained during both the stages indicate that better prediction of yield could be made with soil N values before sowing of maize. While grain yield was predicted to the tune of 97.3% with the help of UIN, $\text{NH}_4\text{-N}$, ASN, $\text{NO}_3\text{-N}$ and NHN fractions of soil N, variability in stover yield could be explained by three fractions viz. UIN, $\text{NH}_4\text{-N}$ and ASN ($R^2 = 0.925^{**}$). The predictability of grain and stover yield could be made with the help of different N fractions to the extent of 76.6 and 60.3%, respectively during silking stage of maize, which remained more or less constant or decreased at dough stage and at harvest of maize (Table 87). Total yield of maize, predicted to the extent of 93.6% with the help of UIN, $\text{NH}_4\text{-N}$ and ASN before sowing of maize (Table 86), was influenced by all the N fractions ($\text{NH}_4\text{-N}$, $\text{NO}_3\text{-N}$, AIN, AAN, ASN, NHN and UIN) at maize harvest (Table 87) but the predictability was lower ($R^2 = 0.672^{**}$).

Table 84. Stepwise linear regression equations of nitrogen uptake by mungbean at maturity with soil nitrogen fractions at different stages of crop growth

Stage	Regression equation	R ²
<i>Flowering stage</i>		
Stover (S):	$Y = 48.808 + 0.532X_4$	0.168*
Root (R):	$Y = 12.935 - 0.048X_7$	0.191*
Total (G + S + R):	$Y = 71.370 + 0.629X_4$	0.196*
<i>Before incorporation</i>		
Stover (S):	$Y = 23.183 + 0.707X_4$	0.206*
Root (R):	$Y = 3.000 + 0.429X_1$	0.267**
Total (G + S + R):	$Y = 45.131 + 0.808X_4$	0.225*

X₁ = Ammonium-N, X₂ = Nitrate-N, X₃ = Acid insoluble-N, X₄ = Amino acid-N, X₅ = Amino sugar-N, X₆ = Ammonia-N and X₇ = Unidentified hydrolysable-N

* Significant at 5% level

** Significant at 1% level

Table 85. Stepwise linear regression equations of alkaline potassium permanganate (KMnO₄) oxidisable nitrogen of soil with nitrogen fractions at different stages of mungbean growth

Stage	Regression equation	R ²
<i>Flowering stage</i>		
	$Y = 31.755 + 0.361X_6$	0.517**
	$Y = 39.294 + 0.274X_6 + 0.486X_1$	0.552**
	$Y = 21.240 + 0.270X_6 + 0.709X_1 + 0.094X_3$	0.591**
	$Y = 21.904 + 0.315 X_6 + 1.163 X_1 + 0.092 X_3$ $- 0.319X_2$	0.617**
<i>Before incorporation</i>		
	$Y = 42.088 + 0.272X_4$	0.603**
	$Y = 10.729 + 0.383X_4 + 0.119X_7$	0.638**
	$Y = -13.513 + 0.348X_4 + 0.169X_7 + 0.176X_6$	0.664**

X₁ = Ammonium-N, X₂ = Nitrate-N, X₃ = Acid insoluble-N, X₄ = Amino acid-N, X₅ = Amino sugar-N, X₆ = Ammonia-N and X₇ = Unidentified hydrolysable-N, Y = Alkaline potassium permanganate (KMnO₄) oxidisable nitrogen

* Significant at 5% level

** Significant at 1% level

Table 86. Stepwise linear regression equations of maize yield at maturity with soil nitrogen fractions at different stages of crop growth

Stage	Regression equation	R ²
Before sowing		
Grain (G):	$Y = 57.154 - 0.233X_7$	0.873**
	$Y = 44.737 - 0.186X_7 + 0.563X_1$	0.901**
	$Y = 26.040 - 0.144X_7 + 0.759X_1 + 0.436X_5$	0.941**
	$Y = 32.736 - 0.156X_7 + 0.933X_1 + 0.474X_5 - 0.529X_2$	0.954**
	$Y = 67.259 - 0.227X_7 + 1.122X_1 + 0.442X_5 - 0.794X_2$ $-0.158X_6$	0.973*
Stover (S):	$Y = 105.889 - 0.399X_7$	0.794**
	$Y = 67.833 - 0.253X_7 + 1.727X_1$	0.876**
	$Y = 30.908 - 0.171X_7 + 2.112X_1 + 0.862X_5$	0.925**
Total (G + S):	$Y = 162.856 - 0.631X_7$	0.829**
	$Y = 111.984 - 0.436X_7 + 2.308X_1$	0.890**
	$Y = 56.492 - 0.312X_7 + 2.887X_1 + 1.295X_5$	0.936**
Silking		
Grain (G):	$Y = -34.301 + 0.457X_6$	0.661**
	$Y = -29.168 + 0.320X_6 + 0.091X_4$	0.690**
	$Y = -53.462 + 0.348X_6 + 0.132X_4 + 0.121X_3$	0.725**
	$Y = -122.469 + 0.443X_6 + 0.317X_4 + 0.174X_3 + 0.189X_7$	0.756**
	$Y = -116.556 + 0.415X_6 + 0.288X_4 + 0.186X_3 + 0.172X_7$ $+0.147X_2$	0.762**
	$Y = -108.810 + 0.379X_6 + 0.274X_4 + 0.180X_3 + 0.157X_7$ $+0.132X_2 + 0.136X_1$	0.766**
Stover (S):	$Y = -42.691 + 0.725X_6$	0.499**
	$Y = -98.328 + 0.916X_6 + 0.252X_3$	0.553**
	$Y = -101.594 + 0.778X_6 + 0.344X_3 + 0.594X_2$	0.585**
	$Y = -96.035 + 0.653X_6 + 0.363X_3 + 0.548X_2 + 0.465X_5$	0.591**
	$Y = -131.463 + 0.747X_6 + 0.368X_3 + 0.569X_2 + 0.816X_5$ $+0.120X_7$	0.603**
Total (G + S):	$Y = -77.064 + 1.183X_6$	0.595**
	$Y = -146.755 + 1.423X_6 + 0.315X_3$	0.632**
	$Y = -151.689 + 1.214X_6 + 0.455X_3 + 0.897X_2$	0.665**
	$Y = -139.344 + 0.937X_6 + 0.496X_3 + 0.795X_2 + 1.033X_5$	0.678**
	$Y = -171.631 + 1.022X_6 + 0.501X_3 + 0.815X_2 + 1.353X_5$ $+0.109X_7$	0.682**

X_1 = Ammonium-N, X_2 = Nitrate-N, X_3 = Acid insoluble-N, X_4 = Amino acid-N, X_5 = Amino sugar-N, X_6 = Ammonia-N and X_7 = Unidentified hydrolysable-N

* Significant at 5% level

** Significant at 1% level

Table 87. Stepwise linear regression equations of maize yield at maturity with soil nitrogen fractions at different stages of crop growth

Stage	Regression equation	R ²
<i>Dough</i>		
Grain (G):	$Y = 2.524 + 1.211X_5$	0.598**
	$Y = -23.241 + 0.689X_5 + 0.278X_6$	0.655**
	$Y = -21.220 + 0.421X_5 + 0.272X_6 + 0.334X_1$	0.686**
	$Y = -39.387 + 0.351X_5 + 0.343X_6 + 0.320X_1 + 0.082X_3$	0.705**
	$Y = -43.594 + 0.039X_5 + 0.299X_6 + 0.335X_1 + 0.102X_3 + 0.095X_4$	0.724**
	$Y = -119.828 + 0.430X_6 + 0.289X_1 + 0.162X_3 + 0.290X_4 + 0.198X_7$	0.764**
Stover (S):	$Y = 15.372 + 1.932X_5$	0.457**
	$Y = 18.578 + 1.343X_5 + 0.708X_1$	0.499**
	$Y = -14.503 + 0.686X_5 + 0.693X_1 + 0.356X_6$	0.527*
	$Y = -62.390 + 0.502X_5 + 0.656X_1 + 0.541X_6 + 0.215X_3$	0.568*
	$Y = -91.660 + 0.797X_5 + 0.614X_1 + 0.631X_6 + 0.222X_3 + 0.088X_7$	0.574*
	$Y = 17.817 + 3.147X_5$	0.543*
Total (G + S):	$Y = 22.568 + 2.275X_5 + 1.050X_1$	0.584**
	$Y = -35.881 + 1.114X_5 + 1.022X_1 + 0.629X_6$	0.623**
	$Y = -101.812 + 0.860X_5 + 0.972X_1 + 0.884X_6 + 0.297X_3$	0.657**
<i>After harvest</i>		
Grain (G):	$Y = -7.630 + 0.250X_4$	0.588**
	$Y = -33.738 + 0.154X_4 + 0.308X_6$	0.658**
	$Y = -79.737 + 0.290X_4 + 0.362X_6 + 0.155X_7$	0.688**
	$Y = -136.045 + 0.356X_4 + 0.500X_6 + 0.246X_7 + 0.127X_3$	0.740**
	$Y = -129.743 + 0.326X_4 + 0.463X_6 + 0.236X_7 + 0.135X_3 + 0.230X_2$	0.754**
	$Y = -119.997 + 0.302X_4 + 0.382X_6 + 0.237X_7 + 0.116X_3$	
Stover (S):	$+ 0.217X_2 + 0.327X_5$	0.766**
	$Y = 14.475 + 2.033X_5$	0.446**
	$Y = 15.198 + 1.557X_5 + 0.978X_1$	0.488**
	$Y = -6.179 + 1.306X_5 + 0.750X_1 + 0.221X_6$	0.496**
	$Y = -44.396 + 1.583X_5 + 0.727X_1 + 0.356X_6 + 0.120X_7$	0.512**
	$Y = -86.036 + 1.414X_5 + 0.798X_1 + 0.534X_6 + 0.144X_7 + 0.133X_3$	0.530**
Total (G + S)	$Y = -191.328 + 1.224X_5 + 0.493X_1 + 0.653X_6 + 0.437X_7$	
	$+ 0.199X_3 + 0.354X_4$	0.565**
	$Y = -189.609 + 1.210X_5 + 0.366X_1 + 0.638X_6 + 0.435X_7$	
	$+ 0.211X_3 + 0.329X_4 + 0.298X_2$	0.572**
	$Y = 16.936 + 3.283X_5$	0.520**
	$Y = 18.130 + 2.496X_5 + 1.616X_1$	0.571**
	$Y = -27.162 + 1.964X_5 + 1.133X_1 + 0.468X_6$	0.587**
	$Y = -67.552 + 1.694X_5 + 1.223X_1 + 0.647X_6 + 0.159X_3$	0.599**
	$Y = -65.671 + 1.568X_5 + 0.941X_1 + 0.587X_6 + 0.185X_3 + 0.571X_2$	0.611**
	$Y = -124.710 + 1.861X_5 + 0.864X_1 + 0.790X_6 + 0.222X_3$	
	$+ 0.702X_2 + 0.161X_7$	0.622**
	$Y = -307.457 + 1.543X_5 + 0.419X_1 + 1.006X_6 + 0.328X_3$	
	$+ 0.508X_2 + 0.668X_7 + 0.628X_4$	0.672**

X₁ = Ammonium-N, X₂ = Nitrate-N, X₃ = Acid insoluble-N, X₄ = Amino acid-N, X₅ = Amino sugar-N,
X₆ = Ammonia-N and X₇ = Unidentified hydrolysable-N

* Significant at 5% level

** Significant at 1% level

As in case of maize yield, N uptake by maize could be explained better (higher R^2 values) by the soil N fractions determined before sowing of maize, as compared to the other three stages, viz. silking, dough and at harvest. Nitrogen uptake by maize grain was explained by UIN and NHN determined before sowing of maize to the extent of 93.8% (Table 88). The same two fractions, along with ASN could explain the variability in total N uptake by maize ($R^2 = 0.897$). But stover N uptake was influenced by AAN and ASN ($R^2 = 0.765$). Although grain N uptake was predicted by four N fractions determined at silking stage of maize viz., $\text{NH}_4\text{-N}$, AIN, AAN, NHN, as compared to two before sowing, the R^2 value was lower in the former stage as compared to the latter (0.810** as compared to 0.938**). Similar was the case with stover and total N uptake, with respect to predictability differences between the two stages. Although various nitrogen fractions determined at the dough stage and at harvest of maize were found to influence N uptake by maize, the predictability values were lower as compared to the first two stages (before sowing and silking). This can be inferred by comparing the R^2 values in Table 88 and 89.

The fractions AAN, AIN, $\text{NO}_3\text{-N}$ and $\text{NH}_4\text{-N}$ were found to predict the fluctuations in $\text{KMnO}_4\text{-N}$ to the extent of 93.5% before sowing of wheat (Table 90). During the subsequent stages the R^2 values were found to decrease. For example, four N fractions, viz. ASN, $\text{NO}_3\text{-N}$, NHN and $\text{NH}_4\text{-N}$ were found to influence $\text{KMnO}_4\text{-N}$ content of soil at silking stage of maize, but the R^2 value (0.698**) was lower than that obtained before sowing of maize. The value came down to 0.650**, after harvest of maize, with the predictors being AAN, $\text{NH}_4\text{-N}$, UIN and NHN.

From the preceding sections and a close inspection of Tables 83 and 90, it can be said that ASN was the dominant fraction influencing available N content of soil during both wheat (heading stage) and maize (silking stage). Earlier, these two stages were taken to be the best for correlation studies with respect to yield and N uptake. Also, from Figures 11, 12 and 17, it was evident that ASN is the fraction responsible for controlling $\text{NH}_4\text{-}$ and $\text{NO}_3\text{-N}$ contents of the soil. All these point out to the fact that ASN is the major contributor of N for crop uptake.

Table 88. Stepwise linear regression equations of nitrogen uptake by maize at maturity with soil nitrogen fractions at different stages of crop growth

Stage	Regression equation	R ²
<i>Before sowing</i>		
Grain (G):	$Y = 87.138 - 0.366X_7$	0.927**
	$Y = 119.785 - 0.439X_7 - 0.163X_6$	0.938**
Stover (S):	$Y = -28.884 + 0.439X_4$	0.719**
	$Y = -38.305 + 0.358X_4 + 0.836X_5$	0.765*
Total (G + S)	$Y = 167.361 - 0.711X_7$	0.818**
	$Y = 117.380 - 0.624X_7 + 1.515X_5$	0.871**
	$Y = 232.669 - 0.878X_7 + 1.282X_5 - 0.538X_6$	0.897**
<i>Silking</i>		
Grain (G):	$Y = -70.200 + 0.822X_6$	0.721**
	$Y = -56.512 + 0.454X_6 + 0.242X_4$	0.790**
	$Y = -85.932 + 0.488X_6 + 0.292X_4 + 0.146X_3$	0.807**
	$Y = -82.429 + 0.443X_6 + 0.291X_4 + 0.145X_3 + 0.201X_1$	0.810**
Stover (S):	$Y = -82.561 + 0.881X_6$	0.515**
	$Y = -70.112 + 0.547X_6 + 0.220X_4$	0.550**
	$Y = -92.347 + 0.573X_6 + 0.258X_4 + 0.110X_3$	0.556**
Total (G + S):	$Y = -153.013 + 1.705X_6$	0.656**
	$Y = -126.831 + 1.002X_6 + 0.462X_4$	0.709**
	$Y = -178.352 + 1.061X_6 + 0.551X_4 + 0.256X_3$	0.720**

X₁ = Ammonium-N, X₂ = Nitrate-N, X₃ = Acid insoluble-N, X₄ = Amino acid-N, X₅ = Amino sugar-N, X₆ = Ammonia-N and X₇ = Unidentified hydrolysable-N

* Significant at 5% level

** Significant at 1% level

Table 89. Stepwise linear regression equations of nitrogen uptake by maize at maturity with soil nitrogen fractions at different stages of crop growth

Stage	Regression equation	R ²
<i>Dough</i>		
Grain (G):	$Y = -25.098 + 0.461X_4$	0.687**
	$Y = -60.449 + 0.286X_4 + 0.459X_6$	0.743**
	$Y = -81.963 + 0.293X_4 + 0.504X_6 + 0.113X_3$	0.756**
	$Y = -176.216 + 0.532X_4 + 0.651X_6 + 0.183X_3 + 0.253X_7$	0.779**
	$Y = -162.933 + 0.498X_4 + 0.602X_6 + 0.166X_3 + 0.234X_7 + 0.205X_1$	0.783**
Stover (S):	$Y = -101.735 + 1.051X_6$	0.503**
	$Y = -88.751 + 0.892X_6 + 0.500X_2$	0.525**
	$Y = -83.951 + 0.843X_6 + 0.327X_2 + 0.348X_1$	0.531**
	$Y = -59.088 + 0.782X_6 + 0.198X_2 + 0.475X_1 - 0.127X_3$	0.540**
	$Y = -57.025 + 0.798X_6 + 0.596X_1 - 0.147X_3$	0.538**
	$Y = -53.597 + 0.661X_6 + 0.518X_1 - 0.136X_3 + 0.099X_4$	0.545**
	$Y = -198.391 + 0.902X_6 + 0.414X_1 - 0.025X_3 + 0.466X_4 + 0.379X_7$	0.575**
Total (G + S)	$Y = -208.838 + 0.923X_6 + 0.399X_1 + 0.484X_4 + 0.396X_7$	0.575**
	$Y = -172.975 + 1.897X_6$	0.507**
	$Y = -138.833 + 1.163X_6 + 0.437X_4$	0.549**
	$Y = -302.813 + 1.406X_6 + 0.911X_4 + 0.512X_7$	0.571**
	$Y = -274.975 + 1.244X_6 + 0.815X_4 + 0.481X_7 + 0.879X_1$	0.588**
<i>After harvest</i>		
Grain (G):	$Y = -24.962 + 0.469X_4$	0.699**
	$Y = -66.128 + 0.316X_4 + 0.485X_6$	0.758**
	$Y = -123.117 + 0.485X_4 + 0.552X_6 + 0.192X_7$	0.774**
	$Y = -185.640 + 0.559X_4 + 0.706X_6 + 0.293X_7 + 0.141X_3$	0.796**
	$Y = -185.640 + 0.559X_4 + 0.706X_6 + 0.293X_7 + 0.120X_3 + 0.373X_5$	0.801**
	$Y = -169.762 + 0.508X_4 + 0.587X_6 + 0.285X_7 + 0.127X_3 + 0.356X_5 + 0.178X_2$	0.804**
Stover (S):	$Y = -108.325 + 1.122X_6$	0.441**
	$Y = -77.583 + 0.785X_6 + 0.988X_2$	0.506**
	$Y = -68.122 + 0.531X_6 + 0.758X_2 + 0.188X_4$	0.534**
	$Y = -198.952 + 0.704X_6 + 0.628X_2 + 0.578X_4 + 0.432X_7$	0.582**
Total (G + S):	$Y = -48.833 + 0.901X_4$	0.543**
	$Y = -138.042 + 0.571X_4 + 1.052X_6$	0.601**
	$Y = -319.879 + 1.108X_4 + 1.265X_6 + 0.614X_7$	0.635**
	$Y = -284.266 + 0.982X_4 + 1.098X_6 + 0.558X_7 + 0.828X_2$	0.648**
	$Y = -386.737 + 1.093X_4 + 1.341X_6 + 0.722X_7 + 0.927X_2 + 0.240X_3$	0.661**

X_1 = Ammonium-N, X_2 = Nitrate-N, X_3 = Acid insoluble-N, X_4 = Amino acid-N, X_5 = Amino sugar-N, X_6 = Ammonia-N and X_7 = Unidentified hydrolysable-N

* Significant at 5% level

** Significant at 1% level

Table 90. Stepwise linear regression equations of alkaline potassium permanganate (KMnO₄) oxidisable nitrogen of soil with nitrogen fractions at different stages of wheat growth

Stage	Regression equation	R ²
<i>Before sowing</i>		
	$Y = 42.795 + 0.288X_4$	0.557*
	$Y = 64.654 + 0.358X_4 - 0.198X_3$	0.649*
	$Y = 88.842 + 0.567X_4 - 0.325X_3 - 2.231X_2$	0.744
	$Y = 132.163 + 0.588X_4 - 0.551X_3 - 4.484X_2 + 2.247X_1$	0.935*
<i>Silking</i>		
	$Y = 44.310 + 2.174X_5$	0.620**
	$Y = 45.508 + 1.471X_5 + 0.748X_2$	0.679**
	$Y = 22.132 + 0.914X_5 + 0.659X_2 + 0.274X_6$	0.694**
	$Y = 19.404 + 0.955X_5 + 0.683X_2 + 0.312X_6 - 0.263X_1$	0.698**
<i>Dough</i>		
	$Y = 2.976 + 0.628X_6$	0.483**
	$Y = 16.156 + 0.480X_6 + 0.493X_1$	0.533**
	$Y = 23.354 + 0.301X_6 + 0.403X_1 + 0.123X_4$	0.561**
	$Y = -71.417 + 0.446X_6 + 0.365X_1 + 0.398X_4 + 0.293X_7$	0.622**
	$Y = -109.599 + 0.520X_6 + 0.312X_1 + 0.465X_4$ $+ 0.355X_7 + 0.091X_3$	0.633**
<i>After harvest</i>		
	$Y = 47.944 + 0.250X_4$	0.504**
	$Y = 51.389 + 0.177X_4 + 0.753X_1$	0.573**
	$Y = 3.397 + 0.358X_4 + 0.699X_1 + 0.179X_7$	0.610**
	$Y = -41.955 + 0.364X_4 + 0.360X_1 + 0.247X_7 + 0.301X_6$	0.650**

X₁ = Ammonium-N, X₂ = Nitrate-N, X₃ = Acid insoluble-N, X₄ = Amino acid-N, X₅ = Amino sugar-N, X₆ = Ammonia-N and X₇ = Unidentified hydrolysable-N, Y = Alkaline potassium permanganate (KMnO₄) oxidisable nitrogen

* Significant at 5% level

** Significant at 1% level

4.3.2.2 Phosphorus

4.3.2.2.1 Wheat

Reductant soluble P determined at the heading stage could predict the grain yield of wheat to the extent of 24.1% (Table 91). The same fraction along with LB-P explained the variability in straw and total yield to the extent of 26.8 and 29.0%, respectively. The predictability of grain yield with the help of RS-P increased slightly ($R^2 = 0.267^{**}$) when determined at the dough stage as compared to the heading stage. Calcium bound P, LB-P and RS-P were found to influence the straw yield of wheat ($R^2 = 0.427^{**}$) estimated at dough stage. The same three factors could predict total yield to the extent of 43.2%. While none of the P fractions present in the soil at the harvest of wheat were found to influence the straw yield, the grain and total yield were functions of Al-P and organic P ($R^2 = 0.276^*$ and 0.235^* , respectively)

Aluminium bound P and LB-P determined at the heading stage of wheat exhibited a significant influence on P uptake wheat grains ($R^2 = 0.378^{**}$), as it evident from Table 92. Straw P uptake was a function of RS-P, organic P and LB-P ($R^2 = 0.640^{**}$), while total P uptake was predicted to the extent of 57.4% with the help of RS-P, organic P and Al-P. During the dough stage only RS-P was found to influence grain P uptake. A combination of four fractions, viz., RS-P, LB-P Al-P and organic P significantly influenced the straw ($R^2 = 0.595^{**}$) and total P uptake ($R^2 = 0.616^{**}$). The predictability of grain P uptake was improved by the P fractions present in the soil after harvest of wheat. The fractions influencing grain P uptake were Al-P, organic P, LB-P and Ca-P ($R^2 = 0.567^{**}$). Aluminium bound P, organic P and LB-P were also instrumental in predicting the total P uptake by wheat to the tune of 65.5%.

Aluminium bound P, Ca-P and RS-P content of the soil at the heading and dough stages of wheat were found to affect Olsen P content of the soil (Table 93). The R^2 values at those two stages were 0.678^{**} and 0.903^{**} respectively. At harvest of wheat it was observed that Olsen P was a function of LB-P, Al-P, organic P and RS-P taken together ($R^2 = 0.867^{**}$).

Table 91. Stepwise linear regression equations of wheat yield at maturity with soil phosphorus fractions at different stages of crop growth

Stage	Regression equation	R ²
Heading		
Grain (G):	$Y = 31.165 + 0.437 X_5$	0.241**
Straw (S):	$Y = 15.224 + 1.539X_5$	0.179*
	$Y = 16.655 + 2.700X_5 - 5.575X_2$	0.268*
Total (G + S):	$Y = 47.192 + 1.966X_5$	0.229*
	$Y = 48.528 + 3.050X_5 - 5.205X_2$	0.290*
Dough		
Grain (G):	$Y = 20.897 + 0.581X_5$	0.267**
Straw (S)	$Y = -7.227 + 0.624X_6$	0.318**
	$Y = -15.178 + 0.824X_6 + 2.085X_2$	0.376**
	$Y = -96.236 + 0.656X_6 - 4.151X_2 + 2.148X_5$	0.427**
Total (G + S):	$Y = 34.499 + 0.719X_6$	0.331**
	$Y = 28.363 + 0.873X_6 - 1.609X_2$	0.358**
	$Y = -81.451 + 0.645X_6 - 4.408X_2 + 2.910X_5$	0.432**
After harvest		
Grain (G):	$Y = 48.188 + 0.253X_3$	0.170*
	$Y = 37.546 + 0.288X_3 + 0.054X_1$	0.276*
Total (G + S):	$Y = 127.270 + 1.072X_3$	0.142
	$Y = 81.118 + 1.221X_3 + 0.233X_1$	0.235*

X₁ = Organic P, X₂ = Loosely bound P, X₃ = Al-P, X₄ = Fe-P, X₅ = Reductant soluble P, X₆ = Ca-P and X₇ = Residual P

* Significant at 5% level

** Significant at 1% level

Table 92. Stepwise linear regression equations of phosphorus uptake by wheat at maturity with soil phosphorus fractions at different stages of crop growth

Stage	Regression equation	R ²
Heading		
Grain (G):	$Y = 14.514 + 0.165X_3$	0.330**
	$Y = 12.223 + 0.107X_3 + 0.326X_2$	0.378**
Straw (S):	$Y = -7.452 + 0.163X_5$	0.546**
	$Y = -9.728 + 0.175X_5 + 0.008X_1$	0.587**
	$Y = -10.168 + 0.233X_5 + 0.010X_1 - 0.264X_2$	0.640**
Total (G + S):	$Y = 1.981 + 0.338X_5$	0.498**
	$Y = -3.537 + 0.368X_5 + 0.020X_1$	0.549**
	$Y = -2.738 + 0.296X_5 + 0.021X_1 + 0.097X_3$	0.574**
Dough		
Grain (G):	$Y = 3.378 + 0.261X_5$	0.435**
Straw (S):	$Y = -8.313 + 0.174X_5$	0.388**
	$Y = -13.842 + 0.311X_5 - 0.247X_2$	0.493**
	$Y = -12.983 + 0.250X_5 - 0.356X_2 + 0.111X_3$	0.544**
	$Y = -13.073 + 0.200X_5 - 0.400X_2 + 0.169X_3 + 0.012X_1$	0.595**
Total (G + S):	$Y = -5.039 + 0.437X_5$	0.519**
	$Y = -10.509 + 0.572X_5 - 0.244X_2$	0.541**
	$Y = -8.778 + 0.450X_5 - 0.464X_2 + 0.223X_3$	0.585**
	$Y = -8.932 + 0.365X_5 - 0.539X_2 + 0.322X_3 + 0.020X_1$	0.616**
After harvest		
Grain (G):	$Y = 15.229 + 0.122X_3$	0.317**
	$Y = 10.942 + 0.136X_3 + 0.022X_1$	0.456**
	$Y = 10.548 + 0.226X_3 + 0.026X_1 - 0.369X_2$	0.528**
	$Y = 3.972 + 0.173X_3 + 0.030X_1 - 0.534X_2 + 0.051X_6$	0.567**
Straw (S):	$Y = -0.206 + 0.077X_3$	0.253**
	$Y = -4.605 + 0.091X_3 + 0.022X_1$	0.548**
	$Y = -4.885 + 0.092X_3 + 0.022X_1 + 0.006X_7$	0.607**
	$Y = -2.730 + 0.109X_3 + 0.021X_1 + 0.005X_7 - 0.102X_4$	0.665**
Total (G + S):	$Y = 14.967 + 0.200X_3$	0.364**
	$Y = 6.264 + 0.228X_3 + 0.044X_1$	0.608**
	$Y = 5.774 + 0.340X_3 + 0.049X_1 - 0.458X_2$	0.655**

X_1 = Organic P, X_2 = Loosely bound P, X_3 = Al-P, X_4 = Fe-P, X_5 = Reductant soluble P, X_6 = Ca-P and X_7 = Residual P

* Significant at 5% level

** Significant at 1% level

Table 93. Stepwise linear regression equations of 0.5 M NaHCO₃ extractable P (Olsen P) of soil with phosphorus fractions at different stages of wheat growth

Stage	Regression equation	R ²
<i>Heading</i>		
	$Y = -18.381 + 0.589X_5$	0.545**
	$Y = -23.725 + 0.517X_5 + 0.055X_6$	0.636**
	$Y = -20.730 + 0.287X_5 + 0.046X_6 + 0.214X_3$	0.678**
	$Y = -21.540 + 0.287X_5 + 0.040X_6 + 0.170X_3 + 0.581X_2$	0.694**
<i>Dough</i>		
	$Y = -14.067 + 0.729X_3$	0.820**
	$Y = -8.063 + 0.659X_3 - 0.039X_7$	0.882**
	$Y = -22.178 + 0.481X_3 - 0.025X_7 + 0.307X_5$	0.898**
	$Y = -28.063 + 0.440X_3 - 0.012X_7 + 0.294X_5 + 0.038X_6$	0.905**
	$Y = -33.100 + 0.405X_3 + 0.337X_5 + 0.052X_6$	0.903**
<i>After harvest</i>		
	$Y = -10.100 + 2.078X_2$	0.746**
	$Y = -14.222 + 1.151X_2 + 0.323X_3$	0.816**
	$Y = -21.521 + 0.924X_2 + 0.401X_3 + 0.038X_1$	0.856**
	$Y = -25.212 + 0.941X_2 + 0.368X_3 + 0.044X_1 + 0.061X_5$	0.867**

X₁ = Organic P, X₂ = Loosely bound P, X₃ = Al-P, X₄ = Fe-P, X₅ = Reductant soluble P, X₆ = Ca-P and X₇ = Residual P, Y = Olsen P

* Significant at 5% level

** Significant at 1% level

4.3.2.2.2. Mungbean

From Table 94 it can be seen that while Fe-P and RS-P content of soil at flowering stage of mungbean were found to determine the grain yield ($R^2 = 0.288^*$), only LB-P influenced the stover yield ($R^2 = 0.212^*$). Only Ca-P content of the soil before incorporation of mungbean could explain the variability in grain yield ($R^2 = 0.210^*$).

The stover and total P uptake by mungbean was found to be influenced by the LB-P content of soil determined at the flowering stage ($R^2 = 0.341^{**}$ and 0.369^{**} , respectively) as is evident from Table 95. Iron bound P and Ca-P could predict the variability in grain P uptake to the extent 27.5%. The later fraction determined before incorporation of mungbean was again found to affect grain P uptake ($R^2 = 0.198^*$). Stover P uptake was a function of Al-P and Res-P during the same stage ($R^2 = 0.226^*$).

Olsen P content of the soil was a function of LB-P content at flowering stage of mungbean ($R^2 = 0.736^{**}$) as shown in Table 96. Inclusion Ca-P further increased the predictability to 80.4%. The R^2 value was enhanced to 0.852^{**} when RS-P and organic P came into picture. While the above fractions also influenced the Olsen P content of the soil before incorporation of mungbean, another fraction, Al-P was also included in the equation at this stage ($R^2 = 0.924^{**}$).

4.3.2.2.3. Maize

Organic P and three fractions of inorganic P of soil, viz., LB-P, Al-P and Fe-P determined before sowing of maize were found to explain the variability in grain, stover and total maize yield at maturity to the extent of 89.7, 95.5 and 94.3%, respectively (Table 97). Inclusion of Ca-P in the equation involving stover yield enhanced the predictability to 96.8%. The predictability of maize yield by the different P forms and fractions was reduced in the subsequent stages of maize growth as is evident from Tables 97 and 98. As an example, during the dough stage of maize all the P fractions taken together were found to significantly influence total yield, but the predictability was only 41.3% (Table 98). It was further reduced to 33.0% after harvest of maize. LB-P fraction was excluded from the equation at this stage.

Table 94. Stepwise linear regression equations of mungbean yield with soil phosphorus fractions at different stages of crop growth

Stage	Regression equation	R ²
<i>Flowering stage</i>		
Grain (G):	$Y = 1.943 + 0.231X_4$	0.239**
	$Y = 3.264 + 0.294X_4 - 0.044X_5$	0.288*
Stover (S):	$Y = 57.557 + 0.615X_2$	0.212*
<i>Before incorporation</i>		
Grain (G):	$Y = -2.461 + 0.052X_6$	0.210*

Table 95. Stepwise linear regression equations of phosphorus uptake by mungbean at maturity with soil phosphorus fractions at different stages of crop growth

Stage	Regression equation	R ²
<i>Flowering stage</i>		
Grain (G):	$Y = 0.838 + 0.109X_4$	0.234*
	$Y = -0.760 + 0.085X_4 + 0.011X_6$	0.275*
Stover (S):	$Y = 10.245 + 0.334X_2$	0.341**
Total (G + S + R):	$Y = 14.209 + 0.390X_2$	0.369**
<i>Before incorporation</i>		
Grain (G):	$Y = -1.155 + 0.024X_6$	0.198*
Stover (S):	$Y = 15.964 - 0.037X_7$	0.167*
	$Y = 10.437 - 0.028X_7 + 0.124X_3$	0.226*
Root (R):	$Y = 0.625 + 0.010X_3$	0.073
	$Y = 2.604 + 0.021X_3 - 0.012X_6$	0.303*
	$Y = 3.807 + 0.017X_3 - 0.019X_6 + 0.018X_2$	0.377*
Total (G + S + R):	$Y = 16.031 + 0.247X_2$	0.183*
	$Y = 11.867 + 0.167X_2 + 0.123X_3$	0.217
	$Y = 7.274 + 0.086X_2 + 0.161X_3 + 0.024X_1$	0.254
	$Y = 5.330 + 0.207X_3 + 0.030X_1$	0.243*

X_1 = Organic P, X_2 = Loosely bound P, X_3 = Al-P, X_4 = Fe-P, X_5 = Reductant soluble P, X_6 = Ca-P and X_7 = Residual P

* Significant at 5% level

** Significant at 1% level

Table 96. Stepwise linear regression equations of alkaline 0.5 M NaHCO₃ extractable P (Olsen P) of soil with phosphorus fractions at different stages of mungbean growth

Stage	Regression equation	R ²
<i>Flowering stage</i>		
	$Y = 1.627 + 1.254X_2$	0.736**
	$Y = -32.678 + 1.095X_2 + 0.185X_6$	0.804**
	$Y = -46.670 + 0.956X_2 + 0.183X_6 + 0.243X_5$	0.844**
	$Y = -47.118 + 0.911X_2 + 0.171X_6 + 0.238X_5 + 0.021X_1$	0.852**
<i>Before incorporation</i>		
	$Y = -1.262 + 1.268X_2$	0.885**
	$Y = -7.690 + 1.144X_2 + 0.191X_3$	0.900**
	$Y = -15.548 + 1.063X_2 + 0.184X_3 + 0.139X_5$	0.911**
	$Y = -11.374 + 1.134X_2 + 0.153X_3 + 0.133X_5 - 0.020X_1$	0.916**
	$Y = -28.490 + 1.023X_2 + 0.119X_3 + 0.129X_5 - 0.027X_1$ $+ 0.107X_6$	0.924**
	$Y = -32.985 + 0.954X_2 + 0.089X_3 + 0.155X_5 - 0.032X_1$ $+ 0.089X_6 + 0.359X_4$	0.928**
	$Y = -33.042 + 0.985X_2 + 0.161X_5 - 0.036X_1 + 0.100X_6$ $+ 0.161X_4$	0.924**

X₁ = Organic P, X₂ = Loosely bound P, X₃ = Al-P, X₄ = Fe-P, X₅ = Reductant soluble P, X₆ = Ca-P and X₇ = Residual P, Y = Olsen P

* Significant at 5% level

** Significant at 1% level

Table 97. Stepwise linear regression equations of maize yield at maturity with soil phosphorus fractions at different stages of crop growth

Stage	Regression equation	R ²
<i>Before sowing</i>		
Grain (G):	$Y = 14.006 + 2.079X_2$	0.562*
	$Y = 1.035 + 1.731X_2 + 0.486X_3$	0.641*
	$Y = 18.809 + 2.390X_2 + 1.013X_3 - 1.636X_4$	0.825*
	$Y = 86.270 + 3.924X_2 + 1.176X_3 - 3.097X_4 - 0.212X_1$	0.897*
Stover (S):	$Y = 29.869 + 3.917X_2$	0.622*
	$Y = 3.806 + 3.218X_2 + 0.976X_3$	0.721*
	$Y = 36.291 + 4.422X_2 + 1.940X_3 - 2.991X_4$	0.912**
	$Y = 128.579 + 6.521X_2 + 2.163X_3 - 4.989X_4 - 0.290X_1$	0.955**
	$Y = 152.884 + 6.428X_2 + 2.161X_3 - 4.768X_4 - 0.317X_1 - 0.113X_6$	0.968**
Total (G + S):	$Y = 43.882 + 5.995X_2$	0.607*
	$Y = 5.094 + 4.955X_2 + 1.453X_3$	0.699*
	$Y = 55.413 + 6.820X_2 + 2.946X_3 - 4.633X_4$	0.890**
	$Y = 215.002 + 10.449X_2 + 3.331X_3 - 8.089X_4 - 0.501X_1$	0.943**
<i>Silking</i>		
Grain (G):	$Y = 14.388 + 1.752X_2$	0.365**
	$Y = 6.401 + 1.892X_2 + 0.035X_1$	0.399**
	$Y = 1.386 + 1.310X_2 + 0.044X_1 + 0.212X_3$	0.436**
	$Y = -2.061 + 1.186X_2 + 0.047X_1 + 0.154X_3 + 0.207X_4$	0.448**
Stover (S):	$Y = 36.935 + 2.431X_2$	0.211**
	$Y = 14.620 + 2.821X_2 + 0.098X_1$	0.292**
	$Y = 6.458 + 2.583X_2 + 0.109X_1 + 0.119X_5$	0.310**
	$Y = -2.356 + 1.691X_2 + 0.124X_1 + 0.141X_5 + 0.310X_3$	0.333**
Total (G + S):	$Y = 51.327 + 4.183X_2$	0.279**
	$Y = 21.070 + 4.712X_2 + 0.132X_1$	0.346**
	$Y = 9.976 + 3.423X_2 + 0.153X_1 + 0.470X_3$	0.370**
	$Y = -3.145 + 2.911X_2 + 0.172X_1 + 0.533X_3 + 0.170X_5$	0.386**

X₁ = Organic P, X₂ = Loosely bound P, X₃ = Al-P, X₄ = Fe-P, X₅ = Reductant soluble P, X₆ = Ca-P and X₇ = Residual P

* Significant at 5% level

** Significant at 1% level

Table 98. Stepwise linear regression equations of maize yield at maturity with soil phosphorus fractions at different stages of crop growth

Stage	Regression equation	R ²
<i>Dough</i>		
Grain (G):	$Y = 16.848 + 1.446X_2$	0.322**
	$Y = 8.774 + 1.067X_2 + 0.376X_4$	0.394**
	$Y = 13.165 + 1.124X_2 + 0.363X_4 - 0.070X_5$	0.434**
Stover (S):	$Y = 38.768 + 2.228X_2$	0.230**
	$Y = 43.128 + 2.275X_2 - 0.074X_5$	0.244**
Total (G + S):	$Y = 55.606 + 3.676X_2$	0.280**
	$Y = 42.838 + 3.075X_2 + 0.595X_4$	0.304**
	$Y = 25.703 + 2.957X_2 + 0.765X_4 + 0.067X_1$	0.331**
	$Y = 5.168 + 2.806X_2 + 1.062X_4 + 0.126X_1 + 0.121X_7$	0.343**
	$Y = -83.887 + 2.344X_2 + 0.830X_4 + 0.244X_1 + 0.288X_7 + 0.355X_6$	0.380**
	$Y = -118.415 + 1.379X_2 + 0.587X_4 + 0.304X_1 + 0.372X_7 + 0.440X_6 + 0.498X_3$	0.398**
	$Y = -194.906 + 0.565X_2 + 0.655X_4 + 0.436X_1 + 0.504X_7 + 0.606X_6 + 0.683X_3$	
	$+0.184X_5$	0.413**
<i>After harvest</i>		
Grain (G):	$Y = 16.858 + 0.372X_4$	0.217**
	$Y = -2.660 + 0.328X_4 + 0.099X_6$	0.303**
	$Y = -12.219 + 0.326X_4 + 0.114X_6 + 0.035X_1$	0.344**
	$Y = -25.277 + 0.353X_4 + 0.110X_6 + 0.048X_1 + 0.152X_5$	0.398**
	$Y = -31.168 + 0.369X_4 + 0.122X_6 + 0.054X_1 + 0.171X_5 + 0.022X_7$	0.408**
Stover (S):	$Y = 41.893 + 0.461X_4$	0.100**
	$Y = 12.320 + 0.394X_4 + 0.150X_6$	0.160**
	$Y = 13.380 + 0.592X_4 + 0.155X_6 - 0.233X_3$	0.195*
	$Y = 3.806 + 0.612X_4 + 0.145X_6 - 0.222X_3 + 0.154X_5$	0.213*
	$Y = -15.514 + 0.596X_4 + 0.164X_6 - 0.193X_3 + 0.219X_5 + 0.055X_1$	0.240*
	$Y = -32.355 + 0.606X_4 + 0.195X_6 - 0.154X_3 + 0.275X_5 + 0.074X_1$	
	$+ 0.059X_7$	0.262*
Total (G + S)	$Y = 58.748 + 0.834X_4$	0.146**
	$Y = 9.608 + 0.722X_4 + 0.249X_6$	0.220**
	$Y = 11.118 + 1.004X_4 + 0.256X_6 - 0.332X_3$	0.252**
	$Y = -4.136 + 1.035X_4 + 0.240X_6 - 0.314X_3 - 0.245X_5$	0.272**
	$Y = -39.491 + 1.006X_4 + 0.275X_6 - 0.261X_3 + 0.365X_5 + 0.100X_1$	0.313**
	$Y = -61.453 + 1.020X_4 + 0.315X_6 - 0.210X_3 + 0.438X_5 + 0.125X_1$	
	$+ 0.077X_7$	0.330**

X₁ = Organic P, X₂ = Loosely bound P, X₃ = Al-P, X₄ = Fe-P, X₅ = Reductant soluble P, X₆ = Ca-P and X₇ = Residual P

* Significant at 5% level

** Significant at 1% level

The grain, stover and total P uptake by maize were significantly influenced LB-P ($R^2 = 0.664^{**}$, 0.676^{**} and 0.788^{**} , respectively) as evidenced from Table 99. While the inclusion of Al-P and Ca-P increased the predictability of grain P uptake to 87.5%, inclusion of Ca-P increased the R^2 value with respect to stover P uptake to 0.788^{**} . As in case of maize yield, predictability of P uptake by both maize grain and stover declined in the stages following the first stage i.e. before sowing (Table 99 and 100).

Olsen P content of the soil before sowing of maize was found to be significantly influenced by LB-P content of the soil at that stage ($R^2 = 0.889^{**}$, Table 101). Inclusion of Ca-P and Res-P increased the R^2 values to 0.940^{**} and 0.965^{**} , respectively. During the remaining stages of maize viz., silking, dough and after harvest, all the fractions were found to influence Olsen P content, but the coefficient of determination decreased as maize growth progressed. The values were 0.864^{**} , 0.761^{**} and 0.461^{**} at silking, dough and after harvest, respectively.

Table 99. Stepwise linear regression equations of phosphorus uptake by maize at maturity with soil phosphorus fractions at different stages of crop growth

Stage	Regression equation	R ²
<i>Before sowing</i>		
Grain (G):	$Y = 3.095 + 0.931X_2$	0.664**
	$Y = -2.297 + 0.787X_2 + 0.202X_3$	0.745*
	$Y = 10.460 + 0.709X_2 + 0.270X_3 - 0.072X_6$	0.875*
Stover (S):	$Y = 1.088 + 1.251X_2$	0.676**
	$Y = -16.281 + 1.286X_2 + 0.085X_6$	0.788**
Total (G + S)	$Y = 4.453 + 2.121X_2$	0.788**
<i>Silking</i>		
Grain (G):	$Y = 3.177 + 0.799X_2$	0.335**
	$Y = 1.828 + 0.508X_2 + 0.100X_3$	0.373**
	$Y = -2.567 + 0.505X_2 + 0.125X_3 + 0.018X_1$	0.409**
	$Y = -4.495 + 0.436X_2 + 0.092X_3 + 0.019X_1 + 0.116X_4$	0.426**
Stover (S):	$Y = -1.353 + 0.298X_3$	0.393**
	$Y = -5.178 + 0.273X_3 + 0.073X_5$	0.455**
	$Y = -4.740 + 0.187X_3 + 0.057X_5 + 0.496X_2$	0.484**
	$Y = -4.965 + 0.193X_3 + 0.055X_5 + 0.472X_2 + 0.018X_7$	0.497**
Total (G + S):	$Y = 3.600 + 1.978X_2$	0.468**
	$Y = -0.108 + 1.179X_2 + 0.274X_3$	0.534**
	$Y = -2.299 + 1.078X_2 + 0.223X_3 + 0.169X_4$	0.542**

X_1 = Organic P, X_2 = Loosely bound P, X_3 = Al-P, X_4 = Fe-P, X_5 = Reductant soluble P, X_6 = Ca-P and X_7 = Residual P

* Significant at 5% level

** Significant at 1% level

Table 100. Stepwise linear regression equations of phosphorus uptake by maize at maturity with soil phosphorus fractions at different stages of crop growth

Stage	Regression equation	R ²
<i>Dough</i>		
Grain (G):	$Y = 4.253 + 0.665X_2$	0.301**
	$Y = 0.312 + 0.480X_2 + 0.184X_4$	0.376**
	$Y = 2.536 + 0.509X_2 + 0.177X_4 - 0.035X_5$	0.421**
Stover (S):	$Y = -2.525 + 0.323X_3$	0.402**
	$Y = -2.322 + 0.209X_3 + 0.544X_2$	0.460**
	$Y = -8.313 + 0.182X_3 + 0.512X_2 + 0.034X_6$	0.476**
Total (G + S)	$Y = -0.341 + 0.513X_3$	0.434**
	$Y = 0.029 + 0.306X_3 + 0.988X_2$	0.515**
	$Y = -3.948 + 0.200X_3 + 0.938X_2 + 0.284X_4$	0.546**
	$Y = -1.541 + 0.205X_3 + 0.961X_2 + 0.273X_4 - 0.039X_5$	0.559**
<i>After harvest</i>		
Grain (G):	$Y = 4.624 + 0.158X_4$	0.173**
	$Y = -5.651 + 0.135X_4 + 0.052X_6$	0.279**
	$Y = -9.391 + 0.146X_4 + 0.048X_6 + 0.060X_5$	0.320**
	$Y = -17.622 + 0.150X_4 + 0.057X_6 + 0.088X_5 + 0.024X_1$	0.397**
	$Y = -20.968 + 0.159X_4 + 0.063X_6 + 0.099X_5 + 0.027X_1 + 0.012X_7$	0.411**
Stover (S):	$Y = 2.130 + 1.298X_2$	0.318**
	$Y = -1.471 + 1.065X_2 + 0.175X_4$	0.421**
	$Y = -7.793 + 0.858X_2 + 0.173X_4 + 0.037X_6$	0.441**
	$Y = -9.610 + 0.857X_2 + 0.180X_4 + 0.042X_6 + 0.012X_7$	0.450**
	$Y = -10.555 + 0.776X_2 + 0.143X_4 + 0.046X_6 + 0.014X_7 + 0.049X_3$	0.461**
	$Y = -15.831 + 0.687X_2 + 0.139X_4 + 0.058X_6 + 0.019X_7 + 0.061X_3 + 0.015X_1$	0.476**
Total (G + S):	$Y = 7.923 + 1.899X_2$	0.287**
	$Y = 1.410 + 1.478X_2 + 0.317X_4$	0.429**
	$Y = -11.789 + 1.058X_2 + 0.312X_4 + 0.074X_6$	0.465**
	$Y = -18.888 + 0.949X_2 + 0.316X_4 + 0.089X_6 + 0.023X_1$	0.483**
	$Y = -26.093 + 0.974X_2 + 0.330X_4 + 0.086X_6 + 0.031X_1 + 0.086X_5$	0.500**
	$Y = -33.837 + 0.948X_2 + 0.352X_4 + 0.102X_6 + 0.039X_1 + 0.110X_5 + 0.028X_7$	0.517**

X₁ = Organic P, X₂ = Loosely bound P, X₃ = Al-P, X₄ = Fe-P, X₅ = Reductant soluble P, X₆ = Ca-P and X₇ = Residual P

* Significant at 5% level

** Significant at 1% level

Table 101. Stepwise linear regression equations of 0.5 M NaHCO₃ extractable P (Olsen P) of soil with phosphorus fractions at different stages of wheat growth

Stage	Regression equation	R ²
<i>Before sowing</i>	$Y = -5.403 + 3.009X_2$	0.889**
	$Y = -30.162 + 3.058X_2 + 0.122X_6$	0.940**
	$Y = -46.948 + 2.902X_2 + 0.201X_6 + 0.252X_7$	0.965**
<i>Silking</i>	$Y = -4.475 + 2.291X_2$	0.654**
	$Y = -11.371 + 2.412X_2 + 0.030X_1$	0.680**
	$Y = -18.462 + 1.994X_2 + 0.038X_1 + 0.305X_4$	0.714**
	$Y = -26.705 + 1.950X_2 + 0.066X_1 + 0.390X_4 + 0.046X_7$	0.733**
	$Y = -34.321 + 1.758X_2 + 0.080X_1 + 0.432X_4 + 0.057X_7$ $+ 0.076X_5$	0.757**
	$Y = -91.775 + 1.420X_2 + 0.155X_1 + 0.500X_4 + 0.146X_7 + 0.156X_5$ $+ 0.178X_6$	0.833**
	$Y = -102.556 + 0.927X_2 + 0.179X_1 + 0.398X_4 + 0.170X_7 + 0.180X_5$ $+ 0.192X_6 + 0.221X_3$	0.864**
<i>Dough</i>	$Y = 0.255 + 1.583X_2$	0.633**
	$Y = -3.633 + 1.149X_2 + 0.195X_3$	0.688**
	$Y = -5.801 + 1.122X_2 + 0.137X_3 + 0.155X_4$	0.703**
	$Y = -8.752 + 1.077X_2 + 0.153X_3 + 0.173X_4 + 0.011X_1$	0.711**
	$Y = -15.096 + 0.984X_2 + 0.184X_3 + 0.242X_4 + 0.029X_1$ $+ 0.035X_7$	0.723**
	$Y = -22.250 + 0.890X_2 + 0.202X_3 + 0.290X_4 + 0.045X_1$ $+ 0.045X_7 + 0.041X_5$	0.737**
	$Y = -57.793 + 0.546X_2 + 0.286X_3 + 0.240X_4 + 0.100X_1 + 0.111X_7$ $+ 0.080X_5 + 0.107X_6$	0.761**
<i>After harvest</i>	$Y = 1.705 + 1.501X_2$	0.306**
	$Y = -0.817 + 1.338X_2 + 0.123X_4$	0.342**
	$Y = -4.354 + 1.319X_2 + 0.127X_4 + 0.019X_1$	0.364**
	$Y = -13.770 + 1.326X_2 + 0.143X_4 + 0.028X_1 + 0.103X_5$	0.406**
	$Y = -17.253 + 1.375X_2 + 0.160X_4 + 0.033X_1 + 0.122X_5$ $+ 0.021X_7$	0.423**
	$Y = -19.401 + 1.279X_2 + 0.105X_4 + 0.037X_1 + 0.133X_5 + 0.025X_7$ $+ 0.078X_3$	0.443**
	$Y = -29.602 + 1.014X_2 + 0.097X_4 + 0.045X_1 + 0.137X_5 + 0.032X_7$ $+ 0.094X_3 + 0.045X_6$	0.461**

X₁ = Organic P, X₂ = Loosely bound P, X₃ = Al-P, X₄ = Fe-P, X₅ = Reductant soluble P, X₆ = Ca-P and

X₇ = Residual P, Y = Olsen P

* Significant at 5% level

** Significant at 1% level

5. SUMMARY AND CONCLUSIONS

Success of any crop depends on the proper combination of inputs, of which fertilizer is of prime importance. Nutrients applied through fertilizers should be in the right proportion and in adequate plant-available amounts. Further they must be able to reach the plants at the right time. Availability of a particular nutrient is dependent on a number of soil factors, pH being the most dominant one. In the absence of favourable conditions, the available forms of a nutrient gets transformed into less available, and subsequently into difficultly available pools. It is therefore necessary to study the factors affecting the availability of nutrients, as well as those pools which are of immediate importance in the replenishment of the plant-available forms of the nutrient in question. Nitrogen and phosphorus, two of the major nutrients required by crops, and perhaps the most widely studied, still stand as challenges in terms of understanding their dynamics in the soil.

Intensification of Indian agriculture has resulted in the emergence of multi-nutrient deficiencies owing to the excessive mining of nutrients by the exhaustive cropping systems, without adequate replenishment through external sources. This, added to the indiscriminate use of natural resources has resulted in the soils showing signs of fatigue. The sustainability of the highly productive cropping systems is now being questioned unless certain corrective measures are taken soon. This is a difficult task, considering the fact that Indian soils are mostly poor in organic carbon. Several studies in the country have shown that integrated use of organic manures along with chemical fertilizers have resulted not only in comparable crop productivity but also have improved soil health. In addition, organic manures supplement the inorganic fertilizers in providing nutrients such as nitrogen and phosphorus, by the phenomena of mineralization, dissolution from minerals, and release from occluded sites. In other words, organics do play an important role in the transformation of added nutrients.

The present investigation was primarily focused on the influence of integrated nutrient management on the dynamics of N and P in soil under a wheat-mungbean-

maize cropping sequence. An attempt was also made to identify the fractions contributing towards the N and P nutrition of each of the component crops of the sequence.

To accomplish the objectives, a field experiment was conducted at the Main Block 3B of the IARI farm taking wheat, mungbean and maize were grown in that sequence. While the design followed for wheat and mungbean was RBD, in plots of $15 \times 3.25 \text{ m}^2$ size, the design followed for maize was split-plot. Nine treatments were applied to wheat, including fertilizers applied at 50, 75 and 100% of the recommended dose, N only, P only, FYM applied alone, or in combination with 50 and 75% recommended NPK, all of which were compared with control. The treatments were replicated thrice to give a total number of 27 plots. Mungbean was grown following wheat without any fertilizer or manure application. It was allowed to grow till two pickings were taken, and the green stover was incorporated into the soil subsequently. Before sowing of maize, each main plot was divided into three sub-plots, and fertilizers were applied to the plots at 0, 50 and 75% of the recommended dose for maize. There were therefore 81 plots for maize.

Surface soil samples (0-15 cm) were collected before sowing of wheat and thereafter at different physiological stages of wheat (heading, dough and after harvest), mungbean (flowering and before incorporation) and maize (before sowing, silking, dough and after harvest). Different organic and inorganic pools of N and P were estimated at all the stages. After the harvest of wheat, mungbean and maize, grain and straw/stover yield were recorded separately for each crop and representative plant samples were collected from all the treatments. Samples were ground in a steel mill, passed through 1 mm sieve and used for estimating their N, P and K content.

A brief summary of the results is presented below:

- Highest wheat yield and nutrient uptake was recorded under the treatment T_7 , which is 100% of the recommended dose of fertilizer. Substituting a part of the inorganic fertilizer through FYM (T_8 and T_9) compared favourably with 100% NPK. However, application of FYM alone did not bring about significant improvement in wheat yield and nutrient uptake as compared to control.

- The grain and straw yield of maize were enhanced with increased level of fertilizer application, with the treatment M_3 (75% recommended dose) being superior to M_2 (50% recommended dose) and M_1 (0% recommended dose), in that order. Among the treatments applied to wheat, the treatments T_8 and T_9 , where FYM was supplied along with inorganic fertilizer, resulted in higher grain yields, with the former treatment being superior to the latter.
- The treatments T_3 , T_6 , T_7 , T_8 and T_9 , where higher amounts of nitrogen-N were added, registered higher contents of ammoniacal, nitrate, organic, hydrolysable organic and total N in the soil. They also maintained higher amounts of amino sugar N (ASN), amino acid N (AAN) and ammonia N (NHN) in the soil under all the crops through out the investigation period.
- The total organic N (TON) constituted about 96% of the total N, which was more or less maintained at that value through out the study period. The total hydrolysable N (THN) fraction varied between 74 and 78% of the TON at different stages of the cropping period. The ASN fraction comprised 3 to 4% of TON, while AAN, NHN and unidentified N (UIN) constituted 24-26, 23-25 and 22-25% of TON, respectively.
- There was a decrease in the TON during the wheat and mungbean seasons, which increased sharply after incorporation of mungbean stover before sowing of maize. With passage of time, the THN content of the soil decreased, except during the period following application of fertilizer and/or manures.
- The values of AAN were less variable about its initial values recorded before sowing of wheat through out the experimental period as compared to THN, although the final AAN content under the treatments T_6 , T_7 , T_8 and T_9 were higher than the initial values. In contrast, the ASN fraction was found to be very sensitive to addition of external inputs. A decrease in the ASN content was accompanied by a increase in available, ammoniacal- and nitrate-N contents of soil.
- Ammonia-N fraction of the soil behaved more or less similarly as AAN, with a higher variability over time as compared to the latter. It was found to increase with addition of fertilizers and manures.

- While the treatments did not differ significantly with respect to the total, organic and inorganic P contents of the soil for most part of the investigation, the Olsen P content was found to be highly influenced by the treatments applied to wheat and maize. In case of the treatments applied to wheat, T₄, T₆, T₇, T₈ and T₉, where higher dose of fertilizer-P were applied, resulted in higher values of Olsen P. These treatments also maintained higher values of the inorganic P fractions (Loosely Bound P, aluminium P, iron P, reductant soluble P and calcium P). The treatment M₃ (75% of recommended dose) performed consistently better during maize season, in maintaining the Olsen P content of the soil.
- Inorganic P showed an inverse relationship with the organic P content at all the growth stages, while the total P remained more or less stable for all the treatments throughout the experimental period.
- Olsen P registered steep increase from sowing of wheat to heading stage. After the heading stage, however, it declined and remained more or less stable till the incorporation of mungbean residues. After incorporation of mungbean residues, there was a slight increase in the soil Olsen P values under the treatments T₁, T₂ and T₃ where, earlier, no fertilizer-P was applied. On the other hand, the treatments T₄, T₆, T₇, T₈ and T₉, where higher doses of P were applied during wheat, registered decline in Olsen P in comparison to the value recorded at the previous stage.
- Calcium bound P (Ca-P) was the most dominant P fraction in the experimental soil, comprising about 50-60% of the total inorganic P. The next dominant fraction was the reductant soluble P (RSP), constituting 15 to 19% of inorganic P. Residual P content of the soil was highly variable, with values ranging from 2 to 16%, while the proportion of aluminium-P (Al-P), iron-P (Fe-P) and Loosely Bound P (LB-P) to the total inorganic P were 8-12, 6-8 and 1-3%, respectively.
- Application of P fertilizers was found to increase all the inorganic P fractions. But, while the relative proportion of Ca-P to the total inorganic P decreased, the proportion of LB-P and Al-P increased up to the dough stage of wheat. There was

a decrease in LB-P fraction after the dough stage of wheat. After the incorporation of mungbean, LB-P and Al-P were found to decline steeply. The LB-P, Fe-P and Al-P contents were found to increase again towards the silking stage of maize. Calcium P was found to increase steadily from sowing of maize till its harvest. The RSP fraction did not undergo much change throughout the experimental period.

Although, it is too early to strongly recommend anything, some interesting points have emerged from this study. This investigation supports the results of several earlier workers as regards to obtaining comparable, if not higher yields of crops by substituting a part of inorganic fertilizers with FYM. Application of higher doses of fertilizers along with FYM improved the N and P status of the soil. But the most salient finding from this study is that ASN fraction of organic N could be used as an indicator to determine the available N status of the soil. It could be also used to predict crop N uptake with the help of in-depth kinetic studies. This finding is justified by the fact that any external fertilizer/manurial addition was found to be reflected immediately in the ASN content of the soil. Further, a decrease in the ASN fraction was accompanied by an increase in the available and mineral (NH_4^- and NO_3^- -N) contents. However, in order to further examine this finding, subsequent monitoring of this fraction in relation to the available pools is necessary.

Similarly, in case of phosphate pools, Loosely Bound P, aluminium P and calcium bound P are the fractions that need close monitoring, as it has been found from this study that, while LB-P and Al-P increased in the soil on addition of fertilizers, they were transformed to the more resistant Ca-P with passage of time. Therefore, LB-P and Al-P could be used as indices of P availability in this soil.

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