NITROGEN MANAGEMENT IN SOYBEAN (*Glycine max* (L.)) AND PIGEONPEA (*Cajanus cajan* (L.))UNDER SOLE AND INTERCROPPING SYSTEMS

Thesis submitted in part fulfilment of the requirements for the degree of DOCTOR OF PHILOSOPHY (AGRICULTURE) IN AGRONOMY to the TAMILNADU AGRICULTURAL UNIVERSITY, COIMBATORE

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CERTIFICATE

This is to certify that the thesis entitled " **NITROGEN MANAGEMENT IN SOYBEAN (*Glycine max* (L.)) AND PIGEONPEA (*Cajanus cajan* (L.)) UNDER SOLE AND INTERCROPPING SYSTEMS** " submitted in part fulfilment of the requirements for the degree of **DOCTOR OF PHILOSOPHY (AGRICULTURE) IN AGRONOMY to the TAMILNADU AGRICULTURAL UNIVERSITY, COIMBATORE** is a record of bonafide research work carried out by ***Ms P.PADMAVATHI*** under our supervision and guidence and that no part of this thesis has been submitted for the award of any other degree, diploma, fellowship or other similar titles or prizes and that the work has not been published in part or full in any scientific or popular journal or magazine.

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ABSTRACT

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NITROGEN MANAGEMENT IN SOYBEAN AND PIGEONPEA UNDER SOLE AND INTERCROPPING SYSTEMS

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Soybean (*Glycine max* (L) Merrill) crop is becoming increasingly popular in central India, particularly in the Vertisol (Black soil) region. Today it commands an area of 5.6 m.ha in the states of Madhya Pradesh and Maharastra. Some area is also planted to the crop in Uttar Pradesh and Andhra Pradesh. An analysis of the area and yield trend of soybean in India show that although the area expanded at a compound rate of 600 per cent, the productivity increase is negligible. The crop yield was low, 862 kg ha^{-1}. Pigeonpea (*Cajanus cajan* (L) Millsp) is an important grain legume crop of the semi arid tropics (SAT). India is the

major pigeonpea producing country accounting for over 90 per cent of the global pigeonpea production. The productivity of the crop in India is low, 533 kg ha^{-1}.

This investigation was therefore planned at the International Crops Research Institute for the Semi-Arid Tropics (ICRISAT) Patancheru center, during the rainy cropping seasons of 1996 and 1997 on a Vertisols (watershed) to evaluate the impact of nitrogen management on the growth, nodulation and yield of soybean, pigeonpea, soybean/sunflower and sorghum/pigeonpea systems and changes in chemical and biological properties of soil under various N x cropping system treatments.

Two experiments were laid out in a split plot design with 24 treatment combinations involving six main plot treatments viz; control (0 N), 20 kg N ha^{-1} sourced from FYM, 20 kg N ha^{-1} from fertilizer N, 40 kg N ha^{-1} from FYM, 40 kg N ha^{-1} from fertilizer N, and 20:20 kg N ha^{-1} from FYM + fertilizer N. The 4 subplot treatments were; sole soybean; soybean /sunflower; sole pigeonpea; and sorghum/pigeonpea; All the treatments were replicated thrice.

Experiment was conducted during the rainy cropping seasons of 1996 and 1997. These two years happened to be consistently different in terms of the meteorological environments in particular with respect to the amount of rainfall and its distribution. The year 1996 was wet. 1062 mm rain was received (25 per cent above normal). The distribution of rainfall was in accord with crop water needs. In contrast, the year 1997, received 743 mm (8% less than normal). There is almost a month drought during the mid season and the crops were exposed to extended water deficits. The results of the experiments therefore should viewed in this context.

Some important findings from the study are as follows :

(1) In 1996, a good rainfall year, significant enhancement in growth (LAI, dry matter production, nutrient uptake) and yield of all the four crops was observed due to N application. All the four systems tested (sole soybean, soybean/sunflower, pigeonpea and sorghum/pigeonpea) with N application @ 40 kg N ha^{-1} (fertilizer or FYM + fertilizer) showed better performance compared to the rest of N combinations, suggesting the beneficial role of N application over control (0 N). Application of N significantly increased the seed yield of sole and intercropped soybean which ranged from (0.8 to 1.1; 0.5 to 0.8 t ha^{-1}); sole and intercropped pigeonpea (1.2 to 1.8; 0.9 to 1.6 t ha^{-1}). The order of response of the N fertilization in enhancing the crop yields was 40 kg N ha^{-1} (fertilizer N) > 40 kg N ha^{-1} (FYM + fertilizer N) > 20 kg N ha^{-1} (fertilizer N) > 40 kg N ha^{-1} (FYM) > 20 kg N ha^{-1} (FYM) > control (0 N). Irrespective of the source of N, improvement in seed yield of soybean due to N fertilization was 12 and 27 per cent higher yield compared to 20 kg N ha^{-1} application and control (0 N) treatments respectively. In pigeonpea the yield improvement over control (0 N) due to 20 kg N ha^{-1} and 40 kg N ha^{-1} was 25 and 41 per cent respectively. Similar increases in the yields of component crops viz; sunflower(301 kg ha^{-1}), sorghum (1.1 t ha^{-1}) due to N application at 40 kg N ha^{-1} (fertilizer N) were observed. Nodulation and nitrogenase activity of soybean and pigeonpea were inhibited at higher levels of N application irrespective of the source of N. The magnitude of inhibitory effect of N on the nodulation was increased when crops received N as mineral source compared to FYM.

The mean amount of abscised dry matter added to the soil by soybean was in range of 750 to 1000 kg ha^{-1} which amounted to 6-10 kg N ha^{-1}and 1.2 kg P ha^{-1}. In case of pigeonpea the mean amount of abscised dry matter added to the soil was 1800 to 3000 kg ha^{-1} which amounted to 20 to 24 kg N ha^{-1} and 2.4 kg P ha^{-1}.

At higher levels of N (40 kg ha^{-1} irrespective of source of N), the soil mineral N content, net N mineralization, soil respiration, microbial C and N biomass were found the be high compared to an application of 20 kg N ha^{-1} and control (0 N) treatments during the both years of the study. Application of N at higher levels [at 40 kg ha^{-1} (irrespective of source)] showed a high mineral soil N content (8.6 to 9.5 mg N g^{-1} soil) and a net N mineralization of 5.0 to 5.6 mg N g^{-1} soil 10 d^{-1} compared to control (5.9; 4.6) and 20 kg N ha^{-1} application (7.1 to 7.7; 4.9 to 5). The increase in mineral N and net N mineralization due to 40 kg N ha^{-1} application was 24 per cent and 56 per cent respectively more than that of 20 kg N ha^{-1} and control (0 N) treatments. The amount of C respired by soil microorganisms due to the application of 40 kg N ha^{-1} (irrespective of its source) was 2 per cent and 8 per cent more than the plots receiving 20 kg N ha^{-1} and 0 N (control) respectively. The mean microbial C biomass content due to the application of 40 kg N and 20 kg N ha^{-1} (irrespective of its source) was 41 per cent and 5 per cent greater than that of the control (0 N) treatment. It was also noted that the microbial N biomass was 27 per cent and 7 per cent greater when compared to the control (0 N) treatment respectively.

In 1997, a deficient rain year, the total amount of annual rainfall received was 92 per cent (741 mm) of the long term average and crops suffered from the lack of moisture, The drought conditions resulted in the nonresponsiveness of all the crops tested in this experiment in terms of the growth, nutrient uptake and seed yields to N application.

The water deficit in 1997 also impacted soil biological properties. The magnitude of the response to N application differed widely. The mean mineral N (NH_4^++NO_3^-) content of the soil increased when 40 kg N ha^{-1} was applied (irrespective of source), it was 130 and 46 per cent more than that of control and the 20 kg N ha^{-1} treatments. The net N mineralized on the other hand was 118 and 66 per cent more than that of control and 20 kg N ha^{-1} (FYM or mineral N) treatments respectively. Due to the application of 40 kg N ha^{-1} (irrespective of source) the increase in soil respiration (by soil microorganisms) was 14 and 33 per cent more than that of the plots which were treated with 20 kg N ha^{-1} and 0 N (control) respectively. Similarly, microbial biomass C and N content due to 40 kg N ha^{-1} (irrespective of source) was 46 per cent more than that of 0 N treatment.

A comparison of the yields of sole and intercrops showed a reduction in the seed yields of soybean and pigeonpea of 31 and 16 per cent respectively due to intercropping in 1996 (a good rainfall year), however in 1997 (a deficit rainfall year) the magnitude of reduction was more i.e., 47 and 120 per cent in soybean and pigeonpea respectively.

The studies on the use of natural resources by different cropping systems showed that the amount of light intercepted by crops, and the dry matter produced per MJ were more in the intercropping systems of soybean/sunflower and sorghum/pigeonpea than their respective sole crops (sole soybean and pigeonpea). Application of N at 20 or 40 kg N ha^{-1} (fertilizer N) in all systems improved the nitrogen use efficiency (kg biomass kg N^{-1} applied), agronomic efficiency (kg grain kg N^{-1} applied), and apparent recovery of N (%). These efficiencies namely NUE, AE, AR were considerably lowered when N was sourced as FYM.

In sum, (1) the application of 40 kg N ha^{-1} (mineral N) increased the LAI, dry matter production, nutrient uptake and seed yields of soybean and pigeonpea under sole and intercropping systems compared to control (0 N) and 20 kg N ha^{-1}; (2) the application of N inhibited nodulation and nitrogenase activity of both soybean and pigeonpea crops under the sole and intercropping systems; (3) the mean amount of leaf fall added to the soil by soybean was in range of 750 to 1000 kg ha^{-1} which amounted to 6-10 kg N ha^{-1} and 1.2 kg P ha^{-1}; while in pigeonpea the mean amount of leaf fall added to the soil was 1800 to 3000 kg ha^{-1} which amounted to 20 to 24 kg N ha^{-1} and 2.4 kg P ha^{-1}. (4) the growth and seed yields of soybean and pigeonpea crops were reduced when these were grown in intercropping systems than when grown as sole crops; (5) in the intercropping systems, soybean /sunflower and sorghum/pigeonpea were more efficient in utilising the natural resources compared to their respective sole crops; and (6) the application of higher levels of N (40 kg N ha^{-1}) irrespective of source of N applied increased the soil mineral N, net N mineralization, soil respiration and microbial C and N biomass in the soil.

The results of this study will have a major impact on the way the soybean and pigeonpea based cropping systems can be managed for justifying the productivity and maintaining soil quality of Vertisols in rainfed agriculture in semi arid tropical India.

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INTRODUCTION

CHAPTER 1

INTRODUCTION

Grain legumes provide a protein-rich source of food which is essential part in the diets of people inhabiting in the tropics. Legumes are productive and protective agricultural food products and also contribute to maintenance and restoration of soil fertility by biologically fixing a large proportion of atmospheric nitrogen (N). All over the world, particularly in the developing countries it is increasing by being realized that we must strive for a sustainable agriculture one which can feed their burgeoning populations not at the environmental cost exacted by present day intensive farming practices. Sustainable agriculture clearly requires that all nutrients removed by the crop or lost from the cropping system must be replenished and in the long-term. However this option exists for N but to restore the supplies of phosphorus (P) and potassium (K) by using fertilizers. But this is not the case for nitrogen, one of the nutrients required in the largest quantities for plant growth, and one which is commonly limiting for agricultural production. N can be directly captured `fixed' from the atmosphere (Giller & Wilson, 1991) by legumes. These crops have therefore been long recognized as important components of crop rotations and intercrops in the semi-arid tropical (SAT) farming systems.

Soybean (*Glycine max* (L.) Merrill) is one of the world's most important grain legume oilseed crop. It is grown on 68 million ha and 147 million tonnes of soybean are produced annually in the world with an average productivity of 2165 kg ha^{-1}. Soybean was grown in a small way for the past many decades in India, but since 1972 the area sown to the crop has increased substantially. Currently area under soybeans is growing at a compound rate of 600% per annum and over 5 million ha of the area are grown today. The average productivity of soybean crop in India is however very low, 862 kg ha^{-1} (FAO STAT 1998).

Pigeonpea (*Cajanus cajan* (L.) Millsp.) is another an important grain legume of the SAT; and India is a major producing country accounting for 90% of the global pigeonpea production. Pigeonpea remains an integral part of the rainfed subsistance cropping systems of the dry tropics. Its popularity can be attributed primarily to it being a deep-rooted and drought tolerant crop. It also adds substantial amounts of organic matter to the soil and meets food and household fuel requirements. The productivity of the crop in India is low, 533 kg ha^{-1} (FAO STAT, 1998).

SAT soils are usually low in organic matter (<1%) as compared with soils in temperate environments (2-4%). Because organic matter is the primary source of N in the soil, many soils in the SAT are incapable of maintaining adequate N amounts, and N fertilization therefore becomes necessary for reasonably high crop yields on tropical soils. Histrocially, N fertilization of crop in the SAT has been considered a risky investment because of the unpredictability of weather. Furthermore, soil nitrate can be left unused in the soil in the absence of rainfall, or be lost through leaching by excessive rains at the onset of the planting season (Adu-Gyamfi *et al* 1996). These soil N and rainfall complexities give rise to highly variable yields, as well as variable use efficiencies of soil- and applied N. Yet, fertilizer use in the SAT can be profitable, particularly if combined with improved fertilizer management practices, high yielding varieties (Katyal 1989; Venkateswarlu 1987), and appropriate cropping system combinations.

Intercropping systems offer an economically attractive and ecologically sound means of reducing external input and improving internal resources. The inclusion of legumes in cropping systems, a common practice of resource-poor farmers in the SAT, is a cheap and efficient means of providing N-input to the system. Yield advantages, efficient light interception production efficiency monetary advantage, and improved N_2 fixation of intercropping over sole cropping has been extensively reviewed (Ali 1990, 1996; Willey 1985, 1996, Ofori & Stern, 1987; Kumar Rao *et al* 1996). The SAT stretches over 48 countries in 4 continents and supports more than 700 million people, most of whom live in rural areas improved and appropriate fertilizer technologies are therefore expected to play a dominant role in meeting projected long-term food requirements (Adu Gyamfi, *et al* 1996).

Further, soil microflora play an important role in the maintenance of soil fertility because of their ability to carry out biochemical transformations and also due to their importance as a source and sink for mineral nutrients (Jenkinson and Ladd, 1981). Because microorganisms affect soil fertility and hence the functioning of ecosystems, measurement of the nutrients held in the soil microbial biomass has attracted considerable attention in recent years (Smith and Paul, 1990). Soil organisms are the arising force behind nutrient transformations and thus make an essential contribution to soil fertility and ecosystem functioning Therefore, changes in the size of the biomass affect the cycling of N and P and their availability to plants. Knowledge of their implications for the availability of plant nutrients in soil (Saffigna *et al* 1989). Organic substances supplied to the soil via residues and waste from animals and plant production are used as an energy and nutrient source for microorganisms (Rauche, 1987). Knowledge on variations in soil biological & chemical properties due to management practices is scarce in dry land farming systems in the tropics (Singh and Singh, 1993).

Realizing the significance of N application in improving the productivity and efficiency of soybean and pigeonpea under sole and intercroppingsystems and their influence on soil biological and chemical properties, the present investigation was carried out with the following objectives :

- to study the impact of N application on pattern of growth,nutrient uptake and seed yield of sole soybean and soybean/sunflower systems.
- to study the impact N application on pattern of growth, nutrient uptake and seed yield of sole pigeonpea and sorghum/pigeonpea systems.
- to evaluate the inhibitory effect of organic and fertilizer N on nodulation and nitrogenase activity of nodules in soybean and pigeonpea under sole and intercropping systems.
- to quantify the addition of biomass and its N and P to the soil through abscised dry matter (leaf fall) by soybean and pigeonpea under different N management practices.
- to assess the impact of intercropping on soybean and pigeonpea in respect of growth rate, N accumulation rate and seed yield.
- to evaluate the efficiency of the sole and intercropping systems; sole soybean, soybean/sunflower, sole pigeonpea and sorghum/pigeonpea systems as influenced by N application.
- to elucidate the changes in biological and chemical properties of soil under different N management practices and cropping systems.

REVIEW OF LITERATURE

CHAPTER 2

REVIEW OF LITERATURE

The literature with reference to fertilizer application in soybean and pigeonpea; intercrops sunflower and sorghum and its impact on soil biological and chemical properties are presented in this chapter.

2.1 SOYBEAN

2.1.1. Importance of Soybean

Soybean (*Glycine max* (L.) Merrill) is one of the world's most important grain legume oil seed crop. It is grown on 68 million ha and 147 million tonnes of soybean are produced annually in the world with an average productivity of 2165 kg ha^{-1} (FAOSTAT, 1998). Soybean was grown in a small way for the past many decades in India, but since 1972 the area sown to the crop has increased substantially. The area under soybean has increased by a compound rate of 600% per annum and currently the crop is grown on over 5 million ha. The average productivity of soybean crop in India is however very low: 862 kg ha^{-1} (FAOSTAT, 1998). The leading soybean producers in the world are USA, Brazil, mainland China, Argentina and Paraguay.

Amongst the abiotic constraints to increased productivity of soybean in the semi-arid tropics (SAT), soil N is prominent. The SAT regions are usually low in organic matter (less than 1%) as compared to the soils in temperate eco-environments (2-4%). Because organic matter is the basic source of available-N in the soil, many soils in the SAT are incapable of maintaining N supply in adequate amounts; N fertilization, therefore, is necessary for obtaining reasonably high yields of soybeans in SAT agriculture. A brief survey of literature on the response of soybeans to soil fertility management follows.

2.1.2. Response of Soybean to Fertilizer Application

2.1.2.1. Growth and development

Jadhav *et al.* (1994) observed that on Vertisols of Pune (Maharastra) in soybean (cv MACS 13), the leaf area produced was slow up to 42 days after sowing (DAS); it increased rapidly thereafter and about 84 per cent of leaf area plant^{-1} was attained at 56 DAS. The dry matter accumulation was also slow during initial stages (up to 28 DAS); thereafter, it progressively increased and 30% of dry matter plant^{-1} accumulated by 56 DAS. Application of 60 and 90 kg N ha^{-1} significantly increased plant leaf area at all stages of crop growth as compared to control and 30 kg N ha^{-1}. The application of 30 kg N ha^{-1} also produced significantly more leaf area plant^{-1} than control. Crop treated with N @ 60 and 90 kg ha^{-1} accumulated significantly more dry matter in leaves, stem, branches and pods and, therefore, produced more total dry matter than control and 30 kg N ha^{-1}. The crop was grown during rainy season and soil was low in available N (140 kg ha^{-1}), medium in available P_2O_5 (22 kg ha^{-1}) and high in available K_2O (413 kg ha^{-1}). During the crop season a well distributed rainfall of 520 mm spread over 35 rainy days was recorded. Krishna *et al.* (1995) grew irrigated soybean (cv. MACS 58) on a Vertisol at Bapatla (Andhra Pradesh) during the post rainy season. N was applied at 30 and 60 kg ha^{-1}. N application increased the dry matter production by 13% over control. No significant difference was observed between 30 and 60 kg N ha^{-1}. The experimental soil was low in available N (220 kg N ha^{-1}), medium in available P (40 kg P_2O_5 ha^{-1}) and high in available K(572 kg K_2O ha^{-1}).

On a sandy loam soil of New Delhi, Nimje and Seth (1988) observed increased soybean dry matter yields at harvest (55 to 79 g plant^{-1}) with the application of increasing rates of P_2O_5 up to 80 kg ha^{-1}. On the same soil containing 0.042% total N, application of 15 t FYM ha^{-1} increased plant dry matter significantly at harvest (61 to 76 g plant^{-1}). Response of soybean to P application at low (10 mM KH_2PO_4) and high (200 mM KH_2PO_4) rates was studied in a nutrient culture solution. The most striking result of low P treatment was a 85% reduction in total leaf area and a

78% reduction in shoot dry weight. The root growth was significantly less affected (Fredeen *et al.* 1989). During the rainy cropping season, Agarwal *et al* (1996) grew soybean on a Vertisol at Jabalpur. They reported a progressive increase of leaf area index (LAI) to blooming growth stage (60 DAS) with the increasing levels of applied P upto 60 kg P_2O_5 ha^{-1}. At 60 DAS a significant decline in LAI was registered due to the senescence of leaves. Maximum LAI was noted at 80 kg P_2O_5 ha^{-1} while leaf weight ratio (LWR) at 100 kg P_2O_5 ha^{-1} and specific leaf area (SLA) at 120 kg P_2O_5 ha^{-1}. No specific trend to P application was noted. The crop growth ratio (CGR) initially reduced with applied P (<60 kg P_2O_5 ha^{-1}) but it significantly increased when 100 kg P_2O_5 ha^{-1} was added; and a maximum was noted at 120 kg P_2O_5 ha^{-1}. Though, 120 kg P_2O_5 treatment registered significantly higher relative growth rate (RGR) as compared to control, it did not differ significantly from other P levels. The available N P K status of the experimental soil was 230 kg N, 14 kg P_2O_5 and 280 kg K_2O ha^{-1}.

Ramamoorthy and Shivashankar (1996) grew irrigated soybean under different levels of applied FYM @ 0, 5 and 10 t ha^{-1} on an Alfisol containing 339 kg ha^{-1} available N during the summer season. They observed that the LAI (2.25 to 3.08) increased significantly as the level of applied FYM was increased. Dry matter (DM) production also significantly increased (from 29 to 42 g $plant^{-1}$) with an increased application of FYM. Khamparia (1996) reported that application of increasing rates of P_2O_5 from 0 to 100, and zinc from 0 to 6 kg ha^{-1} to soybean grown on a Vertisol of Sagar, Madhya Pradesh under rainfed conditions, improved plant growth (plant height and DM) compared to control (no P and Zn). Application of 56 kg P_2O_5 ha^{-1} recorded significantly higher LAI and DM than 37 kg P_2O_5 ha^{-1} at all growth stages. The initial fertility status of the soil was 232 kg N, 19 kg P_2O_5 and 314 kg K_2O ha^{-1}.

2.1.2.2. Nodulation, nitrogenase activity and N_2-fixation

Influence of organic amendments (FYM and oilcakes) on nodulation and nitrogenase activity of soybean was studied on a silt loam (0.011% N) at Pantnagar under rainfed conditions.

Nodulation at 30 DAS was extremely poor. At 60 and 105 DAS a significant improvement in nodulation was observed. With the increased levels of application of FYM/oilcake from 2.5 to 7.5 t ha^{-1}, the nodule weight increased from 625 to 1400 mg $plant^{-1}$ in the FYM (1.13% N) treatment, but reduced from 25 to 17 mg $plant^{-1}$ in the linseed cake (5.3% N) and 35 to 0 mg $plant^{-1}$ in mustard cake (5.4% N) treatments. N balance based on soil N, crop uptake, N fertilizer, and N fixation was calculated; it revealed that maximum amount of N was fixed (165 kg ha^{-1}) in soils which were amended with the highest level of FYM (7.5 to ha^{-1}) (Dev and Tilak,1976). In Bangladesh, Rahman *et al.* (1982) studied the response of applied N to soybean (cv. Davis). They found that N applied @ 100 kg ha^{-1} increased plant growth but drastically reduced the nodule number and nodule weight. The combined application of inoculum + urea (25 kg N ha^{-1}) showed good performance with respect to number of nodules and their dry weight. Katoch *et al.* (1983) conducted a pot culture study on nodulation of soybean in a silty clay loam soil (O.C 2%), and found that nodule number and weight per plant were highest when 30 kg N ha^{-1} was applied. With an increased dose of N to 60 kg N ha^{-1}, the nodule weight and nodule number of the crop were significantly reduced.

The subject of biological N fixation (BNF) by soybean has been pursued by several workers. On coarse loams (Typic Eutocrepts) soybean showed great variability between germplasm in their ability to fix N at different inorganic soil N levels. In almost all the cases, application of 100 kg N ha^{-1} resulted in a lower BNF than at 20 kg N ha^{-1}. However, BNF in one cultivar, cv. *Dunadja*, was not significantly affected by the higher rate of fertilizer N application. Across the varieties the amount of BNF (estimated by ^{15}N method) was reduced from 26 to 8 kg N ha^{-1} by raising the fertilizer N level from 20 to 100 kg N ha^{-1}. The amount of ethylene produced from the soil at 20 kg N ha^{-1} level was higher for most of the cultivars than when the soil was fertilized with 100 kg N ha^{-1}, while cv. *Dunadja* showed a higher acetylene activity at the 100 kg N ha^{-1} level (Hardarson and Danso, 1984). So this type of cultivar would be particularly useful in situations where soil N levels are high or where there is a need to apply high amounts of fertilizer N cv. *Dunadja* was also responsive to fertilizer N; it produced higher seed yield at 100 kg N ha^{-1} fertilizer application compared to 20 kg N ha^{-1}. Coale *et al.* (1985) conducted an experiment on Mattapex silt loams of Beltsville, Maryland, USA. Two replications were planted on soils previously cropped to alfalfa for two years and two replications on soil previously cropped to soybeans for four seasons. Soybeans following soybeans were more dependent upon BNF than soybeans following alfalfa with the former deriving 65% of the total plant N from BNF and the latter only 32%. Soybean cultivars apparently utilized soil N first and then used BNF-N_2 to satisfy their N needs.

Torres *et al.* (1988) conducted four experiments in Los Banos, Philippines: two on a rice-farmer's field and two on the IRRI (International Rice Research Institute) experimental farm (total N 0.9-1.3 g kg^{-1}). They observed that in post-paddy soybean production system a basal dose of fertilizer N can improve N nutrition; however, this study did not reveal any evidence to suggest that basal application of 20 kg N ha^{-1} interacts with BNF to increase N fixation and improves N nutrition of soybeans. Torres *et al.* (1988) opined that if a soybean crop is cultivated in the post-rice season, it requires 500 to 600 mg N $plant^{-1}$ (approximately 150 kg ha^{-1} at 2,50,000 to 3,00,000 plants ha^{-1}). They suggested that more radical BNF and fertilizer N practices than those tested in the study will be needed to promote efficient N assimilation.

Nitrogen fixation by irrigated soybeans was studied in a field experiment on a grey clay soil at Trangie, N.S.W. in Australia during the summer growing season. Plant available N in the soil reduced from 38 to 18 mg N kg^{-1} when oats were grown during the previous winter growing season. Initially, growth and accumulation of N in the plant was lower in pre-cropped than pre-fallowed soil but BNF was higher. Soybeans on pre-cropped soil recorded higher seed yields (3.5 t ha^{-1}) with significantly higher concentration of N in the seed than from plants grown in pre-fallowed soil. This study concluded that growing winter cereals on land newly broken from pasture, coupled with higher rates of inoculation of soybeans may be a profitable way of diminishing plant available soil N, thus maximizing the contribution of N from BNF with the attendant benefits in seed yield and its protein content (Bergersen *et al.* 1989). Brockwell *et al.* (1989) also studied the effect of soil N in pre-fallowed and pre-cropped soils, on the nodulation of soybean on grey clay soils under irrigated conditions at Trangie, N.S.W. in Australia. Mineral N initially was higher in pre-fallowed soil than in pre-cropped soil [38 vs 18 mg N kg^{-1} in surface 10 cm soil]. Depletion of mineral N occurred more rapidly in pre-fallowed treatments so that, 7 days after harvest, mineral-N in pre-cropped soil was significantly higher than in pre-fallowed soil (14 vs. 11 mg kg^{-1}). With higher levels of soil mineral N, plant nodulation reduced. These authors concluded that when levels of soil N are high, cereals or other non-legumes should be grown for most efficient exploitation of N. Legumes should be introduced into the rotation once the soil N level has fallen below a threshold at which legume cropping can be expected to make a positive contribution to the pool of soil N. Non-legumes should be re-introduced when the level of mineral soil N has once again risen above that threshold. The cycle may be continued.

At Kagawa, Japan, Asanuma *et al.* (1992) studied the effect of fertilizer N on biomass production, nodulation, seed yield in soybean (cv. *Akiyoshi*) grown in a sand culture pot experiment in a glasshouse. Plants received nutrient solutions containing either no nitrogen (0 N), 100 ppm N (1 N) or 200 ppm N (2 N) treatments. Dry matter accumulation in the N treatments and the leaf area increased with increasing levels of N, whereas, the nodule development was significantly suppressed in the soybeans receiving fertilizer N supplements. Yield and its components were not significantly affected by the level of fertilizer N, although 2 N gave a slightly higher 100 seed weight and total seed yield $plant^{-1}$.

On Vertisols of Raipur, Madhya Pradesh, Pandey *et al.* (1995) found that in soybeans grown during the summer cropping season under irrigated conditions, the nodule number and weight, and their N content increased upto flowering and thereafter decreased till maturity.

Application of 20 kg N ha^{-1} applied each at sowing time and pod initiation stage affected positively nodule number and dry weight, and the N content of nodules. The experimental soil was low in available N (207 kg ha^{-1}). Response of soybean (cv. *Bragg*) to N fertilization on Vertisols (total N 0.04%) was studied by Haider *et al.* (1995) who found that N application @ 20 kg ha^{-1} had produced twice the number of nodules and weight of nodules compared to the control treatment. Shoot weight increased by 1.3 and 1.4 times due to the application of 20 and 40 kg N ha^{-1} respectively over control. Application of fertilizer N increased root weight over the control treatment.

Sharma (1995) reviewed literature on the response of soybean to fertilization and concluded that although soybean crop responds positively to fertilizer N application at rates as high as 120 kg N ha^{-1}, but nodulation and BNF are adversely affected when more than 30 kg N ha^{-1} is applied. BNF amounting to 60-70 kg ha^{-1} has been reported even under rainfed conditions. P and S are also critical for soybean nutrition.

Igor *et al.* (1997) observed that under controlled conditions, nodulated soybean plants supplied with 10 mol m^{-3} NO_3^-- N at the vegetative stage of growth, caused a rapid decline in BNF (acetylene reduction) and consequently the content of ureides in the xylem sap also declined.

Kundu *et al.* (1996) observed that on Vertisols containing 326 kg available N ha^{-1}, that BNF was increased with an application of 4 tonnes of FYM ha^{-1} (69%), but the application of 8 and 16 t FYM ha^{-1} reduced BNF to 62 and 59%, respectively. However, total N yields from BNF when 8 and 16 t ha^{-1} of FYM applied was higher than that observed from an application of 4 t ha^{-1} of FYM. Beyond 4 t ha^{-1} of FYM application, the increase in seed and straw yields did not contribute much to BNF. The increased N in plants at 8 and 16 t ha^{-1} of FYM application was largely contributed by soil + FYM and fertilizer N. The net contribution of BNF to soil N balance following the harvest of soybean was negative under all the FYM treatments ; it was found to be of the order of -56 kg N to -90 kg N ha^{-1} following the cultivation of soybean and the removal of all the straw from the field. Such losses of N could be minimized substantially (-12 kg N to 36 kg N ha^{-1}) if the straw was returned to the soil. It was concluded that the cultivation of soybean apparently left a negative N balance in the soil; and its magnitude could be still higher if soybean straw is not returned to the soil. Pramilarani and Kodandaramaiah (1997) found that, highest significant dry weight of nodules (695 mg per 5 plants) was obtained when 30 kg N ha^{-1} was applied to a crop grown on a Vertisol under rainfed conditions. During cropping season, rainfall of 775, 792 and 576 mm was recorded during the three years of the experiment.

Sarkar and Tripathi (1996) grew rainfed soybeans on a Vertisol (available N, P_2O_5, K_2O=235, 14, 330 kg ha^{-1}) and found that the application of N and P (N_{30} P_{60}) + rhizobium allowed soybean to fix (182 kg ha^{-1}) more N. The content of soil N was also high (282 kg ha^{-1}) under this treatment. Saran *et al.* (1996) reported that rainfed soybean grown on Vertisols recorded highest nodule mass with 5 t ha^{-1} crop residue + 30 and 12 N P kg ha^{-1} of fertilizer application. Highest nitrogenase activity was observed in the treatment N P at 20:13 kg ha^{-1} + crop residues 5 t ha^{-1} as surface mulch and the nitrogenase activity was the least when N:P was applied @ 20:13 kg ha^{-1} + FYM (6 t ha^{-1}).

Khamparia (1996) found that in rainfed soybean grown on Vertisols (containing 232, 19, 314 available N, P_2O_5, K_2O respectively) the nodule number (30 to 60 $plant^{-1}$) and nodule weight (99 to 244 mg $plant^{-1}$) increased with the application of 50 kg P_2O_5 ha^{-1} and zinc @ 6 kg ha^{-1} compared to control (P_0 Zn_0).

The influence of K nutrition on dry matter yield, nodulation, BNF and nitrogenase activity of soybean was studied under controlled conditions in hydroponic and sand culture at 4 levels of K (1, 5, 10 and 20 mM) in the nutrient solution. The dry matter yield, nodule parameters (nodule number and fresh weight of nodule per plant, average weight of nodule) and total nitrogen accumulation in the plant increased with higher K supply. The K level of 1 mM was found to be suboptimal for normal nodulation and BNF, whereas the K level of 5.0 mM was found to be

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2.1.2.3. Nutrient uptake and yield

The combined application of inoculum + urea @ 25 kg N ha^{-1} to soybean gave increased pods $plant^{-1}$, seeds $plant^{-1}$, seed weight and seed yield (1.7 t ha^{-1}) than control (1.6 t ha^{-1}) and 100 kg N ha^{-1} (1.5 t ha^{-1}) (Rahman *et al.* 1982). In a pot culture study at Palampur, on silty clay loam soils (O.C 2%), soybean seed yield and yield attributes were not significantly influenced by N application (0 to 60 kg N ha^{-1}) according to a report by Katoch *et al.* 1983.

Duong *et al* (1984) reported that soybean (cv. MTD10) cultivated on a moderate acid paddy soil of the Mekong Delta of Vietnam responded well to a multi-strain inoculation and to N fertilizer. Grain yields of uninoculated plants were linearly correlated to N application (0 to 80 kg ha^{-1}). However, protein content of grain and nitrogen uptake per unit area to produce grain decreased with an increasing rate of N application. Inoculated plants (with no N) had superior characteristics viz., shorter life cycle, shorter flowering duration, higher grain yields (2.9 t ha^{-1}), higher 100 seed weight. Grain yields of the inoculated plants was almost 10 times greater than the control (no N) and more than 2.5 times greater than the uninoculated plants receiving 80 kg N ha^{-1}. The uninoculated plants had to be fertilized with 240 kg N ha^{-1} to produce comparable yields to the inoculated plants. Pasaribu *et al* (1987) conducted three experiments on farmers' and experimental fields at Los Banos, IRRI and concluded that, N fertilizer increased the dry matter yield, leaf area and grain yield of soybean grown during short days in the post-paddy rice season. They advocated that soybean cultivation under short days after rice harvest, in southeast Africa, neither N fertilizer nor inoculation with *Rhizobium japonicum* appears capable of meeting N needs for grain yields of 2.0-2.5 t ha^{-1} of varieties which mature in less than 80 days.

Wakimoto (1989) from Hiroshima, Japan examined the effects of application of N fertilizer and FYM on soybean grown in uplands which were converted from paddy fields. When FYM was not applied, the yield-increasing effect of basal or top dressed N could hardly be expected. Particularly, top dressing of 5-10 kg N ha^{-1}, at the flowering stage of the crop resulted in a 10% yield increase. High positive correlation was observed between grain yield and the total top weight or the total amount of N removed by plants. Top dressing by 10 kg N ha^{-1} and 5 t of compost inhibited the root nodule formation. The author suggested that the N and FYM should be applied basally to obtain high yields of soybean. Lamb *et al.* (1990) conducted 12 field experiments in northwest Minnesota to evaluate the effects of fertilizer N on soybean on a variety of soils (20 to 160 kg NO_3^- N ha^{-1}) and reported that soybean grain yield response and BNF is strongly related to the soil NO_3^--N content. When soil NO_3^--N in the surface 50 cm soil was less than 80 kg ha^{-1}, grain yields were still increasing with fertilizer rates of 120 kg N ha^{-1}. In rainfed Vertisols (organic carbon 0.5%) of Akola, N application @ 12.5 to 50 kg ha^{-1} significantly increased the grain yield (2 to 2.4 t ha^{-1}) over the control. The pods and grain yield $plant^{-1}$, grains pod^{-1} and grain weight significantly increased due to N application, highest values were recorded at 50 kg N ha^{-1} (Dahatonde and Shava, 1992).

Significantly higher yield of soybean was observed at 60 kg N ha^{-1} (3.4 t ha^{-1}) compared to control (2.9 t ha^{-1}); 30 kg N ha^{-1} gave 3 t ha^{-1} and 90 kg ha^{-1} produced 3.3 t ha^{-1} yield when the crop was grown during rainy season on Vertisols in Pune (Maharashtra). The soil was low in available N (140 kg ha^{-1}) medium in available P_2O_5 (22 kg ha^{-1}) and high in K_2O (413 kg ha^{-1}). During the crop season a well distributed rainfall of 520 mm spreadover 35 rainy days was received (Jadhav *et al.* 1994).N application at 30 and 60 kg ha^{-1} to soybean (cv. MACS 58) grown on a Vertisol in Bapatla (Andhra Pradesh) during post rainy season with irrigation significantly increased the seed yield to 1.4 t ha^{-1}; haulm yield to 1764 kg ha^{-1} and harvest index to 44% as compared to 0 N (1.1 t ha^{-1}, 1440 kg ha^{-1} and 43%, respectively). Available N status of the soil was high (270 kg ha^{-1}), available P was medium (40 kg P_2O_5 ha^{-1}) and available K was high (572 kg K_2O ha^{-1}) (Krishna *et al.* 1995).

Pandey *et al.* (1995) grew irrigated soybeans during summer and observed the response of the crop to 20 kg N ha^{-1} applied at sowing and pod initiation stages. The N treatment increased N accumulation in plant when it was applied at later stages of growth and the seed yield was also significantly more than that for basal application of N. Pod number $plant^{-1}$ increased 1.2 fold with N fertilizer and the seed yield increased by 16% over the control (Haider *et al.* 1995).

On Vertisols containing 225 kg available N and 14 kg P ha^{-1} rainfed soybean showed maximum N uptake and seed yield (2.3 t ha^{-1}) when 30 kg N ha^{-1} and 26 kg P_2O_5 ha^{-1} were applied alongwith *rhizobium* seed inoculation compared to the individual and combined applications of N and P (Sarkar and Tripathi, 1996).

Patel *et al.* (1996) studied the response of rainfed soybean to N and P on Vertisols (available soil N 172 kg ha^{-1} and P_2O_5 10 kg ha^{-1}) at Indore on its yield and yield attributes. Both these attributes increased with an increasing application of N or P. Highest seed yield was recorded with the application of 45 kg N ha^{-1} which was 48, 29 and 9% respectively higher than the application of 0, 15 and 30 kg N ha^{-1}. The uptake of N, P, and K also increased with increasing level of N application.

Studies by Dev and Tilak (1976) on soybean grown in Pantnagar during rainy season on a silt loam soil (0.11% N) showed that the application of FYM, poultry manure, linseed cake and Indian mustard cake @ 2.5 to 7.5 t ha^{-1} significantly increased crop yield over control. The FYM treatment recorded 26% higher yield than the cakes amended treatment. The yield of soybean oil cake treatment was 1.5 times that of the control, indicating that excessive supply of N inhibits BNF.

In Madhya Pradesh rainfed soybeans grown on a Vertisol (available soil N 225 kg ha^{-1}) yielded significantly more (1.5 t ha^{-1}) when 5 t ha^{-1} FYM and 5 t ha^{-1} sugar press-mud were applied (Jain and Tiwari, 1995). Kundu *et al.* (1996) reported that the application of 4, 8 and 16 t FYM ha^{-1} significantly increased the yield of rainfed soybean (cv. *Punjab 1*) by 40, 69 and 85% respectively compared to no FYM on a Vertisol (326 kg ha^{-1} available N) in Bhopal. The average response of FYM @ 4 t ha^{-1} was 140 kg t^{-1} of FYM and as the level of FYM was increased to 8 and 16 t ha^{-1}, the response to FYM decreased to 125 and 77 kg t^{-1} of FYM respectively. The harvest index in FYM treatment was 37% and it decreased gradually with an increase in the level of FYM. On a Vertisol containing 183 kg available N ha^{-1}, soybeans responded remarkably well to the application of 10 kg N alongwith 6 t FYM ha^{-1} for yield (2 t ha^{-1}) and yield attributes (Sharma and Dixit, 1987). Application of fertilizer N resulted in a significant increase in N and protein content in seed and straw. Application of 6 t FYM ha^{-1} alone and in combination with 10 kg N ha^{-1} through urea were found as good as 20 kg N ha^{-1} applied through urea alone. However, the concentration of oil in the seed decreased significantly by the application of N. Total uptake of N, P, K, Ca and Mg was higher in soybean when N_{10} P_{40} along with FYM (6 t ha^{-1}) was applied.

Sharma and Mishra (1997) reported that on Vertisols of Indore, rainfed soybean (cv. JS 7105) responded positively to N application and its conjunctive use with FYM or crop residues. The highest seed and straw yields of 3 t and 3.7 t ha^{-1} respectively were recorded in the treatment FYM equivalent to 30 kg N ha^{-1} and 20 kg fertilizer N ha^{-1} was conjunctively applied. Application of FYM at 6 t ha^{-1} resulted in an additional recovery of 23% N, 43% P, 50% K, 67% S, 52% Ca and 31% Mg as compared with the apparent recovery of these nutrients when only 30 kg N ha^{-1} was applied. This treatment proved superior to the application of 40 kg N ha^{-1} as far as recovery of primary and secondary nutrients was concerned.

Agarwal *et al.* (1996) reported that soybean cv. Gaurav grown on Vertisols (containing 230 kg N, 14 kg P_2O_5 ha^{-1}) showed increased seed yield of 2.0 t ha^{-1} with 100 kg P_2O_5 ha^{-1}, at par with an application of 80 kg P_2O_5 ha^{-1} which yielded 1.9 t ha^{-1}. Patel *et al.* (1996) grew soybean on a rainfed Vertisol (available P_2O_5 10 kg ha^{-1}) of Indore and observed increased seed yield with increasing levels of P_2O_5 up to 90 kg ha^{-1}. The highest seed yield was obtained at 90 kg P_2O_5 ha^{-1} which was 26, 12 and 7 per cent higher than the application of 0, 30 and 60 kg P_2O_5 ha^{-1}, respectively.

Rainfed soybean cv. PK 327 grown on sandy soil (containing 0.042% total N, 12 kg ha^{-1} available P) with 80 kg P_2O_5 ha^{-1} application proved significantly superior in N, P, K uptake (165 to 260 kg N, 17 to 35 kg P, 54 to 100 kg K ha^{-1}) and seed yield (3.4 t ha^{-1}) over 40 kg P_2O_5 ha^{-1} and control. Farmyard manure (15 t ha^{-1}) increased the uptake of all the nutrients (245 N, 32 P_2O_5, 92 K_2O kg ha^{-1}) at harvesting compared to zero manure (Nimje and Jagdish Seth, 1988). Ramamoorthy and Shivashankar, (1996) reported that irrigated soybean grown during summer on Alfisols (340 kg ha^{-1} available N), application of 10 t ha^{-1} of organic matter (FYM + rice straw in the proportion of 1:1) increased the grain yield by 17%, and stover yield by 12% over 5 tonnes organic matter and 30% in grain yield and 16% in stover yield over control. Higher grain yield (6% more) was recorded in case of 56 kg P_2O_5 ha^{-1} treatment than 38 kg P_2O_5 ha^{-1}.

Influence of biofertilizers and indigenous sources of nutrients on productivity of rainfed soybean was studied by Sharma and Parmar (1997) on Vertisols of Sagar, Madhya Pradesh. Highest uptake of N (170 kg ha^{-1}), P (8 kg ha^{-1}) and S (15 kg ha^{-1}) and yield (1.8 t ha^{-1}) was recorded with an application of 25 kg ha^{-1} of single superphosphate, phosphorus solubilizing bacteria and FYM @ 6 t ha^{-1}. The authors opined that the inclusion of biofertilizers in soil fertility maintenance schedules economise fertilizer use and enhance the productivity of rainfed soybean.

On Vertisols (230, 20, 315 kg ha^{-1} available N P_2O_5 K_2O, respectively) rainfed soybean seed yield was increased by 20% with an application of 50 kg P_2O_5 ha^{-1} and 6 kg Zn ha^{-1} over control. Khamparia, (1996) concluded that for optimum production of soybean the recommended fertilizer dose was N_{20}, P_{50}, and Zn_6 kg ha^{-1}.

On Vertisols containing 170 kg available N ha^{-1} and 10 kg P_2O_5 ha^{-1} rainfed soybean yield was increased to 1.9 t ha^{-1} with an addition of 45 kg N ha^{-1} and to 1.8 t ha^{-1} with an addition of 90 kg P_2O_5 ha^{-1}. On an average 48, 29 and 9% higher seed yield was harvested with the application of 45 kg N ha^{-1} over an application of 0, 15, and 30 kg N ha^{-1}. Similarly, 26, 12 and 7% higher seed yield was obtained with the application of 90 kg P_2O_5 ha^{-1} over 0, 30 and 60 kg P_2O_5 ha^{-1}, respectively. Significant effect of the application of N and P on their concentration in seed and straw was also observed by Patel and Chandravanshi (1996). Pradhan *et al.* (1995) reported that rainfed soybean cv. BR 2 grown on Oxisols (organic carbon 0.4%) with an application of 40 kg N ha^{-1} gave 45% higher seed yield over control. The performance of yield attributing factors was also superior. The yield increase at 80 kg N ha^{-1} application was 50% over control. Similarly an application of 40 kg P_2O_5 ha^{-1} increased grain yield by 40% over control. Further increase in the amount of N and P applied did not show a significant affect on soybean yield.

Saran *et al.* (1996) reported that on Vertisols of Indore, soybean grain yield and plant dry matter were similar and no significant effects of fertility management treatments were observed. The amount of leaf fall varied significantly with fertility management treatments and the highest amount of fallen leaf material of 2 t ha^{-1} was recorded with the application of N:P at 20:13 kg ha^{-1} + FYM @ 6 t ha^{-1} and the lowest in the control treatment (1 t ha^{-1}).

Experiments conducted on Vertisols (available N 150 kg ha^{-1}) revealed that conjunctive use of 6 t FYM ha^{-1} and fertilizer N and P (N_{20} P_{13} + 6 t FYM) proved most effective as it resulted in the highest uptake of nutrients, seed yield (1.9 t ha^{-1}) and water use efficiency (10 kg ha^{-1} mm^{-1}) (Sharma, 1997).

Tiwari and Chourasia (1992) grew rainfed soybean on Vertisols (containing 165, 225, 200 kg ha^{-1} N P_2O_5 K_2O) and found that an application of N_{10}, P_{40}, K_{10} was the most suitable dose. It gave highest grain yield (1.2 t ha^{-1}) and a net return of Rs.3100 ha^{-1}. On sandy clay loam soils of Gwalior, soybean (cv. JS 71-05) was grown during rainy season (with one irrigation), by Trivedi and Sharma (1997), who found that application of N (30 to 50 kg N ha^{-1}) had a significant influence on plant height, number of pods $plant^{-1}$ and seeds $plant^{-1}$. The maximum seed yield of 1.7 t ha^{-1} was recorded with the application of 50 kg N ha^{-1} which was 7% and 18% higher than the application of 40 and 30 kg N ha^{-1} respectively. The available nutrients in the soil were 120 kg N ha^{-1}, P 15 kg ha^{-1} and K 220 kg ha^{-1}. On Vertisols of Krishna-Godavari zone, Pramilarani and Kondandaramaiah (1997) reported that soybean recorded maximum yield of 1.9 t ha^{-1}(mean of three years) with 90 kg N ha^{-1}. A rainfall of 775, 792 and 576 mm was recorded during the crop seasons in three experimental years.

2.2 SOYBEAN/SUNFLOWER

2.2.1. Importance of soybean/sunflower

Shivaramu and Shivashankar (1992) studied on the performance of intercropped rainfed sunflower and soybean on a medium fertility (360 kg N ha^{-1}) sandy loam soil of Bangalore. The yield of sunflower was reduced with intercropping from 820 to 617 kg ha^{-1}. The yield of intercropped sunflower was slightly reduced with increasing plant population of soybean from 50 to 75 or 100%. Though the total dry matter $plant^{-1}$ in sunflower reduced marginally with an increase in soybean population level, its growth attributes were not affected. Intercropping of soybean with sunflower significantly lowered its seed yield from 1.5 t to 1.0 t ha^{-1} and 1.3 t to 0.8 t ha^{-1} in a 2 years study. The extent of reduction in yield due to intercropping was 37% and mainly attributed to the shading effect of sunflower. However, sunflower intercropped with soybean gave higher total income of Rs.6000 ha^{-1} compared with Rs.4200 ha^{-1} and Rs.4300 from sole crops of sunflower and soybean respectively. Under rainfed condition with limited moisture availability, 75%:75% of optimum sole crop population is recommended as an appropriate combination. A little information on soybean/sunflower is available, and a brief review on the effect of fertilizer application on sole crop of sunflower is presented in the following pages.

2.2.2. Response of sunflower to fertilizer application

2.2.2.1. Growth, nutrient uptake and seed yield

Pal *et al.* (1996) found that in irrigated sunflower grown during summer on silty clay loams (total N 1.83%, available P_2O_5 56 kg ha^{-1}, K_2O 232 kg ha^{-1}) N fertilization increased seed yield significantly and the highest yield (2.4 t ha^{-1}) was recorded in the treatment receiving 100 kg N ha^{-1}, though it was at par with 80 kg N ha^{-1} treatment (2.3 t ha^{-1}). The sunflower head diameter, seed weight and 1000 seed weight as well as biological yield increased significantly but stem growth and harvest index significantly were not affected due to N application.

Gimenez *et al.* (1994) grew sunflower on a sandy loam of alluvial soil in Cordoba (Spain) on a site of low N status. The cropping system followed was barley in the winter (without added N) and irrigated sunflower (cv. Sungro 385) was grown in May with two levels of N (-N = 0 and +N = 25 g N m^{-2}). N increased the relative leaf expansion rate (RLER) but the duration of expansion remained constant. The response of RLER to N was most marked in the early stages of leaf expansion; it decreased as leaves reached their maximum size. Differences in RLER produced large differences in final leaf area between N treatments. The response of leaf expansion (120 cm^2; 750 cm^2) was more in +N than in -N (45 cm^2; 200 cm^2) treatment at 33 days and 63 days after sowing. The leaf number increased in response to N with mean values of 29 ± 0.4 and 25 ± 0.6 in +N and -N treatments, respectively. This response contributed to a large response of LAI to N (3.5 at +N; 0.8 at -N). N promoted growth and significant differences were observed in N concentration at 56 and 71 but not at 42 DAS. Leaf expansion was soon restricted in -N plots suggesting that the N limited crop growth. Differences in the N content were evident from 56 DAS. As a consequence of reduced growth in -N plots, total leaf N on an area basis (g N m^{-2}) was significantly smaller in those plots, ranging between 15 for - N and 29% for + N plots.

On red sandy loams of Bangalore, increasing N levels from 0 to 60 kg ha^{-1} increased the yield of rainfed sunflower (hy BSH-1) upto an application of 60 kg N ha^{-1}. The higher mean seed yield of 1.2 t ha^{-1} was obtained with 60 kg N ha^{-1} which was significantly higher over other levels (0, 20, 40 kg N ha^{-1}). The number of filled seeds $head^{-1}$ and test weight increased with the increase in N application levels from 20 to 60 kg ha^{-1}. Rainfall received during three years of study was 397 mm, 479 mm and 389 mm. The initial fertility status of the soil was total N 0.8-1.0%, available P 16 to 21 kg P_2O_5 ha^{-1} and available K_2O 180 to 218 kg ha^{-1} (Ujjinaiah *et al.* 1994).

On lateritic soils (available N, P_2O_5, K_2O, 287-15-298 kg ha^{-1}) of Dapoli, Maharashtra, Wagh *et al.* (1992) reported that addition of different levels of N (0 to 100 kg ha^{-1}) exhibited significant increase in yield and yield attributes of rainfed sunflower. Higher values of yield attributes, viz., diameter of disc, weight $disc^{-1}$, weight of seeds $plant^{-1}$ and number of seeds $plant^{-1}$ when 100 kg N ha^{-1} was applied. It also resulted in higher seed yield (0.9 t ha^{-1}) and stalk yield (1.8 t ha^{-1}). However, the seed yield and all yield of its attributes when 50, 75 and 100 kg N ha^{-1} was applied.

On deep high organic soils (available N 480 kg ha^{-1}) of Palampur, Kharwara and Bindra (1992) reported that irrigated sunflower (cv. EC 68414) accumulated significantly more dry matter at N additions to 90 kg ha^{-1}. With an increased level of N application (0 to 90 kg ha^{-1}) the uptake of N (30 to 107 kg ha^{-1}) P(18 to 38 kg ha^{-1}) and K (33 to 67 kg ha^{-1}) also increased. N @ 90 kg ha^{-1} significantly increased the oil yield (750 kg ha^{-1}) compared with other N application levels (30 and 60 kg ha^{-1}) or control.

On Vertisols (low N, medium P and high K) of Parbhani, Patil *et al.* 1992 studied the performance of rainfed sunflower. Application of 120 kg N ha^{-1} was at par with 80 kg N ha^{-1}. These treatments recorded significantly more sunflower (cv. LSH 3) seed yield $plant^{-1}$, per cent filled grains $plant^{-1}$, test weight and grain yield (1.65, 1.58 t ha^{-1}) and oil yield (555, 561 kg ha^{-1}). However, harvest index was significantly better with 0 N application compared to an application of 120 kg N ha^{-1}.

Ogunremi (1986) studied the influence of N fertilization on sunflower yield at two locations (Ibadan and Ilora) in Nigeria on ferric luvisols. In the Ilora zone, the highest average yield of seed 1.2 t ha^{-1} was obtained with an application of 60 kg N ha^{-1}; higher doses caused a highly significant depression in yield. Yield was reduced by more than 11% when N application was 90 kg ha^{-1}. Yield was significantly improved (1.5 t ha^{-1}) in the lowland rain-forest area of Ibadan when N at an application of 90 kg N ha^{-1}. Further increase in N application to 120 kg N ha^{-1} led to 24% decrease in yield. According to Sonuni and Chaskar (1991) in irrigated sunflower (cv. EC 68414) grown on an Alfisol during post rainy season at Dapoli (Maharashtra) N fertilization significantly increased the dry matter production (DMP) at all stages of crop growth. The response to N application was graded, and was significant up to 60 kg ha^{-1}: the dry matter significantly increased from 80 to 91 g pl^{-1}) at 60 kg N ha^{-1} addition compared to control. Favorable effects of N application were noted on the vegetative growth and yield contributing characters which ultimately resulted in an increased seed yield at 60 kg N ha^{-1} (962 kg ha^{-1}) over control (289 kg ha^{-1}). There was an increase in the seed yield by 155 and 30 per cent when 60 kg N ha^{-1} and 40 kg N ha^{-1} were applied, respectively as compared with the control (N=0). Jagtap and Sabale (1994) reported that sunflower (cv. EC 68414) grown under irrigated conditions, at Pune (Maharashtra) an application of N @ 50 kg ha^{-1} significantly increased its seed yield $plant^{-1}$ (22 g), total seed yield (1.7 t ha^{-1}) and stalk yield (4.0 t ha^{-1}) over control or 25 kg N ha^{-1}. Application of 25 kg P_2O_5 ha^{-1} significantly increased the seed yield $plant^{-1}$ (19.6 g), seed yield (1.5 t ha^{-1}) and stalk yield (3.4 t ha^{-1}) over control.

Lewis *et al.* (1991) found that rainfed sunflower sown (late spring) in seven locations in South Australia, on clay soils where average annual rainfall is 700 mm, only four gave significant responses to applied fertilizers. In one of the sites seed yields were significantly ($P \leq 0.001$) increased by applying P alone. In none of the years the addition of N nor K significantly increased seed yields at this site. This site had the lowest extractable P concentration (7 mg kg^{-1} soil).

Although soil extractable P concentration was high (28 mg kg^{-1} soil) at another site, a small but significant response was observed to applied P. At another site (extractable P 18 mg kg^{-1} soil), the addition of P and K together produced a significant increase ($P \leq 0.05$) in seed yield, but separate application did not show any increase in seed yield. The most significant response to K (extractable K 55 mg kg^{-1} soil) was observed where the addition of K and P significantly increased seed yields from 0.74 t ha^{-1} to 1.2 t ha^{-1} ($P \leq 0.001$). Application of N did not significantly increase seed yields at any of the sites. N @ 50 kg ha^{-1} was applied as urea, P @ 20 kg ha^{-1} as single superphosphate and K @ 50 kg ha^{-1} as KCl.

On Vertisols of Udaipur (Rajasthan), Susheel Kumar *et al.* (1995) observed that in the sunflower (cv. Morden) grown during post rainy season, the application of 80 kg N ha^{-1} significantly increased the plant height and girth of stem. N and P uptake in seed (43 to 64 kg ha^{-1} N; 11 to 16 kg P ha^{-1}) and stover (44 - 64 kg N ha^{-1}; 24 to 34 kg P ha^{-1}) was significantly more than control and the 40 kg N ha^{-1} treatment. Application of P @ 60 kg P_2O_5 ha^{-1} increased the uptake of N and P in seed (49 - 61 kg N ha^{-1}; 12 - 16 kg P ha^{-1}) and stover (50 - 64 kg N ha^{-1}; 26 - 34 kg P ha^{-1}) over control and 30 kg P_2O_5 ha^{-1}. Fertility status of experimental soil was: total N 0.075%, available P 16 kg ha^{-1} and available K 246 kg ha^{-1}. According to Mishra *et al.* (1995) irrigated sunflower (cv. Morden) grown during post rainy season on sandy loams of Bhubaneshwar (Orissa) (0.03% total N, 16 kg ha^{-1} available P and 156 kg ha^{-1} available K) gave increased dry matter accumulation (44 to 50 g $plant^{-1}$) with an increase in the level of N application from 20 to 60 kg N ha^{-1}. Similar effect of N levels was observed on the uptake of N, P and K. Application of 60 kg N ha^{-1} had a significant seed yield advantage of 24 and 8% over 20 and 40 kg N ha^{-1} respectively. Application of P at 60 kg P_2O_5 ha^{-1} significantly increased the dry matter yield $plant^{-1}$ (46 to 49 g) over control. The seed yield obtained with the application of P at 60 kg P_2O_5 ha^{-1} was 8% and 3% more than that of 20 and 40 kg P_2O_5 ha^{-1}, respectively.

Increased application of N upto 90 kg N ha^{-1} increased the sunflower grain yield (2.7 t ha^{-1}) and further increase to 120 kg N ha^{-1} decreased the grain yield (2.6 t ha^{-1}). Increased application of N to 120 kg N ha^{-1} increased the number of filled seeds, total number of seeds $plant^{-1}$, reduced the chaffiness, while the increase in test weight and seed yield was observed only upto the level of 90 kg N ha^{-1}. The increase in seed yield was 280 to 582 kg ha^{-1} and test weight was 3.42 and 275 g as N application was increased from 30 to 60 and 60 to 90 kg ha^{-1}, respectively. Increased application of P from 30 to 120 kg P_2O_5 ha^{-1} to sunflower increased the number of filled seeds and total number of seeds which contributed towards increases in seed yield. The increase in seed yield was 136, 114 and 113 kg ha^{-1} as the application of P was increased from 30 to 60, 90 and 120 kg P_2O_5 ha^{-1} respectively. The crop was grown under rainfed conditions on Vertisols of Dharwad with an annual rain of 726 mm (Megur *et al.* 1993).

On red loams of Bangalore (medium in total N 0.86%, available P 23 kg ha^{-1} and available K 170 kg ha^{-1}), Ujjinaiah *et al.* (1993) grew rainfed sunflower (cv. KBSH 1). The seed yields obtained with the application of 50% (825 kg ha^{-1}) and 25% (497 kg ha^{-1}) of the recommended N P K fertilizer dose (40:50:40 kg ha^{-1}) and 50% (397 kg ha^{-1}) and 25% (250 kg ha^{-1}) of the recommended dose of N only were significant with each other among N P K and only N treatments respectively. The yield were on par with 50% and full recommended N P K dose of fertilizer (907 kg ha^{-1}). Since the yield differences were on par between 50% and cent per cent recommended dose of N P K, an application of only 50% of the recommended dose (20:25:20 kg ha^{-1}) is likely to be more economical than the full dose.

2.3. PIGEONPEA

2.3.1. Importance of pigeonpea

Pigeonpea [*Cajanus cajan* (L.) Millsp] is an important grain legume of the semi-arid tropics (SAT). In the world it is grown on 5.2 million ha and 2.92 million tonnes of grain produced annually. It is grown on 4.88 million ha and 2.68 million tonnes of grain produced

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Pigeonpea has unique place in the cropping systems of the semi arid tropics. It is grown as a sole crop, as a mixed crop, an alley crop and it is often ratooned. Traditionally 90% of the pigeonpea is grown as a mixed crop or as intercrop with cereals, oilseeds or short duration legumes. However, with the development of short duration (120-150 days) and extra-short duration (90-100 days) varieties this crop has been grown as a sequence crop in different cropping systems (Ali, 1990).

One of the factors responsible for the low pigeonpea yields in the SAT has been inadequate soil fertility. The soils of the SAT are generally low in both total and plant available nutrients and therefore because of nutrients related problems in particular N, the crop yields in the SAT are low. As with most crops grown in the tropics the grain legumes too respond to fertilizer application. A brief survey of literature on the response of pigeonpea to fertilizer application follows.

2.3.2. Response of pigeonpea to fertilizer application

2.3.2.1.Growth and development

Matiwade and Sheelawantar (1992) observed that on Vertisols of Dharwad (Karnataka) short duration pigeonpea (cv. DT7) showed significant increase in dry matter production (12.52 to 14.55 g $plant^{-1}$), LAI (0.18 to 0.40) and LAD (18.55 To 26.34) with increasing level of nitrogen upto 50 kg ha^{-1} over zero N (control). The crop was grown under rainfed conditions and the available nitrogen, phosphorus and potassium status of the soil was 179, 18 and 528 kg ha^{-1}

respectively. In a pot culture study Kaushick *et al.* (1993) found that short duration pigeonpea varieties obtain maximum shoot and seed weight with 20 kg N ha^{-1} compared to 40 and 60 kg ha^{-1}.

In Peninsular India, medium duration rainfed pigeonpea (190 days to mature) grown on Vertisols and Alfisols responded to application of 20 kg N ha^{-1} as basal dose in terms of increased early plant growth upto 65 days after planting (Kumar Rao *et al.* 1981). Khan (1988) studied at Bangalore, N influence on pigeonpea (cv 3C) under green house conditions using black polythene bags containing 8 kg soil:sand mix in the ratio of 9:1. Application of urea at 20 and 40 kg N ha^{-1} levels significantly increased shoot, root and total plant dry weight. Total plant weight did not increase beyond 13.2 g $plant^{-1}$ even by application of increased level of N (beyond 40 kg N ha^{-1}). The increase in shoot, root and total plant weights due to application of 20 kg N ha^{-1} over 0 kg N ha^{-1} were 437, 337 and 289 per cent respectively, whereas increase in total plant weight due to application of 40 kg N ha^{-1} over 20 kg N ha^{-1} was only 3 per cent.

On Granite Regosols of SW Japan, pigeonpea (ICPL 312) attained maximum dry weight of whole plant at 92 DAP (days after planting) when it received 2.5 g P_2O_5 pot^{-1} and at 132 DAP under the highest P (5 g P_2O_5 pot^{-1}). The crop was grown during summer and irrigated the plants treatmently (Shoitsu Ogata *et al.* 1988). Short duration pigeonpea (130 days to mature) did not show any significant differences on growth, physiological stages and grain productivity with P application (0 to 75 kg P_2O_5 ha^{-1}). The crop was grown on Alluvial soils of Northern plains (Meerut) under rainfed conditions (Bhagwan Singh and Kalra, 1989). In a pot culture study at ICRISAT Asia Center, the short duration pigeonpea (ICPL 6) was grown on low-P Alfisols (7.2 mg kg^{-1} soil) during rainy season, Chauhan *et al.* (1992) found that low available P conditions crop recorded less biomass, less branching and fewer pods $plant^{-1}$. Leaf area retention was also markedly declined with lower P levels. Delayed flowering and maturity (upto 2 months) under P deficiency conditions. There was a significant fall in leaf area when added phosphorus level reduced from 160 to 80 mg P kg^{-1} soil, eventhough shoot weights were similar at these levels.

Puste and Jana (1988) observed that medium duration pigeonpea showed maximum values of DMP (dry matter production), LAI and CGR (crop growth rate) at all stages of crop growth with P application over control and maximum LAI and CGR were observed at 105 kg P_2O_5 ha^{-1}. The crop was grown under rainfed conditions and the available N, P and K status of the soil was 157, 36 and 112 kg ha^{-1} respectively. On Vertisols of Junagadh, medium duration (200 days to mature) rainfed crop did not respond beyond 25 kg N and 50 kg P_2O_5 ha^{-1} and plant spread, number of branches $plant^{-1}$, number of pods $plant^{-1}$ and number of grains pod^{-1} were maximum at these levels (Gondalia *et al.* 1988).

Patra (1989) found that short duration rainfed pigeonpea grown on Vertisols of North Central Plateau of Orissa, showed more plant height, number of pods $plant^{-1}$ and grains pod^{-1} with N P levels (40 N + 34.8 kg P_2O_5 ha^{-1}) than no fertilizer application. Soliappan *et al.* (1994) observed that rainfed pigeonpea (cv CO4) grown on sandy loams of Madurai, when it received 6.25 kg N and 12.5 kg P_2O_5 ha^{-1} as basal and DAP (diammonium phosphate) at 3 per cent foliar spray to supply 3.24 kg N + 8.28 kg P_2O_5 ha_{-1} at flowering, recorded more plant height (150 cm), LAI (3.0), number of primary branches (14) and dry matter production (5.2 t ha^{-1}) than no fertilizer application (130 cm, 2.0, 9, 3.6 to ha^{-1}) and recommended level (12.5 kg N + 25 kg P_2O_5 ha^{-1}) of fertilizer (150 cm, 2.6, 12, 4.7 t ha^{-1}). The crop was grown under rainfed conditions and available nitrogen and phosphorus status of the soil was 242 and 16.8 kg ha^{-1} respectively. On Vertisols of Dharwad, Chittapur *et al.* (1994) found that under rainfed conditions short duration pigeonpea (cv DR 7) showed significant improvement in plant height, number of branches $plant^{-1}$ at 60 and 90 DAS with increase in level of nitrogen (0.25, 50, 75 kg N ha^{-1}). But increase in P level (0, 25, 50, 75 kg P_2O_5 ha_{-1}) increased the plant height and number of branches $plant^{-1}$ at lower levels of N (0 or 25 kg ha^{-1}) whereas with higher level of N (50 or 75 kg ha^{-1}) the trend was almost reverse. However maximum plant height and number of branches $plant^{-1}$ were observed in the combination of 50 kg N + 25 kg P_2O_5 ha^{-1}. The available N content of the soil was low.

Nagaraju *et al.* (1995) reported that on Alfisols at Bangalore, pigeonpea (cv TTB 7) responded to P and N and attained maximum plant height, number of pods $plant^{-1}$ and number of seeds pod^{-1} at 69 kg P_2O_5 + 27 kg N ha^{-1} compared to control (no fertilizer). The crop was raised under rainfed conditions and rainfall received during two years of experimentation was 322 mm and 933 mm respectively.

2.3.2.2.Nodulation and nitrogenase activity

Khurana and Dudeja (1981) observed that short duration pigeonpea (130 days) grown on sandy loams of Northern Plains (Hisar) did not show significant effect on nodulation at 20 kg N ha^{-1} over control. Virendra Sandana (1997) reviewed the work on nodulation vs. nitrogen fertilization and concluded that the contribution of nitrogen fixing bacteria is high at low levels of nitrogen.

The four growth media, viz., Alfisol soil (total N and P 0.92%, 0.013% P), Vertisol soil (total N, P 0.57%, 0.02%), sand alone and sand-vermiculate-grit-mixture (SVG) in the ratio of 1:2:2 v/v were amended and compared for pigeonpea (cv ICP 1) nodulation and nutrient uptake at different sources (FYM and N) and levels (10% v/v or 30% v/v FYM; 25 or 200 ppm N) and P (0 or 35 kg P_2O_5 ha^{-1}) during postrainy season. From this study Kumar Rao and Dart (1981) reported that crop grown on SVG medium produced more nodule number (57 $plant^{-1}$) and nodule weight (75 mg $plant^{-1}$) than sand alone (21 and 41 mg $plant^{-1}$), Alfisol unamended (28 and 23 mg $plant^{-1}$) and Vertisol unamended (34 and 61 mg $plant^{-1}$). Addition of 25 ppm N to the nutrient solution had no effect on plants grown in sand, but nodulation, plant growth and nutrient (N and P) uptake were stimulated in both Alfisol and Vertisol soils. Nodules were formed in the presence of continuously supplied nutrient solution containing 200 ppm N. Although the N concentration in the dry matter (% N) for plants receiving 200 ppm N in sand culture was marginally higher than that for nodulated plants supplied 0 ppm N, the plant growth was much poorer. It could be that the nodules were ineffective and also that the root development was not good to utilize more available N. Addition of 35 kg P_2O_5 ha^{-1} stimulated nodulation and nitrogen fixation, with a 115% increase in dry matter over plants grown in unamended Alfisol soil; 24% increase for the Vertisol soil. Addition of farmyard manure (1.17% N; 0.39% P) stimulated both root and shoot development considerably in Alfisol, Vertisol and sand, although nodulation was reduced in sand, with virtually no nodules formed with addition of 30% v/v FYM to sand. In Vertisol soil, the nutrient uptake was not much affected by FYM addition, whereas in Alfisol soil and sand, N uptake was increased by three times and P uptake by six and four times, respectively. In sand, increasing FYM from 10 to 30% doubled the nutrient uptake. Possible explanations for increased growth and nutrient uptake may be that more nutrients (N and P) become available and possibly the farmyard manure supplies a plant hormone or absorbs excess seedling-produced hormone. These results suggested that legume growth can be improved by supplying FYM, especially in tropical soils where organic matter levels are generally low. On Alfisols of Peninsular India, Kumar Rao *et al.* (1981) reported that addition of nitrogen @ 100 kg ha^{-1} to the medium duration pigeonpea (rainfed) showed reduced nodule formation by 47 per cent, nodule weight $plant^{-1}$ by 74 per cent and nitrogenase activity per plant by 86 per cent over control at 20 days after sowing. But addition of 20 kg N ha^{-1} reduced nodule formation by 29 per cent, nodule weight by 73 per cent and nitrogenase activity by 54 per cent over control at 20 days after sowing. However, there were no differences between fertilized and unfertilized plants at 60 days after sowing. Similar reduction in nodulation with 200 kg N ha^{-1} was also observed. Kumar Rao *et al.* (1981) further reported that in pigeonpea (cv UWI-17) grown on sand culture, nodulation and nitrogenase activity were depressed by 25 ppm N as nitrate (11.5 to 8.4 m mole C_2H_4 $plant^{-1}$ hr^{-1}) compared to control.

Khan (1988) reported that under green house conditions using black polythene bags containing 8 kg soil:sand mix in the ratio of 9:1, nodule number (42 to 75 $plant^{-1}$) and nodule weight (222 to 8666 mg $plant^{-1}$) were increased with the application of 20 kg N ha^{-1} compared to control. Decreased number of nodules (75 to 7 $plant^{-1}$) and nodule weight (866 to 15 mg $plant^{-1}$)

were observed with increasing level of nitrogen application from 20 to 200 kg N ha^{-1}. However N content (%) in plant was increased from 0.8 to 1.7 with the application of 40 kg N ha^{-1} over control. Further increase in nitrogen application did not improve the N content in plant.

Hernandez and Focht (1985) revealed that the addition of P to an infertile Acid Oxisol in the Republic of Panama, pigeonpea showed increased shoot and nodule mass, acetylene reduction activity. It indicates that for pigeonpea, phosphorus was the most important limiting factor in Acid Bayano soils at SW of Japan. Pigeonpea was grown (ICPL 312) during summer in the plastic pots containing 15 kg of Granite Regosol (P 0.3 ppm). Nodule weight increased with increase of P rates (0 to 5 g P_2O_5 pot^{-1}). Acetylene reduction assay (m mol C_2H_4 pl^{-1} hr^{-1}) increased from 15 to 55 at 92 days after planting and from 4 to 25 at 132 days after planting with the increase in P rates from 0 to 5 g P_2O_5 pot^{-1}. Specific nitrogenase activity (m mol C_2H_4 g^{-1} nodule) was slightly increased with the increase in P rates but it declined after 2.5 g P_2O_5 pot^{-1} at 92 days after planting. On Vertisols of Nagpur containing 177, 63 and 348 kg ha^{-1} N, P_2O_5 and K_2O respectively, Kene *et al.* (1990) reported that the medium duration pigeonpea (cv C11) under rainfed conditions showed no adverse effect on nodulation and N fixation at higher doses of nitrogen and phosphorus (37.5 kg N + 75 kg P_2O_5 ha^{-1}).

On Vertisols of Peninsular India, Kumar Rao *et al.* (1987) quantified the nitrogen fixation with ^{15}N isotope method in medium duration pigeonpea (180 days to mature) under sole and intercropped with sorghum. Sole crop fixed 88% of the total N and intercrop fixed 96% of its total N uptake. The available nitrogen and phosphorus status of the soil was 6.5 mg kg^{-1} soil and 3.0 mg kg^{-1} soil respectively.

2.3.2.3.Nutrient uptake and yield

On Entisols of Rahuri, during rainy season with post monsoon irrigations (total rainfall received during 130 days of crop life was 46 mm) Jagdale and Daftardar *et al.* (1985) reported that the short duration pigeonpea (cv. Prabhat) yield was increased to 2200 kg ha^{-1} with 12.5 kg available N. Addition of 35 kg P_2O_5 ha^{-1} stimulated nodulation and nitrogen fixation, with a 115% increase in dry matter over plants grown in unamended Alfisol soil; 24% increase for the Vertisol soil. Addition of farmyard manure (1.17% N; 0.39% P) stimulated both root and shoot development considerably in Alfisol, Vertisol and sand, although nodulation was reduced in sand, with virtually no nodules formed with addition of 30% v/v FYM to sand. In Vertisol soil, the nutrient uptake was not much affected by FYM addition, whereas in Alfisol soil and sand, N uptake was increased by three times and P uptake by six and four times, respectively. In sand, increasing FYM from 10 to 30% doubled the nutrient uptake. Possible explanations for increased growth and nutrient uptake may be that more nutrients (N and P) become available and possibly the farmyard manure supplies a plant hormone or absorbs excess seedling-produced hormone. These results suggested that legume growth can be improved by supplying FYM, especially in tropical soils where organic matter levels are generally low. On Alfisols of Peninsular India, Kumar Rao *et al.* (1981) reported that addition of nitrogen @ 100 kg ha^{-1} to the medium duration pigeonpea (rainfed) showed reduced nodule formation by 47 per cent, nodule weight $plant^{-1}$ by 74 per cent and nitrogenase activity per plant by 86 per cent over control at 20 days after sowing. But addition of 20 kg N ha^{-1} reduced nodule formation by 29 per cent, nodule weight by 73 per cent and nitrogenase activity by 54 per cent over control at 20 days after sowing. However, there were no differences between fertilized and unfertilized plants at 60 days after sowing. Similar reduction in nodulation with 200 kg N ha^{-1} was also observed. Kumar Rao *et al.* (1981) further reported that in pigeonpea (cv UWI-17) grown on sand culture, nodulation and nitrogenase activity were depressed by 25 ppm N as nitrate (11.5 to 8.4 m mole C_2H_4 $plant^{-1}$ hr^{-1}) compared to control.

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Hernandez and Focht (1985) revealed that the addition of P to an infertile Acid Oxisol in the Republic of Panama, pigeonpea showed increased shoot and nodule mass, acetylene reduction activity. It indicates that for pigeonpea, phosphorus was the most important limiting factor in Acid Bayano soils at SW of Japan. Pigeonpea was grown (ICPL 312) during summer in the plastic pots containing 15 kg of Granite Regosol (P 0.3 ppm). Nodule weight increased with increase of P rates (0 to 5 g P_2O_5 pot^{-1}). Acetylene reduction assay (m mol C_2H_4 pl^{-1} hr^{-1}) increased from 15 to 55 at 92 days after planting and from 4 to 25 at 132 days after planting with the increase in P rates from 0 to 5 g P_2O_5 pot^{-1}. Specific nitrogenase activity (m mol C_2H_4 g^{-1} nodule) was slightly increased with the increase in P rates but it declined after 2.5 g P_2O_5 pot^{-1} at 92 days after planting. On Vertisols of Nagpur containing 177, 63 and 348 kg ha^{-1} N, P_2O_5 and K_2O respectively, Kene *et al.* (1990) reported that the medium duration pigeonpea (cv C11) under rainfed conditions showed no adverse effect on nodulation and N fixation at higher doses of nitrogen and phosphorus (37.5 kg N + 75 kg P_2O_5 ha^{-1}).

On Vertisols of Peninsular India, Kumar Rao *et al.* (1987) quantified the nitrogen fixation with ^{15}N isotope method in medium duration pigeonpea (180 days to mature) under sole and intercropped with sorghum. Sole crop fixed 88% of the total N and intercrop fixed 96% of its total N uptake. The available nitrogen and phosphorus status of the soil was 6.5 mg kg^{-1} soil and 3.0 mg kg^{-1} soil respectively.

2.3.2.3.Nutrient uptake and yield

On Entisols of Rahuri, during rainy season with post monsoon irrigations (total rainfall received during 130 days of crop life was 46 mm) Jagdale and Daftardar *et al.* (1985) reported that the short duration pigeonpea (cv. Prabhat) yield was increased to 2200 kg ha^{-1} with 12.5 kg

N ha^{-1} sprayed at flowering in addition to 12.5 kg N ha^{-1} as basal application as compared to control (1400 kg ha^{-1}) and 25 kg N ha^{-1} as basal application (1700 kg ha^{-1}). The available nitrogen and phosphorus status of the soil was 0.008% and 0.75% respectively. On Vertisols of Kovilpatti higher seed yields (1255 kg ha^{-1}) of pigeonpea (cv C 11) were observed with the combined application of inorganic fertilizers (20 kg N + 40 kg P_2O_5 ha^{-1}) and FYM (10 t ha^{-1}) besides rhizobial seed inoculation (740 kg ha^{-1}). Available nitrogen status of the soil after crop harvest was also high (100 kg N, 8 kg P_2O_5, 360 kg K_2O ha^{-1}) in FYM treated plots compared to control (87 kg N, 7 kg P_2O_5, 337 kg K_2O ha^{-1}), but marked differences were not observed in respect of soil moisture. The available nitrogen status of the soil was low (84 kg ha^{-1}) and phosphorus also low (6.2 kg P_2O_5 ha^{-1}) and the crop was grown during post monsoon season under rainfed conditions (Muthuvel *et al.* 1985). Matiwade and Sheelawantar (1990) observed that short duration pigeonpea grown on Vertisols of Dharwad as rainfed crop yielded 1361 kg ha^{-1} with 25 kg N ha^{-1} application and the yield was 18 per cent more than that of no nitrogen treatment. The available nitrogen and phosphorus status of the soil was 179 kg ha^{-1} and 18 kg ha^{-1} respectively. In a pot culture study on sandy loams (0.042% N) of Hisar, in short duration pigeonpea (125 days to mature) seed weight (2.8 $plant^{-1}$) and nitrogen accumulation (98 mg $plant^{-1}$) were significantly ($P^{3}0.05$) higher at 20 kg N ha^{-1} compared to control (1.9 g $plant^{-1}$; 56 mg $plant^{-1}$) and 40 kg N ha^{-1} (2.2 g $plant^{-1}$; 67 mg $plant^{-1}$) (Kaushick *et al.* 1993).

Kumar Rao *et al.* (1981) found that on Alfisols of Peninsular India, medium duration pigeonpea (ICPL 1) showed increased yields (970 kg ha^{-1}) with 20 kg N ha^{-1} application compared to control (850 kg ha^{-1}). Similar yield (970 kg ha^{-1}) was obtained with 200 kg N ha^{-1}, whereas on Vertisols slight increase in yield (1885 kg ha^{-1}) was observed with 20 kg N ha^{-1} over control (1834 kg ha^{-1}). Significantly higher yield (2234 kg ha^{-1}) was obtained with 200 kg N ha^{-1} application. On Vertisols of Gujarat (Navsari) Patel and Patel (1994) found, medium duration pigeonpea (150 days to mature) showed significantly increased grain yield, nodule number and dry weight with 20 kg N ha^{-1} over 10 kg N ha^{-1} and control (no nitrogen). The net income increased with successive increase in N level and the highest net income of Rs.5680 ha^{-1} was recorded with 20 kg N ha^{-1}. The crop was grown during rainy season and 2-3 irrigations were given during post monsoon period. The initial available nitrogen status of the soil was 115 kg ha^{-1} and phosphorus was 31 kg P_2O_5 ha^{-1}.

Kulkarni and Panwar (1981) summarized the results of experiments conducted on wide range of soils both on research farms and cultivators' fields and concluded that responses to 17 to 26 kg ha^{-1} phosphorus application ranged from 300 to 600 kg ha^{-1} grain yields in majority of the experiments. In summarizing the results of 503 trials measuring phosphorus response to pigeonpea in India, Tandon (1987) calculated a mean increase in yield of 310 kg ha^{-1} over an unfertilized control yield of 480 kg ha^{-1} upto an application level of 17 kg ha^{-1}. Again biologically optimum P application rate appeared to be in the range of 17-26 kg ha^{-1} but some responses upto 43 kg ha^{-1} were also reported.

Matiwade and Sheelawantar (1990) reported that the short duration varieties (140 days to mature) grown on Vertisols of Dharwad under rainfed conditions showed significantly higher seed yields (1379 kg ha^{-1}, at 100 kg P_2O_5 ha^{-1} and it was 12 and 16 per cent higher than no phosphorus (1236 kg ha^{-1}) and 50 kg P_2O_5 ha^{-1} (1298 kg ha^{-1}). The nitrogen and phosphorus availability in soil was 179 kg and 18 kg ha^{-1} respectively. Chauhan *et al.* (1992) found that in short duration (130 days to mature) seed yields increased with P level (5 to 30 g $plant^{-1}$). They further found that from a field experiment on Alfisols (rainfed) with 5 mg P kg^{-1} soil, short duration pigeonpea second flush yields were 46 per cent higher with 32 kg P_2O_5 ha^{-1} when applied at sowing in comparison to no application, whereas, first flush yields were similar in both P treatments. On Vertisols at Navsari (Gujarat) short duration pigeonpea (150 days to mature) grain yield increased significantly (1319 kg ha^{-1}) with 20 kg N ha^{-1} and 40 kg P_2O_5 ha^{-1} over control and 29 per cent above than the application of 10 kg N + 20 kg P_2o_5 ha^{-1}. Chittapur *et al.* (1994) reported that short duration pigeonpea (DT 7) showed increased yield at higher levels of N (50 kg ha^{-1}) over the lower level of nitrogen (25 kg ha^{-1}). Application of 50 kg P_2O_5 ha^{-1} increased yield significantly over control. Maximum grain yield (811 kg ha^{-1}) was recorded with a combination of 50 kg ha^{-1} each of nitrogen and phosphorus. The crop grown under rainfed conditions, soil status of nitrogen is low and phosphorus is medium. In Alfisols (available N was 188 and phosphorus was 18 kg ha^{-1}) of Bangalore short duration pigeonpea under rainfed conditions showed maximum yield when fertilizer was applied at 69 kg P_2O_5 + 27 kg N ha^{-1} (1036, 1626 kg ha^{-1}) over control (625, 668 kg ha^{-1}) and at 23 kg P_2O_5 + 9 kg N ha^{-1} (750, 1011 kg ha^{-1}) in both the years of study (Nagaraju *et al.* 1995).

At Kalyan, West Bengal, on sandy loams during post rainy season, medium duration pigeonpea showed maximum seed yields at 105 kg P_2O_5 ha^{-1} compared to control. The crop was grown under irrigated conditions. The available N and P of the soil was 0.07% N and 36 kg P_2O_5 ha^{-1} (Puste and Jana, 1988). Pigeonpea grown on Vertisols at Junagadh as rainfed crop produced 1110 kg ha^{-1} grain with 25 kg N ha^{-1} and 1090 kg ha^{-1} with 50 kg P_2O_5 ha^{-1} (Gondalia *et al.* (1988). Grain yield of medium duration pigeonpea grown on sandy loams (Madurai) was increased by 74% (1126 kg ha^{-1}) over control (647 kg ha^{-1}) when crop received basal application + foliar spray (6.25 kg N + 12.5 P_2O_5 and a foliar spray of DAP (3%) to supply 3.24 kg N + 8.28 kg P_2O_5 ha^{-1} on 70th day after sowing). Basal application and foliar spray of N and P produced 20% higher grain yield than basal application of N and P (942 kg ha^{-1}). The initial nitrogen and phosphorus status of the soil was 242 kg and 17 kg ha^{-1} respectively.

Kulkarni and Panwar (1981) reviewed the literature on response of pigeonpea to nitrogen, phosphorus and potassium and concluded that starter dose of 20-25 kg ha^{-1} nitrogen was beneficial in most cases and increased the yield by 60 to 280 kg ha^{-1}. Application of 40 to 60 kg P_2O_5 ha^{-1} increased grain yield by 200 to 600 kg ha^{-1} on cultivators' fields. Though the response to potassium was reported to be low in soils with low available potassium and in trials on cultivators' fields potassium gave a positive response ranging from 90 to 200 kg ha^{-1} with 20 kg K_2O ha^{-1} along with application of nitrogen and phosphorus (20 kg N + 40 kg P_2O_5 ha^{-1}). Singh *et al.* (1994) summarized the results of experiments conducted in farmers' fields for four years at 17 different locations. Short duration pigeonpea (125 days) responded to fertilizer application upto 40 kg N and 80 kg P_2O_5 ha^{-1}. The average increase in grain yield due to 40 kg N and 80 kg P_2O_5 ha^{-1} over control (N_0 P_0 K_0) was 77%. Over control 20% higher grain yield was observed with lowest fertilizer (10 kg N +20 kg $P_2O_5ha^{-1}$) rate. Response to 20 kg K_2O ha^{-1} was recorded at lower levels of N and P (20 kg N & 40 kg P_2O_5 ha^{-1}), but at higher levels of N (30-40 kg N) and P (60-80 kg P_2O_5 ha^{-1}) the response to potassium was not significant. With every increase in N P rate, yield increased significantly upto the highest levels tested (40 kg N and 80 kg P_2O_5 ha^{-1}). Kene *et al.* (1990) found that medium duration pigeonpea recorded maximum yield (861 kg ha^{-1}) and N P K content in straw and grain at higher doses of N P K (37.5 kg N + 75 kg P_2O_5 + 20 kg K_2O ha^{-1}) which was 200 per cent more than control and 53 per cent more than the recommended dose (25 kg N + 50 kg P_2O_5 ha^{-1}) indicating that potassium application along with higher doses of nitrogen and phosphorus was beneficial. The crop was grown on Vertisols (available nitrogen-0.08%, phosphorus 62.5 kg ha^{-1} and potassium 343 kg ha^{-1}) under rainfed conditions. Bhandari *et al.* (1989) reported that grain yield of medium duration pigeonpea increased with the increase in levels of nitrogen and phosphorus. Combined application of N and P further increased the yield significantly compared to individual application. Based on grain yields and monetary returns, optimum dose of N P K for pigeonpea was worked out as 20-17.5-16.6 kg N P_2O_5-K_2O respectively. The crop was grown on Vertisols of Ludhiana and the available N P K were in the range of 63-304 kg N, 1.8 to 55 P_2O_5 and 42-729 kg K_2O ha^{-1}.

The review indicates that in many situations a starter dose of 20 to 25 kg N ha^{-1} would be essential. The results indicated that the response to application of 20-50 kg P_2O_5 ha^{-1} in majority of the cases and higher responses upto 105 kg P_2O_5 ha^{-1} application was obtained on the sandy short duration pigeonpea (DT 7) showed increased yield at higher levels of N (50 kg ha^{-1}) over the lower level of nitrogen (25 kg ha^{-1}). Application of 50 kg P_2O_5 ha^{-1} increased yield significantly over control. Maximum grain yield (811 kg ha^{-1}) was recorded with a combination of 50 kg ha^{-1} each of nitrogen and phosphorus. The crop grown under rainfed conditions, soil status of nitrogen is low and phosphorus is medium. In Alfisols (available N was 188 and phosphorus was 18 kg ha^{-1}) of Bangalore short duration pigeonpea under rainfed conditions showed maximum yield when fertilizer was applied at 69 kg P_2O_5 + 27 kg N ha^{-1} (1036, 1626 kg ha^{-1}) over control (625, 668 kg ha^{-1}) and at 23 kg P_2O_5 + 9 kg N ha^{-1} (750, 1011 kg ha^{-1}) in both the years of study (Nagaraju *et al.* 1995).

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The review indicates that in many situations a starter dose of 20 to 25 kg N ha^{-1} would be essential. The results indicated that the response to application of 20-50 kg P_2O_5 ha^{-1} in majority of the cases and higher responses upto 105 kg P_2O_5 ha^{-1} application was obtained on the sandy loams, low in available phosphorus. Significantly higher yields were obtained by applying a part of recommended fertilizer doses through foliage at flowering stage. Potassium (20 kg ha^{-1}) application along with higher doses of N and P would be beneficial for balanced nourishment.

2.4. SORGHUM/PIGEONPEA

2.4.1. Importance of sorghum/pigeonpea

In India, pigeonpea/sorghum intercropping is widely practiced on medium to heavy textured soils in dryland areas and this is also prevalent in the semi-arid tropics of Africa. Willey *et al.* (1981) reported that on deep Vertisols of Peninsular India, sorghum/medium duration (200-220 days) pigeonpea intercrops were highly productive. Results from large number of experiments conducted under All India Coordinated Research Project for Dryland Agriculture (AICRPDA) showed that pigeonpea/sorghum (90-100 days duration) is most productive on Vertisols of Central and Peninsular India (Ali, 1985). The most critical management factor when considering N economy is the use of N fertilizer; the requirement for the cereal/legume intercropping systems is still poorly understood (Willey, 1996). A brief review on fertilization effect in sorghum/pigeonpea and sorghum follows.

2.4.2. Response of Sorghum/Pigeonpea to fertilizer application

2.4.2.1.Growth, nutrient uptake and seed yield

Narain *et al.* (1980) found that in sorghum/pigeonpea (1:1 30-cm apart) application of nitrogen (75 kg ha^{-1}) increased the grain yield of sorghum (2.1t ha^{-1}) over control (1.1 t ha^{-1}), but the yield of pigeonpea (868 to 396 kg ha^{-1}) was affected adversely owing to smothering effect of sorghum on pigeonpea. There was no significant difference between 25 kg and 50 kg ha^{-1} or 50 and 75 kg N ha^{-1} on the yield of sorghum. The average yield of sorghum stover increased (10 to 15 t ha^{-1}) by the application of N at 75 kg ha^{-1} over control. The yield of pigeonpea stover was not influenced by the application of nitrogen. The addition of leaf litter as well as nitrogen added through leaf litter corresponded well with the growth of pigeonpea. The leaf litter addition was maximum in control treatment (2262 kg ha^{-1}) and decreased with the application of N to sorghum (1093 kg ha^{-1}). The addition of total N through leaf litter was more in control plot (3 kg N ha^{-1}) compared to application of N to sorghum (1.5 kg N ha^{-1}). The experiment was conducted at Kota (Rajasthan) on Vertisols which contained 0.05% total N.

Under rainfed conditions, on sandy loams of Peninsular India, sole sorghum and sorghum/pigeonpea (alternate rows) were compared for the productivity of the two systems. The increase in grain yield with the application of 40 and 80 kg N ha^{-1} was 49 and 62% over control. Application to sorghum did not influence the grain yield of the intercropped pigeonpea but it influenced the total biomass significantly. The yield of sorghum however increased equally in intercropped or when it was grown as a sole crop. But, when compared with the sole crop of sorghum, intercropped sorghum yielded statistically less under all the N treatments. Available N P K status of the experimental soil was 300 kg N, 38.5 kg P_2O_5 and 413 kg K ha^{-1} respectively (Reddy *et al.* 1980).

On sandy loams soils (0.4% total N, 16 kg ha^{-1} available P and 167 kg ha^{-1} available K) of New Delhi, Ahlawat and Kumar (1988) reported that during rainy cropping season intercropping of pigeonpea with sorghum caused a significant reduction in its biomass yield (102 to 2 g $plant^{-1}$), grain yield (1600 to 350 kg ha^{-1}) and N P K uptake (98-12-40 to 22-2-9 kg ha^{-1}). Application of N upto 50 kg ha^{-1} had no effect on dry matter yield, grain yield and uptake of N P and K by pigeonpea both in sole crop and intercrop. However, the total uptake of N P K by the system was significantly increased (from 92-14-39 to 109-18-17 kg ha^{-1}) owing to the inclusion of the N-responsive nonlegumes in the system.

Tobita *et al.* (1994) studied on field evaluation of nitrogen fixation and use of nitrogen fertilizer by sorghum/pigeonpea (2:1) intercropping on an Alfisol in the Indian semi-arid tropics, their studies indicated that sole and intercropped sorghum reached maximal total dry matter at 50 kg N ha^{-1} (11460; 8670 kg ha^{-1}) or 100 kg N ha^{-1} (11510; 8920 kg ha^{-1}). Sole cropped pigeonpea (medium duration) had a higher total dry matter at 50 and 100 than at 0 and 25 kg N ha^{-1}. In intercropping, the pigeonpea had a lower total dry matter at 50 and 100 kg N than at 0 and 25 kg N ha^{-1}. The crops were grown during rainy cropping season. The N concentration in sorghum at harvest was not altered by the level of N application or the cropping system. The total N yield of sorghum significantly increased due to N application. The concentration of N in intercropped pigeonpea was higher than that in the sole-cropped plants, the total N yield of pigeonpea decreased due to intercropping because of the significant reduction in dry matter yield. The sole and intercropped sorghum reached maximal grainyield at 50 or100 kg N ha^{-1}, whereas pigeonpea showed a negligible response to N application but was significantly affected by cropping systems. Although the interaction between N application and cropping system was insignificant, the sole cropped pigeonpea had a higher grain yield at 50 and 100 kg N than at 0 and 25 kg N ha^{-1}. In the intercropping system, however,pigeonpea gave a lower grain yield at 50 and 100 than at 0 and 25 kg N ha^{-1}. The soil had an available moisture storage capacity of about 100 mm and was inherently low in fertility (57, 100, and 200 mg kg^{-1} of available N, P and K respectively).

On Vertisols (available nutrients kg ha^{-1}; 284 N, 40 P_2O_5 and 342 K_2O) of Nagpur, Balpande *et al.* (1994) observed that the grain yield of sorghum ranged from 3.2 to 4.0 and 2.8 to 3.7 t ha^{-1} in sole and intercropping, respectively. Pigeonpea yields were low in intercropping (0.2 t ha^{-1}) than its sole cropping (1.1 t ha^{-1}). Total grain production in intercropping is quite impressive (3.0 to 3.9 t ha^{-1}). Intercropped sorghum yield (2.8 to 3.7 t ha^{-1}) increased with increasing levels of nitrogen (40 to 100 kg N ha^{-1}). Available N content of the soil decreased significantly after harvest of sorghum. Sole sorghum is an exhaustive crop. It utilized fertilizer N and also depleted available N in soil by about 30 per cent in single and 17 per cent in intercrop. On the other hand, pigeonpea showed a build up available N in the soil by 10%. It was significantly superior treatment. Available P and K contents significantly increased under both intercropped and sole pigeonpeas. In rainfed agriculture sorghum/pigeonpea intercropping is a suitable cropping system. It gives satisfactory grain yield as well as maintains soil fertility.

2.4.2.2.Nodulation and nitrogen fixation

Tobita *et al.* (1994) estimated the nitrogen fixation (by ^{15}N isotope method) medium duration pigeonpea grown as sole and intercrops on Alfisols of Peninsular India during rainy cropping season. The fractional contribution of N derived from air was affected by both the N application and the cropping system. Lesser fertilizer N application and the intercropping environment raised its contribution. In sole cropped pigeonpea, 50-60% of N came from air, whereas 65-85% of N in the plant was derived from atmospheric N when intercropped. The soil had an available moisture storage capacity of about 100 mm and was inherently low in fertility (available NPK 57, 100 and 200 mg kg^{-1} respectively). Ito *et al.* (1993) observed that nodulation and ARA (Acetylene reduction activity) tended to be higher in the intercrop than in monocropped pigeonpea. A medium duration pigeonpea (cv ICPL 1-6) and a hybrid sorghum were sown in a shallow Alfisol during rainy cropping season at ICRISAT Patancheru Center, India. Nitrogen application reduced the specific nitrogenase activity in intercrop, but the effect was not clear in the mono crop and they opined that the presence of sorghum in an adjacent row and the higher planting density of pigeonpea in intercropping than in monocrop may have decrease available N in the soil between rows thereby alleviating the inhibitory effects of mineral N on biological N_2 fixation.

Kumar Rao *et al.* (1987) measured the N_2 fixation (^{15}N isotope dilution technique) by sole pigeonpea and when intercropped with sorghum grown on Vertisols (available N 6.5 mg kg^{-1} soil) under rainfed conditions. It was found that 88% of the N in pigeonpea grown as a sole crop was derived from biological N_2 fixation whereas intercropped pigeonpea derived 96% of its N from symbiosis. This presumably happened because the sorghum crop depleted most soil available N reserves, thereby making pigeonpea additionally dependent on BNF for its N needs. By the difference calculation method using cv IS 3003 as the nonfixing (sorghum) reference 81 kg N ha^{-1} was fixed by the sole crop and intercropped with sorghum (hy CSH 6) fixed 76 kg N ha^{-1}.

2.4.3. Response of sorghum to fertilizer application

2.4.3.1. Growth, nutrient uptake and grain yield

Rao *et al.* (1995) observed that in sorghum (cv SPV-86) grown on Vertisols in Bellary during the post rainy season gave a grain yield of 2.1 t ha^{-1} (under control) and 2.4 t ha^{-1} with an application of 40 kg N ha^{-1}, but further increase of N application was not beneficial. The soil moisture was adequate. Application of 20 kg N ha^{-1} recorded highest straw yield (3.4 t ha^{-1}), followed by 40 kg N ha^{-1} (3.3 t ha^{-1}) and the lowest (3.1 t ha^{-1}) was recorded in the 0 N treatment. During years of low rainfall, sorghum grain yields were 0.7 t ha^{-1} with an application of 20 kg N ha^{-1} compared to control (0.5 t ha^{-1}); the yields with 40 and 60 kg N ha^{-1} (0.7 t ha^{-1}) respectively. Straw yield was 1.5 t ha^{-1} in the 20 kg N ha^{-1} treatment which was significantly ($P \leq 0.05$) superior to other treatments. Rao *et al* (1995) opined that insufficient moisture during crop growth period (specially during six weeks after sowing) had resulted in the reduction of grain and straw yields with increased N fertilizer beyond 20 kg ha^{-1}. The functional relationship between levels of N and grain + straw yields during adequate soil moisture seasons and the inadequate soil moisture seasons was found to be quadratic in nature. Application of 38 kg N ha^{-1} gave maximum benefit of Rs.2.67 Re^{-1} invested during good years of rainfall, whereas the optimum dose was 33 kg N ha^{-1} with Rs.1.29 Re^{-1} benefit during poor rainfall years. The available N, P_2O_5 and K_2O of the soil was 150, 22 and 650 kg ha^{-1} respectively.

In Udaipur, Dashora and Porwal, (1994) conducted an experiment during the rainy cropping season on loamy soils (available N = 0.03% , P_2O_5 = 25 kg ha^{-1}, K_2O = 187 kg ha^{-1}) the yield of sorghum (hy CSH-9) increased from 1.9 to 2.5 t ha^{-1} grain; 4.6 to 4 t ha^{-1}) with an increased application of N to 80 kg ha^{-1} (0 to 80 kg ha^{-1}). The increase in grain and stover yields with the application of 80 kg N ha^{-1} over 40 and 0 kg N ha^{-1} was 14% and 35% and 7% and 29% respectively.

In a scarce rainfall-shallow soils ecosystem of Peninsular India, sorghum (hy CSH-9 and cv CSV 11) produced significantly higher yields of grain and straw with the addition of 80 kg N ha^{-1} in three years out of the five years of study. However, the rationalized rate of 40 kg N ha^{-1} was at par for grain and straw yields in another two years of study. The authors opined that prolonged dry spells and variable degree of losses due to crop lodging by the heavy rain at maturity were the reasons which showed no distinct yield response to different rates of N. The economics of N application showed that it was profitable to apply 80 kg N ha^{-1} to sorghum. The net returns were invariably more with 80 kg than with the 40 kg N ha^{-1} during all the years. But the return of each investment on N fertilizer showed that the rational rate of 40 kg N ha^{-1} led to higher profits in three years. The rainfall during the growing season was erratic and ranged from 445 to 884 mm with a 66 % CV. The soil on which experiment was conducted was a shallow Alfisol with a content of 220 kg N, 22 kg P_2O_5 and 250 kg K_2O ha^{-1} in available form in the soil to 60 cm depth (Shaik Mohammed *et al* 1993).

On a deep Vertisol in Bhopal in rainfed conditions during rainy cropping season the application of N fertilizer application to sorghum (hy CSH-5) significantly increased its grain, straw and protein yields. The increased yield was basically a result of significantly higher number and weight of grains ear^{-1} and 1000 grain weight. The yield effects were significant to 80 kg N ha^{-1} in the first year of the experiment and to 40 kg ha^{-1} application in the second year. The authors (Nimje and Gandhi, 1993) opined that lower response to N in the second year was probably due to the build up of residual N in the soil. The experimental soil was had available nutrients as under: N = 172 kg ha^{-1}; P_2O_5 = 12 kg ha^{-1} and K_2O = 260 kg ha^{-1}. The rainfall received during crop season was 781 mm and 690 mm in first and second year of the experiments respectively.

Hirapara *et al* (1992) observed that Sorghum fertilized with 120 kg N ha^{-1} outyielded the rest of the lower doses of N by recording a grain yield of 1.9 t ha^{-1} and 1.4 t ha^{-1} respectively. The grain and straw yields in 120 kg N ha^{-1} treatment were higher by 220 and 272% respectively over the control. A marked increase in total N and P uptake @ 138 and 43 kg ha^{-1} respectively was also observed at 120 kg N ha^{-1}. Yield obtained was 1.4 t ha^{-1} at 20 kg P_2O_5 ha^{-1}, which evidently resulted from higher grain weight $plant^{-1}$ with an improved test weight. P application did not affect the total N uptake but resulted in a significantly higher P uptake. The authors concluded that hybrid sorghum may be fertilized with 120 kg N + 20 kg P_2O_5 ha^{-1} for harvesting a profitable yield of the rainy season crop on Vertisols with available N and P2O5 content of 0.53% N, 32 kg ha^{-1} of P_2O_5) of the Saurastra region.

Powell and Hons (1992) observed that, in Texas, sorghum yields, fertilizer N use efficiency (FNUE) and N, P and K uptake and partitioning varied with the fertilizer N level applied (0, 112, 224 kg N ha^{-1}). Fertilizer N application rate of 112 kg ha^{-1} was sufficient to produce maximum yield, attain the greatest FNUE, and the highest % partitioning of N, P and K uptake into grain. The crop was grown on Udic Chromustert having organic carbon content of 1.3%, very low total nitrogen, and available phosphorus and potassium. Annual rainfall received was 980 mm.

On Vertisolsof Parbhani (medium in nitrogen and phosphorus), Bhosekar and Raikhelkar (1990) found that in sorghum (hy CSH-6) an application of 80 kg N ha^{-1} gave significantly higher ear weight, grain weight; ear $head^{-1}$ and number of grains $earhead^{-1}$ and seed yield (5.9 t ha^{-1}) as compared to its higher as well as lower nitrogen levels (0 to 120 kg N ha^{-1}). FYM at 6 t ha^{-1} gave significantly higher yield (5.3 t ha^{-1}) and better yield attributes compared to control (no FYM) (3.9 t ha^{-1}). The crop was grown under rainfed conditions.

On Vertisols of Sehore (Madhya Pradesh) Thakre *et al.* (1989) reported that yield response of hybrid sorghum to applied N was linear where $Y=2401.5 + 9.449x$ ($R^2=0.76$) where x is the kg of N applied and Y is yield of sorghum per ha.. The average grain yield in terms of kg grain kg N^{-1} at 50, 100 and 150 kg N ha^{-1} were 12, 11 and 9, respectively. The highest additional returns of Rs.1719 ha^{-1} was obtained with the addition of 150 kg N ha^{-1} The net return was Rs.2.18 for every rupee invested. The crop was grown under rainfed condition and total rainfall received during crop seasons was 1167 mm and 989 mm during two years of experimentation. The fertility status of the soil was 268, 10, 518 kg ha^{-1} of available N, P_2O_5 and K_2O, respectively.

In Nebraska, Zweifel *et al.* (1987) found that sorghum grain dry weight, total above ground biomass and N content means were higher in N fertilized plots, but plant N content showed the largest response to applied N fertilizer. The ratio of grain N to total N content, NHI was also lower at higher (112 kg N ha^{-1}) N application (59%) over control (64%). This indicated that a smaller fraction of the above ground N was partitioned to the economic portion of the plant (grain) in high N plots. The crop was grown under rainfed conditions. The soil was a valentine fine sand (Typic Ustipsamment).

On Vertisols of Solapur, Patil *et al.* (1996) observed that the grain and stover yields of sorghum were increased to 10 to 23% and 3.4 to 14%, respectively due to P application over control during three years of experimentation. The maximum increase in the grain (23%) and stover (14%) yields of sorghum was noted when 25 kg P_2O_5 ha^{-1} was applied. The highest uptake of N (45 kg ha^{-1}), P (12 kg ha^{-1}) and K 135 kg ha^{-1}) was found when 25 kg P_2O_5 ha^{-1} applied. The crop was grown during post-monsoon dry season under rainfed conditions. The experimental soil was low in total N (0.036%) and available P (10 kg ha^{-1}) but was high in available K (478 kg ha^{-1}).

On Vertisols of Peninsular India showing an extractable P of 0.4 mg kg^{-1} soil, Sahrawat *et al.* (1995) found that phenology of the sorghum (hy CSH-6) crop was greatly affected by P application. In the first season of the two year experiment unfertilized crop took 99 and 133 days respectively for 50% flowering and physiological maturity. The application of P @ 10 kg ha^{-1} reduced the time taken to flowering and maturity by 34 and 33 days, respectively. Further increases in the rate of P application beyond 10 kg P ha^{-1} did not significantly affect the time to 50% flowering or physiological maturity. In the second season the phenology of the crop was significantly affected by P applied in the current season but not by the residues of fertilizer P applied in the previous season. Further, in the first year, sorghum grain yield increased from 0.1 t ha^{-1} (no P added) to 3.5 t ha^{-1} with P added at the rate of 40 kg P ha^{-1}. P applied in the previous year was 58% as effective as currently applied P, but P applied two years earlier was only 18% as effective as current year's applied P.

Fa Elkased and Lannadi (1987) reported that on sandy loams of Zaria, Nigeria sorghum responsed significantly to applied P @ 22 kg ha^{-1}. Beyond this level there were increases in yield but were not statistically significant. These results agree rather closely with the current recommendation for the application of P to sorghum in the northern Guinean Savannah bioclimatic zone. The crop is generally grown there during rainy season (May-September). The mean annual rainfall of Zaria is 1050 mm. The available P in Zaria soils was 5 ppm.

On Vertisols of Akola with available N, P_2O_5 and K_2O of 120, 8 and 358 kg ha^{-1} Deshmuk *et al* (1994) showed that in rainy season sorghum, the efficiency of N was tremendously increased when P was also applied by raising yield of sorghum 4.5 t ha^{-1}. No additional benefit of K application along with N P was observed (might be due to high level of available K content in the soil). Maximum grain yield (5.2 t ha^{-1}) was obtained when 150% of the recommended dose of N P K was applied. The control yield was 1.6 t ha^{-1} and the recommended dose of fertilizer yielded 3.4 t ha^{-1}.

On shallow Alfisols of Peninsular India, Shaik Mohammed *et al.* (1995) found that the fertility variations did not influence the plant height, number of leaves $plant^{-1}$ or the panicle length, number of leaves $plant^{-1}$ or panicle length. The grain yield $plant^{-1}$ significantly increased from 46 to 84 g in response to the increasing fertilizer rates from 20-10 to 100-50 N-P_2O_5 kg ha^{-1}. The crop yielded 1.6 t ha^{-1} at the low rate of 20+10 N+P_2O_5 kg ha^{-1} and the response increased at higher rates yielding 104% additional grain (3.3 t ha^{-1}) at the high fertility level of 100+50 N+P_2O_5 kg ha^{-1}.

The crop was grown under rainfed conditions during rainy season. The fertility status of the soil is 108, 12, 150 kg ha^{-1} of N-P_2O_5-K_2O, respectively.

Sorghum (cv CSH9) grown during rainy cropping season, on Vertisols of Indore showed significant yield differences under different fertility levels. Highest yield (3.6 t ha^{-1}) was recorded with recommended dose of N, P and K (80-40-40 kg ha^{-1}), compared to (2.6 t ha^{-1}) under half of recommended dose and (1.2 t ha^{-1}) under control. The total precipitation during two years of experimentation was 540 and 1090 mm (Kushwaha and Kushwaha, 1995).

Kasole *et al.* (1994) observed that sorghum (hy CSH-9) grown in farmer's fields, gave significantly higher grain yield (5.4 t ha^{-1}) with the recommended dose of fertilizers (120, 60 and 60 kg N, P and K ha^{-1}) compared to 75% and 50% of the recommended dose of fertilizer (5.1 and 4.8 t ha^{-1}). The highest productivity of 9.2 kg grain rupee^{-1} invested on fertilizer was recorded under the lowest level of applied nutrients i.e 50% of recommended dose, the productivity declined to 6.6 and 5.2 kg grain rupee^{-1} invested for 75% of recommended dose and the full recommended dose of fertilizers, respectively. The soils of the experimental site were low in available N, medium in P and rich in K. The crop was grown during the rainy cropping season in north-eastern part of Kolhapur (Maharashtra) at 12 locations.

2.5. INFLUENCE OF FERTILIZER APPLICATION ON LIGHT INTERCEPTION BY CROP

In Trinidad (West Indies) Hughes and Keatinge (1983) observed a linear relationship between the maximum amount of biomass accumulation by pigeonpeas and the amount of solar radiation intercepted by the foliage during crop growth. Moisture stress adversely affected radiation interception, photosynthetic efficiency and harvest index. Relation between maximum above-ground biomass and radiation intercepted by foliage throughout the period of growth was estimated both for irrigated crop (DM_{max} = 1.23 (±0.12) R-549) and for dryland crop (DM_{max} = 0.65 (±0.07) R-137).Where DM_{max} is maximal dry matter accumulated and R is the total solar radiation intercepted by the crop.

Raj Singh *et al.* (1996) reported that on sandy loam soils of Hisar, mustard grown during the post rainy cropping season, produced dry matter which was linearly related to the amount of solar radiation intercepted by crop canopy. The mean conversion efficiency of light energy into dry matter (indicated by the slope of regression of dry weight on radiation absorption) was 3.13 - 3.35 g MJ^{-1} in 'cv Sangam' and 2.66 - 3.61 g MJ^{-1} in for cv T1168. The average value of radiation use efficiency of both the cultivars was 3.15 ± 0.30 g MJ^{-1} of absorbed photosynthetically active radiation.

Sunflower when grown as a sole crop absorbed significantly higher PAR (356 MJ m^{-2}) compared to its being intercropped with soybean (2 rows of sunflower + 2 rows of soybean) (336, 329 MJ m^{-2}) at 84 DAS. Sole soybean intercepted significantly lower PAR (461 MJ m^{-2}) practically throughout the crop growth period compared to other combinations (sole sunflower, sole groundnut, sunflower (2) : Groundnut (2), sunflower (2) : soybean (2)). 2 sunflower + 2 soybean intercropping systems and was comparatively more efficient in conversion of absorbed PAR into biomass particularly during the late crop growth period, probably owing to an efficient utilization of natural resources. This study conducted by Shinde *et al* (1996) indicated that it would be beneficial to adopt intercropping of sunflower either with groundnut or with soybean at 30 or 45 cm intra-row sunflower spacings. The crop in this study was grown on a Vertisol of Pune under rainfed conditions).

On Vertisols of Peninsular India, Natarajan and Willey (1985) compared the alternate row arrangement of the two crops (sorghum, pigeonpea) (SP) with the standard 2 rows of sorghum : 1 row of pigeonpea arrangement for the utilization of resources. Sorghum reached its peak light interception at about 50-60 DAE while the much slower growing pigeonpea did not peak until about 90-100 DAE, around the time of sorghum harvest. The light interception of the standard sorghum in sorghum/pigeonpea intercrop lagged behind that of the sole sorghum initially, despite the intercrop's higher total plant population density. This lag was obviously because in the intercrop the poor light interception in the pigeonpea rows was not fully compensated by its higher interception in the sorghum rows. Because of an increasing pigeonpea contribution, however, the intercrop interception caught up with and then exceeded that of the sole sorghum from about 50-60 DAE up to the sorghum harvest. Totalled over the full sorghum growing period the absolute amount of energy intercepted by the intercrop (891 MJ m^{-2}) was very similar to that intercepted by the sole sorghum (889 MJ m^{-2}). Immediately after sorghum, pigeonpea intercepted of the PAR only 30% but it subsequently peaked to 63% at 130-140 DAE.

On Vertisols of Peninsular India, Siva Kumar and Virmani (1980) observed that PAR (photosynthetically active radiation) interception in the sole pigeonpea crop showed low values up to about 70 days after planting, where LAI was only about 0.9. Interception increased up to 93 per cent with the steady increase in LAI up to about 130 days, after which increasing leaf senescence contributed to a steady decrease. Maize/pigeonpea canopy maintained higher levels of interception up to the time of maize harvest because of its higher LAI values. PAR interception dropped to about 24% after the maize harvest, but later increased with the accelerating canopy development. The relations between total dry matter produced and the cumulative intercepted PAR for the three canopies, viz., sole pigeonpea, sole maize and maize/pigeonpea were also recorded. For the maize/pigeonpea intercrop the total drymatter is for both crops up to the maize harvest, after which the total dry matter of maize produced at harvest (923.3 g m^{-2}) was added to the dry weight of pigeonpea taken at each subsequent sampling date. Production efficiency (DM produced per unit of intercepted PAR) was very low for the sole pigeonpea crop, and sole maize was also less efficient than the intercrop. The efficiency of maize/pigeonpea was more at all stages of crop(s) growth than individual crops.

In Northern Australia, Muchow and Davis (1988) studied the influence of N on radiation interception and biomass accumulated (RUE) by sorghum and maize under irrigated conditions. It was observed that radiation use efficiency was more responsive to N supply than radiation interception. RUE increased with higher rate of applied N (0 to 50 g m^{-2}); maximum RUE was greater in maize than in sorghum; and RUE declined during grain filling in maize more than in the sorghum crop. It is concluded that RUE may not be stable across environments as it was previously thought, but it rather depended on the balance of leaf growth, N uptake and allocation to leaves and N mobilization from leaves to grain.

On sandy loam of alluvial origin of Cordoba (Spain) Gimenez *et al* (1994) selected a site of low N status, prepared by cropping barley in the preceding winter without added N. Sunflower (Cv. Sungro 385) was then grown with two levels of N (-N = 0 and +N = 25 g N m^{-2}). The +N plots reached full canopy cover at 53 DAS while maximum radiation intercepted by the canopy in -N plots occurred at 65 DAS, 4 days before beginning of flowering. Maximum radiation interception values were 0.99 for +N and 0.50 for -N plots. Over the crop growing cycle from 9 to 71 DAS, cumulative radiation interception by the crops was 216 and 411 MJ of PAR m^{-2} for treatments -N and +N respectively. Large response of RUE to N was observed. Between 9 to 42 DAS, RUE was 0.35 and 0.92 g MJ^{-1} PAR for -N and +N treatments respectively. The relative difference in RUE between +N and -N treatments also increased with crop development: it was 1.82 for 42 to 57 DAS and 2.32 for 52 to 71 DAS. The maximum RUE observed was 2.3 g MJ^{-1} PAR recorded between 57 and 71 DAS in +N plots.

2.6. INFLUENCE OF N FERTILIZATION ON SOIL AND BIOLOGICAL PROPERTIES

2.6.1. Importance of soil biological and chemical properties

Soil microflora plays an important role in the maintenance of soil fertility because of its ability to carry out biochemical transformations and also due to their importance as source and sink for mineral nutrients (Jenkinson and Ladd, 1981). The decomposition of plant and animal residues in soil constitutes a basic biological process which is brought about by successional population of microorganisms. In this process carbon (C) is recycled to the atmosphere as carbondioxide (CO_2), nitrogen is converted to ammonium (NH_4^+), and nitrate (NO_3^-) and other associated elements appear in forms required by higher plants (McGill and Cole, 1981). In this process, part of nutrients are assimilated by microorganisms and incorporated into microbial tissues (soil biomass). Microorganisms regulate the nutrient flows in the soil by assimilating nutrients and producing soil biomass (immobilization) and converting C, N, P and S to mineral forms (mineralization) (Wani and Lee, 1995).

Microorganisms perform a key role in sustaining the productivity of soils. They stimulate it and help sustain biological production on an enduring basis. In the absence of a vibrant soil life all biochemical transformations in the soil cease and in such situations agricultural production suffers (Wani and Lee, 1995). Crop and soil management influence the biological processes in the soil.

A brief review of the influence of crops and fertilizers/manures on mineral N, net N mineralization, microbial biomass C and N and soil respiration follows.

2.6.2. Mineral N and net N mineralization

Rochester *et al.* (1993) conducted two experiments to monitor mineral N contents in N-fertilized cotton growing soils. The experimental site was in the cotton growing belt of north-west New South Wales at Agricultural Research Station, Narrabri (150°E, 30°S). Rochester *et al.* (1993) observed that in heavy grey clay overlying brown clay contained 0.08% total N and 0.9% organic carbon, the application of N fertilizer (urea) resulted in increased mineral N content in soil rapidly and subsequently declined at a slower rate. The recovery of ^{15}N-labelled urea as mineral N declined exponentially with time. Generally, biological immobilisation is believed to be the major process reducing post-application soil mineral N, because the decline can not be accounted for by crop N uptake alone. Progressively less N was mineralized upon incubation of soil sampled through the growing season. Little soil N mineralized at crop maturity. Considerable quantities of fertilizer N were immobilized by the soil microbiomass; immobilized N was remineralized and was subsequently taken up by the cotton crop. A large proportion of the crop N (in cotton) was taken up in the latter part of the season when the soil mineral N content was low. The results suggested that much of N taken up by cotton was derived from microbial sources, rather than the crop residues. The application of cotton crop residue (stubble) slightly reduced the mineral N content in the soil by encouraging biological immobilization. ^{15}N studies showed that it was mineralized very slowly from the labelled crop residues and did not contribute significantly to the supply of N to the current crop. Recovery of labelled fertilizer N and labelled crop residue N by the cotton crop was 28 and 1% respectively. In comparison, the apparent recovery of fertilizer N was 48%. Indigenous soil N contributed 68% of the N taken up by the cotton crop.

At Indore, Madhya Pradesh, an experiment is being conducted since 1992 on Vertisols to evaluate effects of fertility levels on the soil mineral N and net N mineralization. The soil samples collected before sowing of the rainy season soybean crop during third year of the experiment, showed a maximum mineral N concentration of 49 mg g^{-1} soil. The net N mineralized was 16 mg N g^{-1} soil 10 d^{-1} from the plots which received N P at 20:13 kg ha^{-1} for each crop (soybean-safflower) + crop residues 5 t ha^{-1} and N P at 20:13 kg ha^{-1} for each crop + FYM 6 t ha^{-1} applied in the rainy season, respectively (Saran *et al.* 1996).

Wani *et al.* (pers. communication) studied the mineralization of ^{14}C and ^{15}N from labelled barley and fababean residues incorporated in Gray Luvisol in two cropping systems under laboratory conditions. The cropping systems included: (i) an agroecological 8-year rotation (AER) involving fababeans as green manure and (ii) continuous grain system (CGE) with fertilizer N at 90 kg N ha^{-1} y^{-1}. Mineral N content in both the soils decreased significantly initially (at 2 wk) and then increased significantly with time (4 wk onwards). Mineralization of N was significantly more in AER-fababean than in AER-barley and was also more in CGE-fababean than CGE-barley.

In an experiment initiated in 1987 on a Vertisol at Akola, India, Deshmukh *et al.* (1996) observed that fertility treatments had a significant effect on the mineral N content and net N mineralisation of soil. Prior to sowing of the rainy season crop, the plots which received half or full N through *Leucaena* loppings or FYM contained significantly ($P \leq 0.01$) more mineral N content (6.9 and 5.9 mg g^{-1} soil) than the treatments which received zero N or 25 and 50 kg N ha^{-1} through mineral fertilizers. Similar trend, as that of mineral N content was observed, for net N mineralization due to early fertility management treatments.

At Solapur, Maharashtra, India, an experiment is being conducted since 1990-91 on a Vertisol. It has shown that cropping history and application of 25 kg N ha^{-1} to a postrainy season sorghum crop affects mineral concentration of N in soil samples collected just before the sowing of the sequential rainy season crop. A maximum mineral N concentration of 16.2 mg N g^{-1} soil was observed in case of soybean-sorghum system. Application of 25 kg N ha^{-1} to postrainy season sorghum increased mineral N concentration in soil by 2.6 times over the mineral N concentration of treatments that did not receive any N for postrainy season sorghum (14 vs. 5 mg N g^{-1} soil). Net N mineralization was similar in all the treatments irrespective of whether the legumes were grown during rainy cropping season or not and also whether N was applied or not during the postrainy cropping season (Patil *et al.* 1996).

Mineral N content in surface soil (Vertisol) samples collected after the ninth season in a long-term crop rotation experiment at ICRISAT Patancheru Center showed generally a higher amount of mineral N in the soil from legume-cropping systems (pigeonpea, chickpea) than that in nonlegume-cropping systems (sorghum, safflower). Mineral-N (NO_3^-+NH_4^+) in soil decreased from 8 to 6 mg g^{-1} soil at 30 DAE and further decreased to 4 mg g^{-1} soil at 58 DAE. At harvest (106 DAE), the mineral N content in the soil was 3 mg g^{-1} soil. The sorghum/pigeonpea-sorghum-safflower treatment had the highest mineral N content and sorghum-chickpea-sorghum-chickpea treatment showed the lowest. The net N mineralization temporarily in pigeonpea based systems was 9 to 14 times higher (2 mg g^{-1} soil 10 d^{-1}) than that in the sorghum-safflower-sorghum-safflower system (Wani *et al.* 1996).

2.6.3. Relationship between mineral N content and nodulation, nitrogenase activity

Wani *et al.* (1997) conducted a pot culture experiment using Vertisol at ICRISAT Patancheru Center to study the effect of the application of 0.5% FYM and 0.5% bioearth (a commercial organic product prepared from agricultural wastes and distillery effluents using microbial inoculants) on soil N fractions, nodulation and nitrogenase activity of pigeonpea. Results of experiment revealed that soil mineral N concentration increased from 8 mg N g^{-1} soil in the control (no amendments) to 10 mg N g^{-1} soil in the case of 0.5% N FYM and 17 mg N g^{-1} soil in the case of 0.5 of N bioearth treatments. There was a net N immobilization in the no amendment treatment and in the 0.5% N bioearth amended treatments at the time of sowing. At flowering stage of pigeonpea net N mineralization and microbial biomass N varied significantly. The soil mineral N concentration did not show any difference in the amendment treatment of Vertisol with 0.5% each of FYM or bioearth. Nodule number $plant^{-1}$ and nitrogenase activity $plant^{-1}$ were not influenced significantly by FYM or bioearth amendments. However, specific nitrogenase activity substantially increased to 42 mmol C_2H_4 mg^{-1} nodule in the 0.5% N FYM treatment and decreased to 22.1 mmol C_2H_4 mg^{-1} in bioearth treatment.

At ICRISAT Patancheru Center two contrasting mineral soil N regimes to represent those that exist on farmers' fields were created through an application of 20 and 100 kg N ha^{-1} on a Vertisol that was previously depleted of mineral N by growing cover crops. The plots were replicated four times. The field received about 150 mm rain after N-fertilizer was applied. It was observed that mineral N concentration increased to 31 mg g^{-1} soil (in plots receiving 100 kg N) and 7 mg g^{-1} soil (in plots receiving 20 kg N) compared with 5 mg g^{-1} soil in the top 15 cm layer before fertilizer application. Nodulation, proportion of N-fixed and the amount of N_2-fixed by the four chickpea lines sown 24 days after N application were adversely affected due to the high mineral soil N. Mean nodule number decreased by 14%, nodule mass by 30%, and proportion of

N derived from air by 63% due to the high N in plots (31 mg N g^{-1} soil in top 15 cm) compared with the low N plots (7 mg N g^{-1} in top 15 cm) (Wani *et al.* 1997).

Wani *et al.* (1997) also conducted another pot culture experiment in which a range of soil N concentrations were simulated on an Alfisol through the application of five levels (0, 20, 50, 100, 200 kg ha^{-1} equivalent) of N through urea. Twelve days later, at the time of sowing of five different legumes, the soil under the five fertilizer treatments had 23, 31, 43, 66 and 92 mg mineral N g^{-1} soil. At the flowering stage of respective crops, mean mineral N concentration in the soil varied significantly amongst the legumes. The highest mean soil mineral N concentration (45 mg N g^{-1} soil) was observed when mineral N content at sowing was highest, and the least mineral N concentration of 8 mg N g^{-1} when the mineral N was lowest at sowing. Significant interactions for soil mineral N concentration (at flowering) between crops and the mineral N at sowing were observed, these results indicated differential N uptake by the legumes resulting in varied soil mineral N concentrations at flowering stage, which in turn, could affect nodulation and nitrogenase activity in the legumes. The differences in mineral N in soil at sowing also affected net N mineralization in soil at flowering stage of the different legumes. At 23 and 31 mg N g^{-1} soil concentration, immobilization of N was observed resulting in a net negative N mineralization. In case of 43 and 92 mg N g^{-1} soil amount of net N mineralized, during 10 days of laboratory incubation increased from 1 to 7 mg N g^{-1} soil. Similarly, mean net N mineralization was influenced by the crops and there was a significant ($P \leq 0.01$) interaction between crops and the mineral N concentration at sowing for the net N mineralization in soil at flowering stage. It was also observed that with increasing mineral N in the soil, the amount of net N mineralized also increased at flowering, thus, suggesting that internal N cycle in the soil was influenced by crop N uptake and mineral N fertilizer applied. The rate of mineral N fertilizer applied would have varying effect on nitrogenase activity of different crops.

Mean nodule number decreased significantly from 61 $plant^{-1}$ in case of 23 mg N g^{-1} soil to 0.044 mg $plant^{-1}$ in case of 92 mg N g^{-1} soil. Significant interaction between legumes and soil mineral N levels for nitrogenase activity was observed. In case of pigeonpea and cowpea, nitrogenase activity at 31 mg N g^{-1} soil (at sowing) increased two fold over the nitrogenase activity at 23 mg N g^{-1} soil. Mean nitrogenase activity, however, increased from 4 m mol C_2H_4 $plant^{-1}$ h^{-1} in case of 31 mg N g^{-1} soil and then decreased with the increasing soil mineral N concentration (Wani *et al.* 1997).

The relationship between nitrogenase activity of the five legumes and the different soil N pools at sowing and at flowering stages was also studied by the use of stepwise regression by Wani *et al.* (1997). It was concluded that a significant relationship between nitrogenase activity and soil N fractions in most of the legumes existed.

2.6.4. Soil respiration, Microbial biomass carbon and nitrogen

Perucci (1990) studied the effect of application of municipal solid-waste compost on biomass C, N, P and S in the soil under laboratory conditions. Soil, was collected from the surface layer (0-25 cm) of a Vertic Eutrochrept fine mixed thermic soil, which is considered typical of the mid-Tiber Valley near Perugia (Italy). In the control treatment, a decreasing trend in microbial C starting from time 0 was observed. In contrast, in the enriched soil, a significant increase in biomass C (350 mg g^{-1} soil) was noted immediately after the addition of the compost. This increase was present even 1 month after incubation, but the level thereafter decreased until it reached the initial values observed in the control soil at the beginning of the experiment. Similar behaviour was observed for biomass N, biomass S, but biomass P showed an increasing trend up to the 5^{th} month, in both the samples.

Ocio *et al.* (1991) reported the results of a field experiment in which 10 t ha^{-1} wheat straw with or without fertilizer N was allowed to decompose. The site in Long Hoos Bare Fallow Field at Rothamsted Experimental Farm, was a silty clay loam. The straw (10 t ha^{-1}) and N (100 kg N

ha^{-1}) were incorporated into the surface soil and hand-dug to 15 cm. The soil contained 1.2% C and 0.1% N. The treatments were imposed in the autumn of 1987. The amount of soil C biomass roughly doubled within 7 days of straw incorporation, it remained constant for the next 27 days and then slowly decreased. In soils which did not receive straw, the amount of soil C biomass remained fairly constant over the next 12 months, despite seasonal changes in soil moisture and temperature. Overall, in both the treatments (straw and N), the soil biomass C at the end of the experiment was still 20% greater than in the untreated soil, and the biomass N was 18% greater. Seven days after incorporation, the increase in biomass N was virtually the same with and without inorganic N (50 kg ha^{-1}). Between day 7 and 14, further increase in biomass N was observed in the soil receiving straw +N.

Wani *et al.* (per. comm.) studied the mineralization of ^{14}C and ^{15}N from labelled barley and fababean (fb) residues incorporated in a Gray Luvisol obtained from two cropping systems under laboratory conditions. The cropping systems were: (i) an agroecological 8-year rotation (AER) involving fababeans as green manure and (ii) continuous grain system (CG) with fertilizer N at 90 kg N ha^{-1} yr^{-1}. Microbial biomass C estimated by ninhydrin reactive N method was higher during initial incubation period (1-4 wk) which then declined considerably with time. In AER soil at wk 1, biomass-C was higher by 3 times than in CG soil. In both the soils having fababean residues incorporation, biomass C was higher than where barley residues were incorporated. Such differences were maintained till wk 8. At 16 wk only AER-Fb supported higher biomass compared to the remaining combinations. Biomass-C in all the treatments was similar after an elapse of 24 wk.

Singh (1993) conducted experiments to evaluate the influence of application of straw and chemical fertilizers in an Inceptisol on the microbial biomass C in rice-lentil sequential cropping in dryland agriculture at Varanasi (northern India). Microbial biomass C was maximum in the wheat straw + fertilizer treatment (408-420 mg g^{-1}) followed by straw (360-392 mg g^{-1}) and fertilizer treatment (272-357 mg g^{-1}). The value for control was the lowest: 238-246 mg g^{-1}. The straw +

fertilizer treatment accumulated more microbial biomass C in the soil (77% over control), followed by the straw treatment (51% over control). However the effect of fertilizer was transient in nature with the microbial C value at the end of the experiment not being statistically different from the control. A very large and rapid increase is reported in the size of the microbial biomass following straw incorporation.

Singh and Singh (1993) studied the influence of crop residue (wheat straw) and chemical fertilizer on soil microbial biomass under tropical dryland Inceptisol at Varanasi (northern India). Crop sequence used was rainy fallow-lentil-summer fallow-rice. The soil total N was 0.1% and total P was 0.012%. The treatments compared were: control; chemical fertilizer (80-40-30 kg NPK ha^{-1}); wheat straw @ 2 kg m^{-2} yielding N equivalent of 80 kg N ha^{-1}; wheat straw @ 1 kg m^{-2} + fertilizer @ 40-20-15 kg NPK ha^{-1}. There was a wide seasonal variation in the microbial C and N biomass. The biomass C ranged from 194 to 279 mg g^{-1} dry soil for the control; from 183 to 463 for the fertilizer; from 258 to 466 for the straw; and from 267 to 491 mg g^{-1} for the straw + fertilizer treatment. Biomass N ranged from 20 to 28; from 15 to 36; from 32 to 39; and from 33 to 50 mg g^{-1} soil in the control, fertilizer, straw, and straw + fertilizer treated plots respectively. Application of straw increased the levels of microbial biomass in the soil, but the maximum effect on the microbial biomass was realized with the straw + fertilizer treatment. By the end of study, the straw + fertilizer treatment had increased biomass C and N by 77% whereas biomass P increased by 81%.

Srivastava and Lal (1994) studied the influence of fertilizer and FYM application on crop growth and microbial C and N biomass in a Indo-Gangetic Inceptisol. The crop sequence studied was rainfed rice-lentil. The mean annual rainfall of the region is 1105 mm, 88% of which occurs during the rainy season. The use of fertilizers and manures, either alone or in combination, significantly changed the microbial C, N, and P contents of the soil compared to the control. Mean microbial C over all samplings was maximal in the soil treated with FYM @ 20 t ha^{-1} y^{-1}.

Mean microbial N and P reached a maximum values in soil amended with FYM @ 10 t ha^{-1} y^{-1} + fertilizer @ 40-20-15 kg N-P_2O_5-K_2O ha^{-1}. All three microbial nutrients reached significantly higher values under lentil compared to rice cultivation. The grain yield was positively related to crop biomass and to the microbial nutrients. A significant positive correlation between grain yield and microbial nutrients indicated that the microbial biomass contributed to grain production by meeting some N and P needs of the crop. A reciprocal relationship between plant growth and microbial biomass was observed; it showed that the microbial biomass decreased at the early stages of crop growth, then it increased. A decrease in the microbial biomass level during the early crop growth lead to increased nutrient availability. Organic C, total N and P in the soil, crop biomass, grain yield, and the soil microbial C, N and P changed significantly compared to control and the changes were maximum in soil amended with FYM either alone or when combined with fertilizers. Application of N without C containing materials had very little effect on the microbial biomass. In the present study, the addition of N and P fertilizers alone reduced the C:N and C:P ratios of the microbial biomass, but the application of FYM widened these ratios. However, the application of N and P increased microbial C through an increase in the root biomass; which may also stimulate N and P immobilization in the microbial biomass. The concentration of N and P in the microbial biomass increased in NPK or NPK + manure-treated soil and decreased in manure-treated soil, and indicated that N and P concentrations in the biomass were influenced by N and P pools in the soil solution.

At Indore, a long-term experiment is in progress since 1992 on a Vertisol. Saran *et al.* (1996) reported that the soil fertility levels influenced the microbial C and N biomass in soils collected before sowing. The maximum microbial biomass C (741 mg N g^{-1} soil) and N (35 mg N g^{-1} soil) were observed when fertilizer applied at 20:13 N P kg for each crop (soybean-safflower) + crop residues applied @ 5 t ha^{-1} as surface mulch and incorporated in the soil after harvest of each crop. Higher values of microbial biomass C and N were observed wherever organic manures were added to the soil.

At Solapur, a long term experiment, underway since 1990-91 on a Vertisol showed that cropping history and application of 25 kg N ha^{-1} to a postrainy season sorghum affected microbial soil biomass N, whereas microbial biomass C was not influenced significantly. The maximal value of microbial biomass N (7 mg N g^{-1} soil) was observed in soybean + sorghum cropping system when no N has been applied to postrainy season sorghum (Patil *et al.* 1996). Deshmukh *et al.* (1996) observed that fertility treatments imposed earlier had a significant effect on soil microbial C and N biomass. Prior to sowing of rainy season crops which received FYM, the content of biomass C and N (317 to 329 mg C g^{-1} soil; 11 to 13 mg N g^{-1} soil) was more as compared to the treatments which received fertilizer N. This long-term study was conducted on a Vertisol and was initiated at Akola in 1987. At Solapur, Maharashtra, a long term experiment (since 1990-91) on a Vertisol showed that cropping history and application of N to the postrainy season sorghum did not affect respiration of soils in samples taken prior to the sowing of the postrainy season sorghum (Patil *et al.* 1996). At Indore, experiments conducted since 1992 on Vertisols have shown that soil fertility levels influenced soil respiration. Soil samples collected before sowing of the following rainy season crop (soybean) during third year of the experiment showed maximum soil respiration (90-95 mg C g^{-1} $soil^{-1}$ 10 d^{-1}) in soils amended with organic manures (FYM and crop residues); the lowest value (35 mg C g^{-1} soil 10 d^{-1}) was observed in the control treatment (Saran *et al.* 1996).

The review of literature presented in the foregoing pages indicates that the application of fertilizer/manure and crops (legumes and cereals) influence the status of soil mineral N, net N mineralization, microbial soil biomass of carbon and nitrogen and indirectly nodulation, and BNF of the legumes. The influence on soil properties vary with the type of amendment used and land use.

MATERIALS AND METHODS

CHAPTER 3

MATERIALS AND METHODS

Experiment was carried out in the watershed of ICRISAT, Patancheru during rainy seasons 1996 and 1997, with a view to find out the impact of N application on soybean and pigeonpea under sole and intercropping systems and its impact on biological and chemical properties of soil. The details of the procedures and techniques adopted for field study and the analytical techniques followed during the present investigation are enumerated in this Chapter.

3.1. LOCATION OF THE EXPERIMENT

3.1.1. Geography

The experiment was conducted at ICRISAT Center (International Crops Research Institute for the Semi-Arid Tropics), Patancheru, which is located in Southern India at 17^0 35' N, 78^0 15' E, 545 meters a.m.s.l. The institute is situated near the village Patancheru about 25 km north west of Hyderabad, the state capital of Andhra Pradesh. The experimental farm extending over 1400 ha includes two major soil types found in Semi-Arid Tropics; Alfisols (red soils) and Vertisols (black soils). The research farm has a characteristic semi arid tropical climate and region is located in the Deccan Plateau.

3.1.2. Climate

The climate of Hyderabad is semi-arid tropical. Troll (1965) classified the semi-arid tropics (SAT) as a region within the tropics where monthly rainfall exceeds mean potential evapotranspiration (PE) during 2 to 7 consecutive months of the year. Within the SAT two sub-zones can be distinguished, the dry SAT in which rainfall exceeds PET for 2 to 4.5 months and the Wet-Dry SAT where rainfall exceeds PET for 4.5 to 7 months. ICRISAT lies right at the margin of the Dry and Wet-Dry SAT with 4.5 months where rainfall exceeds PET (Murthy and Swindale, 1993).

The SAT is characterized by a highly variable inter annual and intra-seasonal rainfall. The coefficient of variation of inter-annual rainfall is 20-30% in the SAT. In common with most parts of India, in the Hyderabad area there are three seasons during a year viz; rainy season (Jun-Oct), post-rainy dry season (Oct-Feb) and a summer (Mar-May) season. The temporal distribution of rainfall has a marked influence on soil water availability, the length of the growing season and hence, on crop production (Virmani and Eswaran, 1990).

The SAT regions in Asia get rainfall under the influence of monsoon circulation which usually sets-in around early Jun and extends till mid-Oct. During those four and half months more than 80% of the annual rainfall is received at Hyderabad. The pattern of rainfall is slightly bimodel with one peak occurring during the south west (in Jul) rainy season and the second peak in the intervening period of SW and NE monsoons in September (Virmani, 1995). The mean annual rainfall recorded for a period of 30 years i.e., 1940-70 is 704 mm and the annual PET is 1758 mm. The variation in annual rainfall at Hyderabad has been observed from 320 mm to 1460 mm during the last 89 years (Virmani and Eswaran, 1990). The post-rainy cropping season (*rabi*) or cool season starts in Oct and continues until Jan. During this period the climate is dry and temperatures are relatively low and days are short. Crops grown during this time have to thrive on stored soil moisture. From Feb onwards until the following rainy season, the climate is hot and dry. Any crop grown at that time would need supplementary irrigation. The hottest month of the year is May with ambient temperatures of 42^0 C to 43^0 C. During the hot and dry season some pre-monsoon rains are received. The regular monsoon rain sets-in mid-Jun and receedes in early Oct. For the Hyderabad area the growing period lasts 120 days for Alfisols (available water holding capacity-AWHC=100 mm) and 180 days for Vertisols (AWHC=250 mm) (Virmani, 1995).

3.2. WEATHER

3.2.1. Weather during 1996

Total annual rainfall was 1062 mm which was 25% above the long-term average annual rainfall. During the rainy season (Jun to Oct), a total of 994 mm rainfall was received which was 33% above the long-term average seasonal rainfall (Table 1). The rains arrived in the month of Jun with 87 mm shower on time. Between 10 Apr to 27 May, it rained 46 mm which was well utilized for tillage operations. Out of 80 rainy days in the year, 73 rainy days were recorded in the period Jun to Nov and during this period 1017 mm was recorded. The rainy season crops established very well and the crop growth in the watersheds was good to excellent. During the rainy season the crops did not suffer from water deficits at any time.

Table 1. Mean monthly weather data of the year 1996.

Month	Mean solar radiation ($MJ\ m^{-2}\ d^{-1}$)	Evapo-ration (mm)	Mean temperature (°C) Daily Max.	Daily Min.	Daily Avg.	Monthly rainfall (mm)	No. of rainy days
JAN	17.3	159	29.6	15.4	22.5	0	0
FEB	19.1	194	31.4	16.8	24.1	0	0
MAR	22.0	266	36.0	19.3	27.7	0	0
APR	22.2	254	36.6	22.5	29.6	40	6
MAY	25.0	380	40.4	24.7	32.6	6	1
JUN	19.0	240	35.2	24.1	29.7	87	11
JUL	17.5	184	31.7	23.0	27.4	211	17
AUG	13.3	109	28.9	22.1	25.5	451	22
SEP	17.4	119	29.9	22.0	26.0	161	14
OCT	15.4	141	29.1	20.0	24.6	84	8
NOV	16.7	136	29.2	15.3	22.3	22	1
DEC	15.0	129	27.7	13.2	20.5	0	0

3.2.2. Weather during 1997

A total of 741 mm rainfall was recorded which was 92% of the long term average annual rainfall (Table 2). During the rainy season, a total of 574 mm was received and the long term average rainfall during this period is 593 mm. The amount of rainfall and rainy days were 19 mm and 6 respectively during Jun, indicating delayed onset of the rainy season and consequently crop sowing. Out of 79 rainy days in the year, 61 rainy days occurred in the period of Jun to Nov.

Table 2. Mean monthly weather data of the year 1997.

			Mean temperature (°C)				
Month	Mean solar radiation ($MJ\ m^{-2}\ d^{-1}$)	Evapo-ration (mm)	Daily Max.	Daily Min.	Daily Avg.	Monthly rainfall (mm)	No. of rainy days
JAN	16.0	134	27.2	14.0	20.6	11	2
FEB	20.4	176	31.6	13.7	22.7	0	0
MAR	21.3	249	35.2	18.4	26.8	57	3
APR	23.0	254	34.9	20.9	27.9	38	5
MAY	24.3	329	38.3	24.0	31.2	32	3
JUN	21.4	307	36.2	23.9	30.1	19	6
JUL	15.8	203	31.8	23.3	27.6	157	17
AUG	15.8	174	30.6	22.5	26.7	140	13
SEP	17.4	132	30.3	21.9	26.1	133	13
OCT	18.2	141	30.6	19.5	25.1	74	5
NOV	15.2	116	29.3	19.6	24.5	50	7
DEC	14.2	107	28.1	18.0	23.1	31	5

3.3. EXPERIMENTAL DETAILS

3.3.1. Soil characteristics

The experiment was conducted during 1996 and 1997 rainy season (*kharif*) on a Vertisol (Typic Pellusterts) watershed. The physical and chemical properties of the soil are given in Table 3. The Vertisol used in the experiment belonged to the *Kasireddipalli* soil series as classified by Murthy and Swindale (1993).

Table 3. Soil physico-chemical properties of experimental site.

Depth of soil (cm)	pH	Electrical conductivity (ds m^{-1})	Organic carbon (%)	Available Olsen P (ppm)	Exchan-geable K (kg ha^{-1})	Available N (mg g^{-1} soil)
0 - 15	8.2	0.15	0.64	0.77	180	3.83
15 - 30	8.3	0.17	0.44	0.10	109	2.50
30 - 60	8.3	0.19	0.36	0.10	157	1.91
60 - 90	8.3	0.02	0.37	0.10	159	1.80
90 - 120	8.3	0.22	0.32	0.10	169	1.59
Average	8.3	0.19	0.45	0.23	155	2.33

Electrical conductivity (Keeney and Nelson 1982)
Organic C (Nelson & Sommer, 1982)
Available P (Olsen&Sommer, 1982)
Exchangeable K (Thomas, 1982)
Mineral N (Dalal *et al.* 1984).

3.3.2. Design and treatments

The experiment was conducted in the rainy cropping seasons of 1996 and 1997. The levels and sources of N were imposed as main plot treatments, and cropping systems were assigned to subplots. The treatments were allocated in the field in a split plot design with three replications.

Treatment details:

Mainplot: **Nitrogen levels: Six**

N1. Control
N2. 20 kg N ha^{-1} from FYM
N3. 20 kg N ha^{-1} from fertilizer
N4. 40 kg N ha^{-1} from FYM
N5. 40 kg N ha^{-1} from fertilizer
N6. 20:20 kg N ha^{-1} from FYM:fertilizer

Subplot: **Cropping Systems: Four**

C1. Sole Soybean
C2. Soybean / Sunflower (4:1)
C3. Sole Pigeonpea
C4. Sorghum / Pigeonpea (2:1)

Replications: Three

Plot size: 13 x 6 = 78 m^2

net plot size: 9 x 3 = 27 m^2

3.4. AGRONOMIC PRACTICES

3.4.1. Field preparation and sowing

Seedbed was prepared on a tilled field before sowing. Broad bed and furrows were laid out with a bed of 1.2 m breadth and a furrow of 0.3 m width. The field was levelled to erase any micro-relief. Seed bed preparation was completed during dry season, well ahead of the sowing time, with minimal tillage and soil compaction. A basal dose of 250 kg ha^{-1} of Single Superphosphate (16% P_2O_5) was incorporated before sowing. Seed was treated with *Rhizobium* inoculum @ 70 g per 30 kg seed and dried in the shade.

Main plots and subplots were demarked with iron pegs at the four corners and the treatments were arranged by randomization. FYM (1.2%N) was incorporated in the soil as per the treatment ahead of the sowing of crop. The crop varieties used in the experiment were: soybean - cv. PK 472; pigeonpea - cv. ICPL 87119; sorghum - cv. CSH-9; and sunflower - cv. Morden. Sowing was done with a bullock operated seed drill at recommended plant spacings. Soybean and sunflower were sown on 27 Jun 1996 immediately after the onset of monsoon and dry seeding of pigeonpea and sorghum was done during first fortnight of Jun in 1996. but dry seeding of sorghum failed; it was resown on 5 Jul 1996. In 1997, all crops were sown on 8 Jul. The sowing pattern on each broad bed, in case of sole crops it was 4 rows of soybean, and one row of pigeonpea. In case of intercropping: 4 rows of soybean and 1 row of sunflower in the center of the broadbed in soybean/ sunflower (4:1); 2 rows of sorghum and 1 row of pigeonpea in sorghum/pigeonpea (2:1). For weed control, pre-emergence herbicide (paraquat @ 4 kg ha^{-1}) was sprayed on the soil in the field. Gap filling was done 5 days after emergence (DAE) when the plants were still very young. Thinning was done 20-25 days after sowing (DAS) to secure appropriate plant density. N was applied in the form of KNO_3 (potassium nitrate) as per the treatment. The fertilizer was evenly incorporated manually into the top 5 cm of soil. Three hand weedings were given at 20-25 days interval depending on weed infestation in the experiment. Full plant protection was provided to control pests and diseases. Various pesticides used including; Cypermethrin (25%) and Furadan granules against shootfly in sorghum during early stages of crop growth; Nuvacron against stemfly in soybean; Carbaryl against head bugs in sunflower; Lannate and Sandovit against *Helicoverpa* in pigeonpea. The crops were harvested at maturity.

Harvest was carried out from an area of 27 m^2 which included 2 broad-beds located in the middle of each plot. The plants were cut to the ground level, and seeds were separated by machine threshing after field drying.

3.5. OBSERVATIONS AND MEASUREMENTS

3.5.1. Meteorological observations

Weather data were obtained from the ICRISAT meteorological station. Monthly weather data of the two rainy seasons of 1996 and 1997 are presented in Tables 1 and 2. The rainfall

Figure 1. Layout of field experiment

N_1C_3	N_1C_4	N_4C_4	N_4C_1	N_5C_2	N_5C_4
N_1C_1	N_1C_2	N_4C_3	N_4C_3	N_5C_3	N_5C_1
N_2C_3	N_2C_1	N_6C_1	N_6C_3	N_3C_1	N_3C_4
N_2C_4	N_2C_2	N_6C_2	N_6C_4	N_3C_2	N_3C_3

R3

N_1C_3	N_1C_2	N_6C_2	N_6C_3	N_2C_1	N_2C_2	N_6C_1	N_6C_3	N_2C_1	N_2C_3	N_1C_1	N_1C_4
N_1C_4	N_1C_1	N_6C_1	N_6C_4	N_2C_3	N_2C_4	N_6C_2	N_6C_4	N_2C_2	N_2C_4	N_1C_3	N_1C_2
N_3C_2	N_3C_1	N_4C_1	N_4C_4	N_5C_1	N_5C_3	N_3C_2	N_3C_1	N_4C_4	N_4C_3	N_5C_1	N_5C_3
N_3C_4	N_3C_3	N_4C_2	N_4C_3	N_5C_2	N_5C_4	N_3C_4	N_3C_3	N_4C_1	N_4C_2	N_5C_2	N_5C_4

R1 *R2*

TREATMENTS

MAINPLOT:

N_1: Control
N_2: 20 kg N ha^{-1} (FYM)
N_3: 20 kg N ha^{-1} (Fertilizer)
N_4: 40 kg N ha^{-1} (FYM)
N_5: 40 kg N ha^{-1} (Fertilizer)
N_6: 20:20 kg N ha^{-1}(FYM: Fertilizer)

SUBPLOT:

C_1: Sole Soybean
C_2: Soybean/Sunflower (4:1)
C_3: Sole Pigeonpea
C_4: Sorghum/Pigeonpea (2:1)

received in the two years of study is substantially different. The total amount of rainfall recorded during 1996 and 1997 was 1062 mm and 741 mm respectively.

3.5.2. Plant growth

3.5.2.1. Growth analysis:

In each plot an area of 0.9 m^2 was sampled, by destructive sampling for growth analysis at weekly intervals in the first season of experiment and at fortnight interval in the second season of the experiment. The plants were cut at the base of stem and thus roots weight was excluded while recording dry matter (TDM).

Leaf area of fresh leaf samples was determined by using a leaf area meter (LI-3100 LI-COR). In case where the amount of leaf sample was large, Sub sample of leaves was taken and determined seperately the leaf area (LA_s) dry weight (DW_s). Total leaf area (LA) was calculated based on total dry weight of leaves (DW_t).

$$LA = DW_s \times LA_s/DW_t$$

Leaf area Index (LAI) was calculated by dividing LA by ground area (GA)

$$LAI = LA / GA$$

Drymass of leaves, stems and reproductive structures (including flowers and pods) was determined after oven-drying of samples at 60^0 C to a constant weight.

Crop growth rate was (CGR) calculated as per Beadle (1993)

$$CGR\ (g\ m^{-2}\ day^{-1}) = (W_2-W_1)/GA \times (T_2-T_1)$$

3.5.2.2. Nodulation and Acetylene reduction assay

This was done twice. Plants were cut at ground level, and the roots and nodules dugout and collected. Soil was dug out carefully to capture most of the roots and nodules readily apparent in the soil matrix. Roots and nodules were placed into 800 ml glass bottle. The bottles were closed with a lid and sealed to make them air tight. 80 ml of air was evacuated from bottle and then 80 ml of acetylene was injected into the bottle. After an incubation of 30 min, 5 ml gas sample was collected in pre-evacuated venoject tubes and stored for subsequent gas-chromatography analysis (Perkin-Elmer, Gas Chromatograph, F33) of acetylene and ethylene. The sample was analyzed for C_2H_4 on a gas chromatograph fitted with a flame ionization detector and a 150 cm long glass column of .6 cm O.D., packed with porapack. The oven temperature of the gas chromatograph was kept at 100° C and the carrier gas (N_2) flow rate was maintained at 45 ml min^{-1}. Calculation of acetylene reduction assay (ARA) was as follows:

$$\mu M\, C_2H_4 h^{-1} = \frac{S.C_2H_4}{S.C_2H_2} \text{ X } (Bl.C_2H_2 - Bl.C_2H_4) \text{ X } \frac{VCF \times BV \times 0.06 \times V_{pm}}{22.4 \times Std.C_2H_4 \times T}$$

where $\mu M\, C_2 H_4\, h^{-1}$ = Micro moles of ethylene produced per hour. .

$S\, C_2 H_4$ = Sample ethylene (chart unit x attenuation)

$S\, C_2 H_2$ = Sample acetylene (chart unit x attenuation)

$Bl\, C_2 H_2$ = Blank acetylene (chart unit x attenuation)

$Bl\, C_2 H_4$ = Blank ethylene (chart unit x attenuation)

VCF = Vacutainer Correction Factor (total volume of vacutainer/amount of gas sample injected.

BV = Bottle Volume

V_{pm} = Volume of standard ethylene (per million)

$Std\, C_2 H_4$ = Standard ethylene (chart unit x attenuation)

T = Time of incubation (min)

22.4 = Gas constant

After the ARA were completed, nodules were counted and roots and nodules oven-dried to a constant weight. Other parameters such as root dry weight number of nodules and nodule mass were calculated. Data were analyzed statistically using GENSTAT package (Genstat manual 1983).

3.5.3. Light interception

Canopy light interception (LI) was measured at mid-day by using a 1 m line quantum sensor (LI-COR, Inc) at different growth stages. The line quantum sensor was placed across crop rows below the canopy to measure the radiation transmitted to the ground (I) while the quantum sensor was placed above the canopy to measure the total incoming radiation (I_0). The LI value (%) was calculated using following equation:

$$LI(\%) = (I - I/I_0) \times 100$$

Light interception data taken at 7-10 day intervals during growing season were plotted and interception for each day was calculated. Daily solar radiation for ICRISAT were used to calculate photosynthetically active radiation (PAR) values for each day from the relation between solar radiation and local PAR (ICRISAT, 1978). PAR intercepted each day and cumulative intercepted PAR for the growing season for each canopy were calculated from daily PAR and data for canopy interception. Radiation use efficiency was calculated as the ratio of total DM accumulation to the cumulative radiation intercepted at different crop growth stages.

3.5.4. Fallen plant material

Starting from the flowering stage, fallen plant material of the various crops was collected at fortnightly interval from an area of 3 m^2. The area was marked with iron pegs in four corners and each time fallen plant material was collected from the same area. Weights were recorded after drying the material in the oven at 60° C. Cumulative leaf fall was gathered and weighed (as g per plot) for each treatment and N, P were estimated.

3.6. SOIL CHEMICAL & BIOLOGICAL PROPERTIES

3.6.1. Sampling details

Soil samples from 0 to 30 cm depth were collected in polythene bags and stored at low temperature (4-5°C) in coldroom till they were analyzed. Samples were processed and sieved through 2 mm sieve and used for analysis. Samples were collected at pre-sowing and at harvest, and twice during crop growth.

3.6.2. Mineral N

Mineral N (NH_4^+ + NO_3^--N) content in the soil was estimated by extracting soil (20 g dry weight based moist soil) with 2 M KCl (1:5 W/V) after shaking it for an hour. The soil extracts were filtered through Whatman filter paper No.1. An aliquot (25 ml) of KCl extracts were analysed for NO and NH - N (t_0) by distilling the aliquot in a microkjeldahl apparatus using Mg O and Devard's alloy and titrated with 0.005 N H_2SO_4 (Jackson, 1973).

$$N\ (mg\ g^{-1}\ soil) = \frac{(\text{ml of acid consumed-blank})\ (A)\ [\text{KCl added (ml)}]}{[\text{Weight of soil (g)}]\ [\text{aliquot taken (ml)}]}$$

Where

A = Normality of H_2SO_4 (0.005 N)

This mineral N content of soil (t_0) was used to calculate net N mineralization.

3.6.3. Net N mineralization

Net N mineralization is the difference between actual N mineralization and microbial immobilization of N.

Net N mineralization = $(NH_4^+\text{-N} + NO_3^-\text{-N})_{t+1} - (NH_4^+\text{-N} + NO_3^-\text{-N})_{t0}$

20 g dry weight basis moist soil was weighed and placed in a glass beaker. The moisture content of the soil sample was adjusted to 55% WHC (water holding capacity) and the sample was incubated in a glass jar containing water at the bottom to avoid desiccation of the soil sample. It was incubated at 25°C for 10 days and then extracted with 2 M KCl. Mineral N (t_{10}) was estimated as described under mineral-N in this chapter.

Net N mineralisation = Mineral N content mg g^{-1} soil (t_{10}) - mineral N mg g^{-1} soil (t_0)
(mg N g^{-1} soil 10 d^{-1})

3.6.4. Soil respiration

It was estimated according to the method of Anderson, (1982). 20 g dry weight based moist soil was weighed into a beaker and the moisture content of the soil sample was adjusted to 55% of the WHC. To avoid desiccation of soil samples during incubation 10 ml of distilled water was added to the glass jar. 20 ml of standard NaOH solution (0.05 M) was pippeted into another glass bottle and it was placed in the same jar near the beaker containing the incubated soil. Glass jar was closed with a lid and it was made airtight, then the samples were incubated for 10 days at 25°C. Alkali bottles were removed from the jars and sealed immediately with parafilm to avoid CO_2 absorption. The alkali bottles were kept frozen till assayed for soil respiration. An aliquot of 2 ml alkali was added to the 5 ml $BaCl_2$ (0.5 M) to precipitate the carbonate as $BaCO_3$ and titrated with HCl (0.05 M).

Milligrams C = (B - V) NE

where B = volume of acid (ml) to titrate blank alkali.

V = volume of acid (ml) to titrate the alkali in the CO_2 collectors from the treatments.

N = normality of acid

E = equivalent factor (if it is in terms of carbon, E=6; if expressed as CO_2, E=22)

3.6.5. Microbial biomass

Microbial biomass was estimated by ninhydrin-reactive nitrogen extracted from soil fumigated for 5 days according to the method of Amato and Ladd, (1988). Twenty g (dry weight basis) moist soil was weighed in duplicate was placed in a glass beaker. Water was added to bring the samples to 55% of WHC. One set was fumigated with $CHCl_3$ (chloroform) and the other set was left unfumigated. For fumigating the soil samples, glass beakers were kept in a large vaccum desiccator that was lined with moist filter paper. A beaker containing 20 ml of alcohol-free $CHCl_3$ and antibumping granules were placed in the desiccator. The desiccator was then evacuated with the help of vaccum pump till the chloroform started boiling. $CHCl_3$ was allowed to boil for 1-2 minutes and then sealed the desiccator and incubated the samples under chloroform vapour for 5 days at 25°C. Non-fumigated control soil samples were also kept in a desiccator lined with moist paper for 5 days period at 25°C. The vaccum was then cleared in the desiccator slowly and it was opened. The moist paper was removed and $CHCl_3$ vapours were evacuated. Soil samples were extracted with 2 M KCl (1.5 W/V) on a shaker for one hour. The extracts were filtered through a Whatman No.1 filter paper. The extracts were kept frozen till assayed for ninhydrn-reactive N. Five ml aliquots of the extract was passed through millipore prefilter (AP20 01300). Ninhydrin-reactive N was estimated by reacting 0.5 ml aliquots of 2M KCl extracts with a ninhydrin reagent (2 ml) (Aldrich

Chemicals). And the absorbances were read at 570 mm. Unfumigated soil samples incubated for 10 days were treated similarly and used as blanks. Biomass-C and N were estimated by multiplying the ninhydrin N with the factor given by Amato and Ladd (1988) which is given as under:

Biomass C = 21 X ninhydrin reactive-N

Biomass N = 3.1 X ninhydrin reactive-N

3.7. TOTAL DRY MATTER AND YIELD

3.7.1. Total dry matter (TDM) at harvest and grain yield

Total dry matter (TDM) and grain yield at harvest were determined by harvesting all plants in each net plot (9 x 3 m). For calculating TDM, total number of plants in each net plot were counted and then total fresh weight was recorded. The fresh weight of 5 plant sub sample, which was randomly selected was also taken and its dry weight was recorded after oven-drying it at 60°C to a constant weight. Finally TDM in each net plot was determined (based on subsample dry weight) and expressed as kg ha^{-1}. In order to determine total dry matter in soybean crop, dry matter of all plants in the net plot was taken after oven-drying the samples at 60°C.

3.7.2. Grain yield

For determining grain yields all capitula/panicles/pods were separated and threshed by a threshing machine after drying the samples at 60°C in the draft-air oven. Grain and seed yield has been expressed as kg ha^{-1}.

3.8. PLANT CHEMICAL ANALYSIS

To 100-150 mg samples of ground plant material 4 ml of concentrated H_2SO_4 containing 1.5% Selenium was added. The sample was digested on a block digestor at 360°C for one hour and fifteen minutes. Volume was made upto 75 ml after cooling. It was mixed thoroughly and N and P were determined by using a Skalar autoanalyzer. One ml of digest was diluted to 25 ml and K was estimated by using atomic absorption spectrophotometer.

Crop uptake (kg ha^{-1}) = Drymatter (kg ha^{-1}) x % of nutrient

3.9. AGRONOMIC EFFICIENCY (AE)

The agronomic efficiency i.e., the response in yield per unit input as indicated by kg of grain per kg of applied N was computed by the following formula (Yoshida, 1981).

$$AE = \frac{\text{grain yield of fertilizer plot (kg ha}^{-1}\text{) - grain yield of unfertilizer plot (kg ha}^{-1}\text{)}}{\text{quantity of fertilizer N applied (kg ha}^{-1}\text{)}}$$

3.10. NITROGEN USE EFFICIENCY (NUE)

The nitrogen use efficiency was calculated as follows:

$$NUE = \frac{\text{total biomass in fertilized plot (kg ha}^{-1}\text{) - total biomass in unfertilized plot (kg ha}^{-1}\text{)}}{\text{quantity of N applied (kg ha}^{-1}\text{)}}$$

3.11. APPARENT RECOVERY (AR)

Apparent recovery also known as recovery fraction was computed as per the formula suggested by Pillai and Vamadevan (1978).

$$\text{Apparent recovery of N (\%)} = [(Y_t - Y_0) / N_t]100$$

Where Y_t = Uptake of N in particular treatment (kg ha^{-1}).

Y_0 = Uptake of N in unfertilized plot (kg ha^{-1}).

N_t = Quantity of N applied for the treatment (kg ha^{-1}).

3.12. NITROGEN HARVEST INDEX (NHI)

It is the proportion of N partitioned into seed according to Wood and Myers (1987). Whether a crop legume is ultimately a net contributor or net exploiter of soil N could be determined by this index.

3.13. NITROGEN ACCUMULATION RATE (NAR)

It was calculated as per the formula given by Katayama *et al* (1996).

$$NAR\ (Kg\ N\ ha^{-1}\ day^{-1}) = (NA_2 - NA_1) / (t_2 - t_1)$$

where

NA_1 and NA_2 are the amounts at t_1 and t_2 respectively with t being days after sowing.

3.14. STATISTICAL ANALYSIS

Experimental data were analyzed for statistical variance using a standard split plot design analysis as described by Gomez and Gomez (1984). The GENSTAT package (Genstat Manual 1983) in a Vax mainframe computer system was also used. But the growth parameters (viz., dry matter and yield) of soybean and pigeonpea were analyzed individually in split plot design and intercrops viz., sunflower and sorghum were analyzed in RBD analysis as described by Gomez and Gomez (1984).

RESULTS

CHAPTER 4

RESULTS

The results of the field experiments carried out on watershed at the International Crops Research Institute for the Semi-Arid Tropics (ICRISAT) Patancheru center, during the rainy cropping seasons of 1996 and 1997 on Vertisols to evaluate the impact of nitrogen management on the growth, nodulation and yield of soybean and pigeonpea; and systems efficiency (unit area productivity of cropping) viz., soybean/sunflower, sorghum/pigeonpea were compared; and the changes in the properties of soil under various N x cropping system treatments are presented in this chapter.

4.1 WEATHER

4.1.1 Weather during 1996

In 1996, 1062 mm rainfall was recorded at the agrometeorological observatory at ICRISAT Patancheru Center, 25% above the long term annual average. Rainfall totaled 994 mm from June to Sept, 33% above the long-term seasonal average(Fig. 2a).

The rainy season began on time with an 18 mm shower on 5 Jun. Earlier, 46 mm of rainfall was received from 10 Apr to 27 May, which helped tillage operations. There were 80 rainy days in 1996, with 73 rainy days from Jun to Nov when the total was 1017 mm. Soil water balance of a typical Vertisol was estimated using Ritchie's model (Fig. 2a). From the last week of Jun soil moisture began to build up in soil. Soil reached field capacity at the end of Aug. The rainy season crops established very well and crop growth was good to excellent.

Figure 2a. Water balance at ICRISAT during 1996

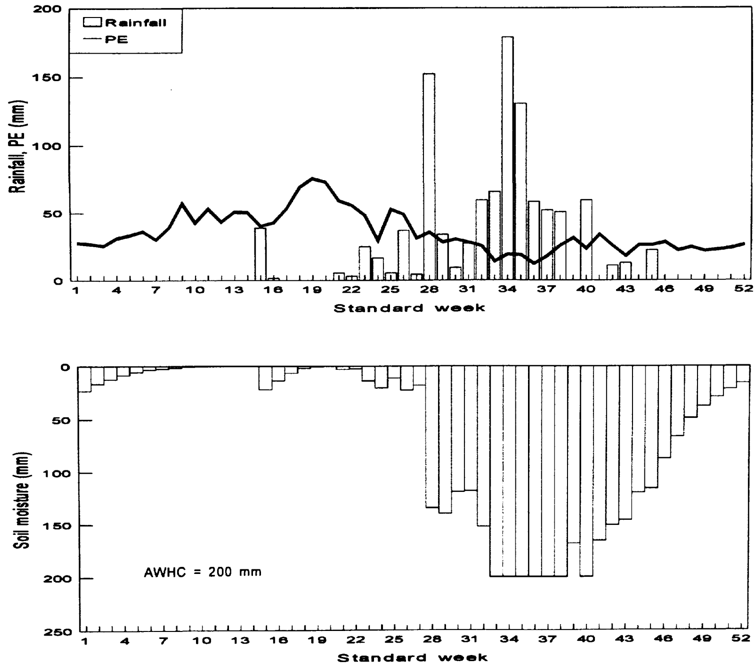
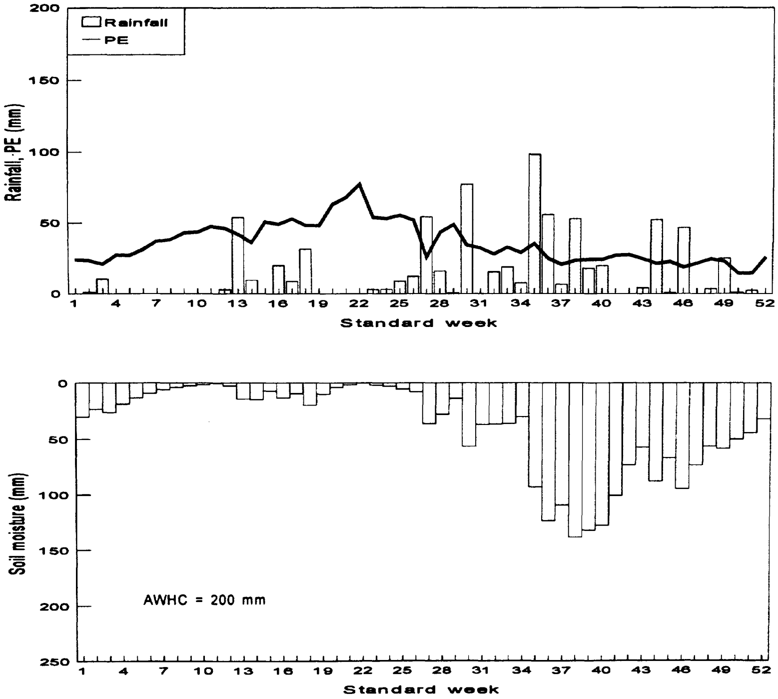


Figure 2b. Water balance at ICRISAT during 1997



Crops did not suffer from water deficit at any time during the rainy season. After Sep the soil water content declined gradually as post rainy-season crops depleted the stored soil water, except for a few rainfall events that caused occasional accretion of soil water storage. Above average rainfall caused runoff and deep drainage. On Vertisols 38% of rainfall was lost as runoff and deep drainage, and 49% was used as evapotranspiration. The remaining soil moisture left at the year end was used by post rainy-season crops until harvest in 1997.

High seasonal rainfall led to several problems related to crop production. Rainfall received during Sep (161 mm) caused lodging, grain molds, and other biotic stresses. October rainfall (83 mm) also affected grain quality. *Helicoverpa* infestation on pigeonpea was high. Overall, 1996 was a good year for rainfed crop production.

4.1.2 Weather during 1997

In 1997, 743 mm rainfall was recorded at the agrometeorological observatory at ICRISAT Patancheru Center, 92% of the long-term annual average (Fig. 2b). Rainfall totaled 449 mm from Jun to Sep , 48% less than long-term seasonal average.

The rains arrived during 1st week of Jul. Earlier, 64 mm of rainfall was received from 17 Apr to 6 May, which helped tillage operations. During Jun, there were only 6 rainy days (19 mm). There were 79 rainy days in 1997, with 61 rainy days from Jun to Nov when the total was 573 mm which was nearly 50% of the rainfall received during the same period in 1996. Soil water balance was estimated using Ritchie's model (Fig. 2b). During the entire rainy season, the soil moisture could not reach to a level of 150 mm. In Jun, only 19 mm of rain was received which delayed the sowing of the crops. 52 mm of rainfall was received during 1st week of July, which helped sowing of the crops. From Jul to Oct, only 430 mm of rain was received which was nearly half of the rain that received from Jul to Oct during 1996 (823 mm). Crops suffered from moisture stress during rainy season. After Sep the soil water content declined gradually as post rainy-season crops depleted the stored soil water, except for few rainfall events that caused occasional accretion of soil water storage.

Crops suffered from moisture stress during entire crop/s growth period *Helicoverpa* infestation on pigeonpea was high. Overall, 1997, was not a good year for rainfed crop production.

4.2 GROWTH AND DEVELOPMENT OF CROPS DURING 1996

4.2.1 Sole Soybean

4.2.1.1 Leaf area index (LAI)

The mean leaf area index (LAI) increased from 0.28 at vegetative stage to a peak of 1.02 at flowering stage and lowest value of 0.21 LAI was observed at maturity (Fig 3; Appendix 1.1). During the both vegetative and flowering stages of crop growth, N application favourably influenced the LAI. The LAI was maximum at flowering stage due to the application of 40 kg N ha^{-1} irrespective of source compared to control (0 N) treatment. During the stage of peak LAI the increase in LAI due to 20 kg N ha^{-1} (FYM or fertilizer N) and 40 kg N ha^{-1} (FYM or/and fertilizer N) over control was 31% and 35% respectively. During the pod development and maturity stage, LAI was not significantly influenced by N application.

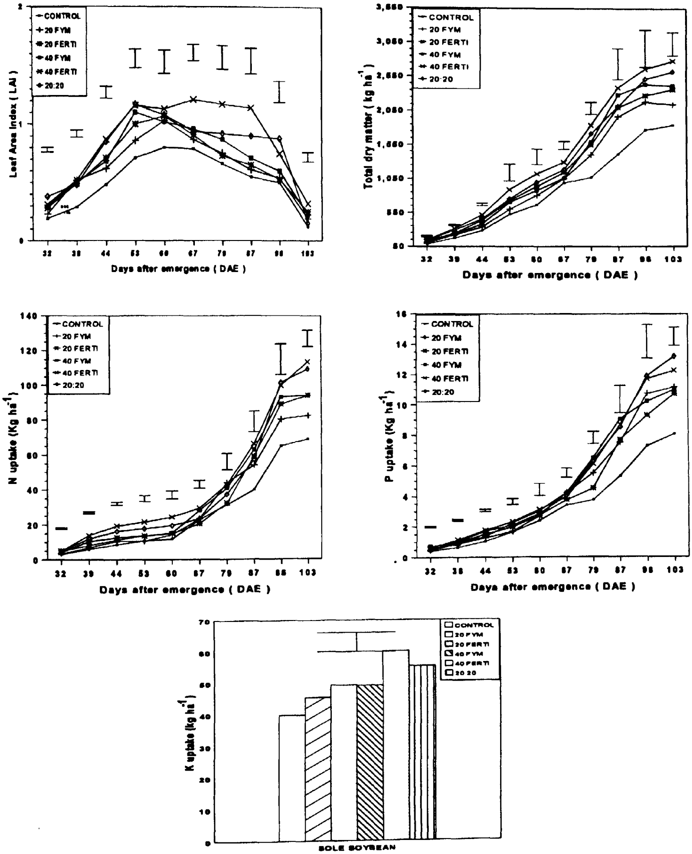
4.2.1.2 Dry matter production

Dry matter production (DMP) increased with crop age i.e. from vegetative stage (123 to 403 kg ha^{-1}) flowering stage (701 to 902 kg ha^{-1}) and pod development and maturity stage (1120 to 2364 kg ha^{-1}) (Fig 3; Appendix 1.2). During the vegetative stage of crop growth, N application influenced the DMP significantly. The highest DMP was observed due to 40 kg N ha^{-1} (fertilizer N) application. During vegetative stage the mean DMP produced in control (0 N) (286 kg ha^{-1}) was less than that of 20 kg N ha^{-1} (386 kg ha^{-1}) and 40 kg N ha^{-1} (453 kg ha^{-1}) irrespective of source of N. However, during flowering stage, the DMP was not influenced significantly due to N application. During pod development and maturity stage, the mean DMP was increased from 1120 to 2364 kg ha^{-1}. The maximum DMP was observed due to 40 kg N ha^{-1} (fertilizer N) application (2785 kg ha^{-1}) followed by 20:20 kg N ha^{-1} (FYM: fertilizer N) (2626 kg ha^{-1}). The increase in DMP due to 20 kg N ha^{-1} and 40 kg N ha^{-1} application over control was 22% and 42% respectively.

4.2.1.3 Nitrogen uptake

The mean uptake of N by sole soybean increased from 4.4 to 13.1 kg ha^{-1} during vegetative stage, 14.8 to 16.6 kg ha^{-1} during flowering stage and 24.6 to 93.7 kg ha^{-1} during pod development and maturity (Fig 3; Appendix 1.3). The uptake of N increased with crop age, and N application influenced the uptake of N significantly ($P \leq 0.05$) only during vegetative to flowering stage of the crop. Significantly higher uptake of N was observed due to application of N @ 40 kg N ha^{-1} from fertilizer N. In the vegetative stage, the uptake of N due to 40 kg N ha^{-1} application as fertilizer N alone (19.4 kg ha^{-1}) or FYM:fertilizer N (16.2 kg ha^{-1}) is double than that of the control treatment (8.6 kg ha^{-1}). Same trend was observed during flowering and pod development stages also. The N uptake at maturity was significantly more in 40 kg N ha^{-1} application as fertilizer N source alone or FYM:fertilizer N than other treatments.

Figure 3. Growth and nutrient uptake of Soybean 1996



4.2.1.4 Phosphorus uptake

The uptake of phosphorus by soybean increased with crop age i.e., from vegetative stage (0.57 to 1.45 kg ha^{-1}), flowering stage (2.01 to 2.82 kg ha^{-1}) and pod development and maturity stage (3.92 to 11.1 kg ha^{-1}) (Fig 3; Appendix 1.4). During vegetative stage and at maturity, the uptake of P varied significantly ($P \leq 0.05$) due to N application. In the vegetative stage of crop growth, increasing the level of nitrogen irrespective of source, increased the uptake of P significantly over control. However in the flowering stage, N application did not influence the P uptake. At the maturity stage N application (irrespective of level and source of N) significantly improved the P uptake (11.7 kg ha^{-1}) compared to control (8.1 kg ha^{-1}).

4.2.1.5 Potassium uptake

At maturity uptake of K by soybean varied significantly ($P \leq 0.01$) due to N application (Fig 3; Appendix 1.4). Higher uptake of K (60.1 kg ha^{-1}) was observed due to application of N @ 40 kg ha^{-1} as fertilizer source than all other treatments (39.8 to 49.3 kg ha^{-1} except with 20:20 kg N ha^{-1} (FYM : fertilizer N) (55.3 kg ha^{-1}).

4.2.2 Soybean/Sunflower

4.2.2.1 Leaf area Index of Soybean/Sunflower

Mean LAI of soybean/sunflower increased with time and attained a peak of 1.72 at flowering stage of crops and reached a lowest of 0.73 at maturity. The LAI was influenced significantly due to N application (Fig 4; Appendix 1.5). Throughout crop growth, application of N @ 40 kg N ha^{-1} (fertilizer N) recorded significantly maximum LAI followed by 20:20 kg N ha^{-1} (FYM: fertilizer N). Application of 40 kg N ha^{-1} (fertilizer N) recorded significantly maximum

LAI values at vegetative stage (1.72), at flowering stage (2.02) and at maturity (0.87). This treatment was found superior compared to other treatments.

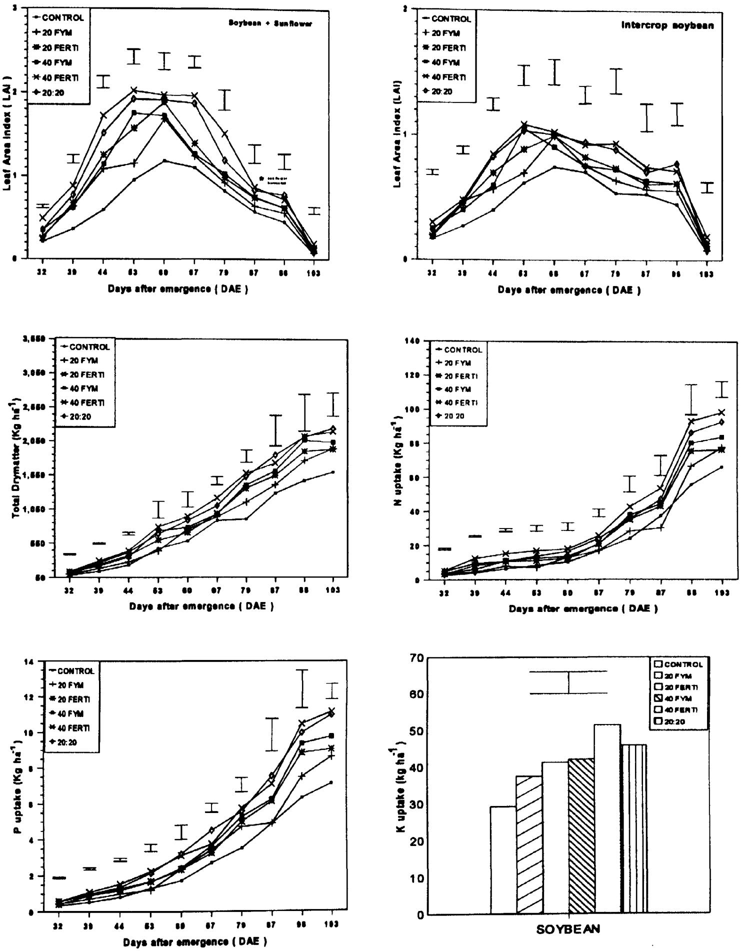
4.2.2.2 LAI of intercrop Soybean

LAI increased with time and attained a peak of 0.95 at flowering stage and then declined to 0.11 at maturity. LAI was influenced favorably due to N application, however, the effect was found to be significant only during vegetative stage of crop growth (Fig 4; Appendix 1.1). Significantly maximum LAI was obtained due to 40 kg N ha^{-1} application followed by 20:20 kg N ha^{-1} (FYM: fertilizer N) treatment. The increase in LAI due to 20 kg N and 40 kg N ha^{-1} treatments irrespective of source of N at flowering stage was 33% and 31 % respectively compared to control (0 N). During the later stages of crop growth, LAI was not affected due to N application.

4.2.2.3 Dry matter production of intercrop Soybean

Dry matter production increased with the age of the crop i.e., from vegetative stage (113 to 349 kg ha^{-1}) and flowering stage (632 to 777 kg ha^{-1}) to maturity (1989 kg ha^{-1}) (Fig 4; Appendix 1.2). During vegetative stage, N application influenced the dry matter production significantly. At vegetative stage, significantly ($P \leq 0.05$) maximum dry matter (440 kg ha^{-1}) production was observed due to 40 kg N ha^{-1} (fertilizer N) followed by 20:20 kg N ha^{-1} (FYM:fertilizer N) (418 kg ha^{-1}). The improvement in dry matter production due to 40 kg N ha^{-1} (irrespective of source of N) over control at vegetative stage was 73 %. In the flowering stage, the dry matter production did not differ significantly due to application of N. During pod development stage, significantly ($P \leq 0.05$) higher dry matter production was observed due to 40 kg N ha^{-1} (fertilizer N) than all other treatments, however it was on par with 20:20 kg N ha^{-1}

Figure 4. Growth and nutrient uptake of Soybean intercropped with Sunflower 1996



treatment. At maturity, significant differences were not observed due to N application, however, the dry matter production recorded due to 40 kg N ha^{-1} (irrespective of source of N) was 35 % more than that of control (0 N).

4.2.2.4 Nitrogen uptake by intercrop Soybean

The mean uptake of N was increased from 3.9 to 10.4 kg ha^{-1} (vegetative stage); 11.7 to 14.1 kg ha^{-1} (flowering stage) and 21 to 82.5 kg ha^{-1} (pod development and maturity stage) (Fig 4; Appendix 1.3). In the vegetative stage, significantly ($P \leq 0.05$) maximum uptake of N (15.4 kg ha^{-1}) was observed with 40 kg N ha^{-1} (fertilizer N) application over all other treatments. Significantly maximum uptake of N 15.4 and 17.1 kg ha^{-1} was observed at vegetative and flowering stage respectively, due to application of N @ 40 kg N ha^{-1} (fertilizer N). At maturity, uptake of N differed significantly among treatments, and maximum uptake was observed due to 40 kg N ha^{-1} (fertilizer N) followed by 20:20 kg N ha^{-1} (FYM:fertilizer N). The increase in uptake of N due to 20 kg N ha^{-1} and 40 kg N ha^{-1} (irrespective of source) over control was 16 % and 39 % respectively.

4.2.2.5 Phosphorus uptake by Soybean

The mean uptake of P increased with crop age (0.50 to 9.4 kg ha^{-1}) till maturity. During vegetative stage (1.6 kg ha^{-1}) and maturity (11.1 kg ha^{-1}) significantly maximum uptake of P was observed due to 40 kg N ha^{-1} (fertilizer N) treatment followed by 20:20 kg N ha^{-1} (FYM: fertilizer N) treatment (1.4 & 11.0 kg P ha^{-1}) (Fig 4; Appendix 1.4). Nearly 3 times increase in mean uptake of P was observed from starting to end point of pod development and maturity stage.

4.2.2.6 Potassium uptake K by Soybean

At maturity, significantly maximum uptake of K (51.4 kg ha^{-1}) was found due to 40 kg N ha^{-1} (fertilizer N) treatment than all other treatments however it was on par with 20:20 kg N ha^{-1} (FYM: fertilizer N) treatments (Fig 4; Appendix 1.4)

4.2.2.7 Dry matter production of Sunflower

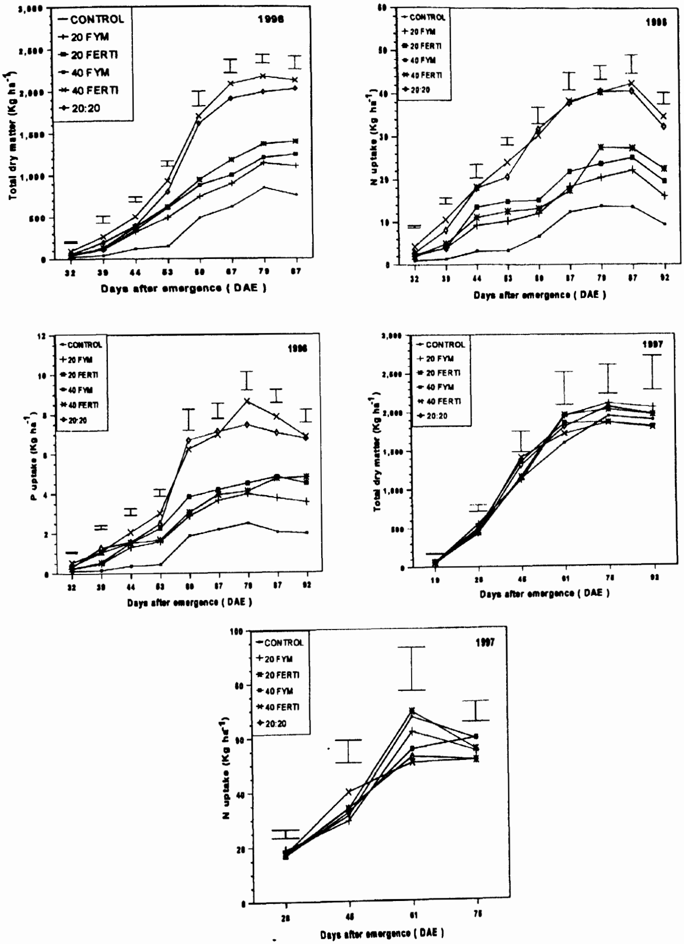
The mean dry matter production increased from 56.5 kg ha^{-1} (vegetative stage) to 1229 kg ha^{-1} (maturity). Two fold increase in dry matter production was seen from flowering stage to maturity. During the entire crop growth period, N application influenced the dry matter production significantly ($P \leq 0.05$) (Fig 5; Appendix 1.6). Maximum dry matter production was recorded due to 40 kg N ha^{-1} (fertilizer N) followed by 20:20 kg N ha^{-1} (FYM:fertilizer N) treatments. At maturity the increase in dry matter production due to application of 20 kg N ha^{-1} and 40 kg N ha^{-1} as fertilizer source alone was two fold and three fold respectively, over control (0 N) treatment.

4.2.2.8 Nutrient uptake by Sunflower

The mean uptake of N increased with the age of crop i.e. from vegetative stage (2.5 kg ha^{-1}) to maturity (28.6 kg ha^{-1}) however at the time of harvest uptake of N was lowered (22.4 kg ha^{-1}) (Fig 5; Appendix 1.7). Application of N influenced the uptake of N significantly ($P \leq 0.01$) during entire crop growth. At all the stages of crop growth significantly ($P \leq 0.05$) higher uptake of nitrogen was noticed in 40 kg N ha^{-1} (fertilizer N) followed by 20:20 kg N ha^{-1}) (FYM:fertilizer N). At harvest, the uptake of N was lowered due to leaf fall.

Mean uptake of P increased with the age of crop i.e. from vegetative stage to maturity (0.31 to 5.04 kg ha^{-1}), further it reduced to 4.7 kg ha^{-1} at harvest. Nitrogen application

Figure 5. Growth and N uptake by Sunflower 1996 & 1997



significantly influenced the P uptake during entire crop growth period (Fig 5; Appendix 1.8). Application of 40 kg N ha^{-1} as fertilizer N recorded maximum uptake of P in the entire crop growth period. Significantly ($P \leq 0.01$) maximum uptake of K (2.42 kg ha^{-1}) at harvest was observed due to N application @ 40 kg N ha^{-1} as fertilizer N than all other treatments. (Appendix 1.8).

4.2.3 Sole Pigeonpea

4.2.3.1 Leaf area index (LAI)

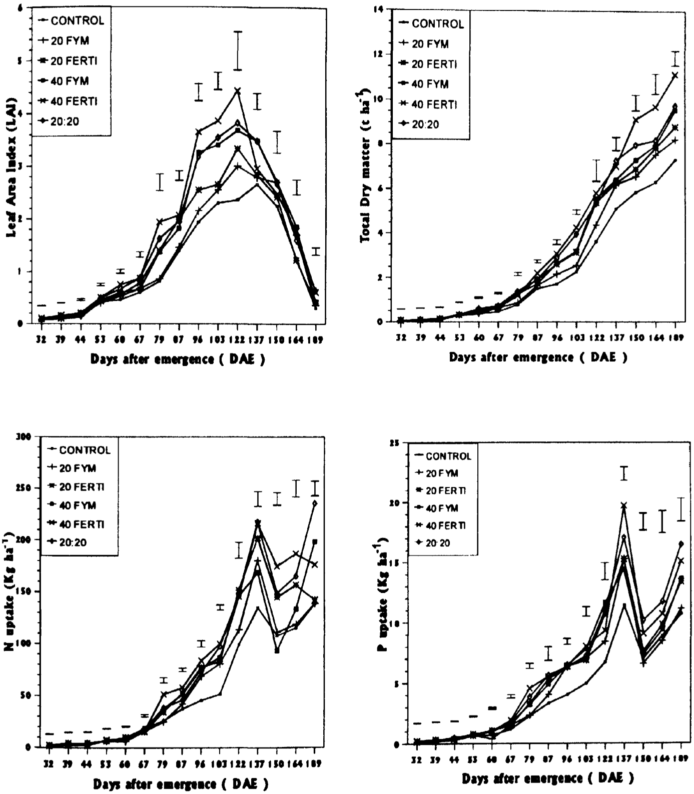
Leaf area index (LAI) increased upto 3.44 at flowering stage and then it decreased and reached a lowest value of 0.46 at maturity stage. During vegetative stage, the mean LAI increased from 0.09 to 3.05, and it was influenced significantly ($P \leq 0.05$) due to N application (Fig 6; Appendix 1.9). Application of N increased the LAI, irrespective of source and level of N. Application of 40 kg N ha^{-1} irrespective of source of N significantly ($P \leq 0.05$) increased the LAI, compared to 20 kg N ha^{-1} (FYM or fertilizer N) and control (0 N) treatments which were on par to each other. The improvement in LAI, due to 40 kg N ha^{-1} was 57% and 38 % more than control and 20 kg N ha^{-1} (FYM or fertilizer N) treatments. Among the 40 kg N ha^{-1} treatments, maximum LAI (3.86) was recorded when crop received N as fertilizer source recorded maximum LAI (3.86) than that of FYM alone or FYM and fertilizer N sources.

At flowering stage, though LAI was not influenced significantly due to N application, maximum LAI (4.43) was observed due to 40 kg N ha^{-1} (fertilizer N) treatment. At maturity stage also, N application did not influence the LAI significantly.

4.2.3.2 Dry matter production

The dry matter production increased with the age of the crop i.e. from vegetative stage (52.7 to 3233 kg ha^{-1}) to flowering (5028 to 5401 kg ha^{-1}) and to pod development and maturity stage (7301 to 9142 kg ha^{-1}) (Fig 6; Appendix 1.10). At all stages, N application increased the dry matter production. During the vegetative stage, application of N @ 40 kg N ha^{-1} (fertilizer N alone or FYM:fertilizer N) significantly increased the dry matter production (3968; 4263 kg ha^{-1}) compared to all other treatments (2266 to 3197 kg ha^{-1}). The dry matter production recorded due to application N @ 40 kg N ha^{-1} (FYM alone) and 20 kg N ha^{-1} (fertilizer N alone) was significantly more than that of control and 20 kg N ha^{-1} (FYM alone) treatments. At vegetative stage he increase on dry matter production due to 40 kg N ha^{-1} and 20 kg N ha^{-1} (irrespective of source of N) over control was 68 and 26 % respectively. During flowering stage, significantly ($P \leq 0.05$) maximum dry matter production was recorded due to 40 kg N ha^{-1} (irrespective of source of N) treatments, however, no significant difference in dry matter production was observed due to application of N @ 20 kg N ha^{-1} (FYM or fertilizer N) and 40 kg N ha^{-1} (FYM or fertilizer N) treatments. The increase in dry matter production due to 40 kg N ha^{-1} and 20 kg N ha^{-1} application over control was 35 and 22 % respectively. At pod development and maturity stage, significantly greater dry matter production (1167 kg ha^{-1}) was recorded due to application of N @ 40 kg N ha^{-1} (fertilizer source alone) than all other treatments (7325 to 9764 kg ha^{-1}). No significant difference was observed between the application of 40 kg N ha^{-1} (FYM), 40 kg N ha^{-1} (FYM + fertilizer N) and 20 kg N ha^{-1} (FYM or fertilizer N) treatments, however the dry matter production was significantly more than that

Figure 6. Growth and uptake of N & P in Pigeonpea 1996



of control (0 N) treatments. The improvement in dry matter production due to 40 kg N ha^{-1} treatments over 20 kg N ha^{-1} and control treatments was 19 and 39 % respectively.

4.2.3.3 Nitrogen uptake

The nitrogen uptake increased from vegetative stage (1.90 to 83.4 kg ha^{-1}) to flowering stage (133.8 to 186.6 kg ha^{-1}). At all the stages of crop growth, the uptake of N was significantly influenced due to N application (Fig 6; Appendix 1.11). At vegetative stage, the uptake of N was in the range of 51.7 to 100 kg ha^{-1} and significantly greater uptake (100; 97.7 kg ha^{-1}) of N was observed due to 40 kg N ha^{-1} application as fertilizer N alone or FYM + fertilizer N than all other treatments. The N uptake did not significantly differ between N application at 20 kg N ha^{-1} (FYM or fertilizer N) and 40 kg N ha^{-1} (FYM), however, the uptake of N was significantly higher than that of control (no N) treatment. The uptake of N due to 40 kg N ha^{-1} irrespective of source of N was 83% and 16 % more than that of control and 20 kg N ha^{-1} treatments. At flowering stage, the N uptake ranged from 134.7 to 217.6 kg ha^{-1}, and significantly maximum uptake of N was observed due to application of 40 kg N ha^{-1} as fertilizer source alone (216.5 kg ha^{-1}) and FYM + fertilizer N (217.6 kg ha^{-1}). Similarly, no significant difference in uptake of N was observed due to 20 kg N ha^{-1} either of the source of N, however the N uptake was significantly higher than control (no N). The uptake of N due to 40 kg N ha^{-1} and 20 kg N ha^{-1} of N was 49 and 41 % higher than that of control (0 N) respectively. At pod development and maturity stage, a mean uptake of 184.1 kg ha^{-1} was recorded, significantly maximum uptake (235.6 kg ha^{-1}) was found due to 40 kg N ha^{-1} (fertilizer N) application. The next best treatment was 20:20 kg N ha^{-1} (FYM:fertilizer) which recorded an uptake of N 213.7 kg N ha^{-1}. Amongst the 20 kg N ha^{-1} treatments, significantly higher uptake (198.4 kg ha^{-1}) of N was observed when applied N was fertilizer source than that of FYM source. The uptake of N due to 40 kg N ha^{-1} and 20 kg N ha^{-1} was 50 and 22 % more than that of control (0 N) treatment.

4.2.3.4 Phosphorus uptake

The phosphorus uptake increased from vegetative stage (6.97 kg ha^{-1}) to flowering stage (15.54 kg ha^{-1}) further it reduced (7.97 kg ha^{-1}) at the pod development stage due to leaf fall and finally it reached a peak at maturity stage (13.44 kg ha^{-1}) (Fig 6; Appendix 1.12). N application affected the phosphorus uptake at all stages of crop growth. At vegetative stage, with the N application irrespective of source and level of N, significantly increased the P uptake (6.86-8.00 kg ha^{-1}) compared to control (4.97 kg ha^{-1}). At flowering stage, application of 40 kg N ha^{-1} (fertilizer N) significantly increased the P uptake (19.74 kg ha^{-1}) than all other treatments (11.42 to 17.08 kg ha^{-1}). At 20 kg N ha^{-1}, both sources of N failed to influence the P uptake significantly however, the P uptake was higher than that of control (0 N) treatment. At pod development and maturity stage, significantly maximum uptake was observed due to 40 kg N ha^{-1} irrespective of source of N (13.68 to 16.52 kg ha^{-1}) than control (no N) (10.72 kg ha^{-1}).

4.2.3.5 Potassium uptake

The K uptake ranged from 65 to 90.6 kg ha^{-1}, which was influenced significantly due to N application. Significantly maximum uptake of K was observed due to 40 kg N ha^{-1} (fertilizer N) than control (0 N). The uptake of K was more with 40 kg N ha^{-1} (87.8 kg ha^{-1}) than 20 kg N ha^{-1} (71.8 kg ha^{-1}) and control (65.9 kg ha^{-1}) (Appendix 2.9).

4.2.4 Sorghum/pigeonpea

4.2.4.1 Leaf area index of Sorghum/Pigeonpea

The mean leaf area index (LAI) of sorghum/pigeonpea increased from 0.16 to 3.57, then it declined to 3.45 at the of harvest of sorghum. Throughout crop growth period, LAI was affected significantly due to N application (Fig 7; Appendix 1.13). At a mean LAI of 3.44 which was peak during crop/s growth period, significantly ($P \leq 0.05$) more LAI (3.88 to 4.25) was observed due to 40 kg N ha^{-1} (irrespective of source of N) compared to 20 kg N ha^{-1} (2.88 to 3.50) and control (no N) (2.70). The increase in LAI due to 40 kg N ha^{-1} (irrespective of source of N) was 52% and 29 % more than that of control and 20 kg N ha^{-1} (FYM or fertilizer N).

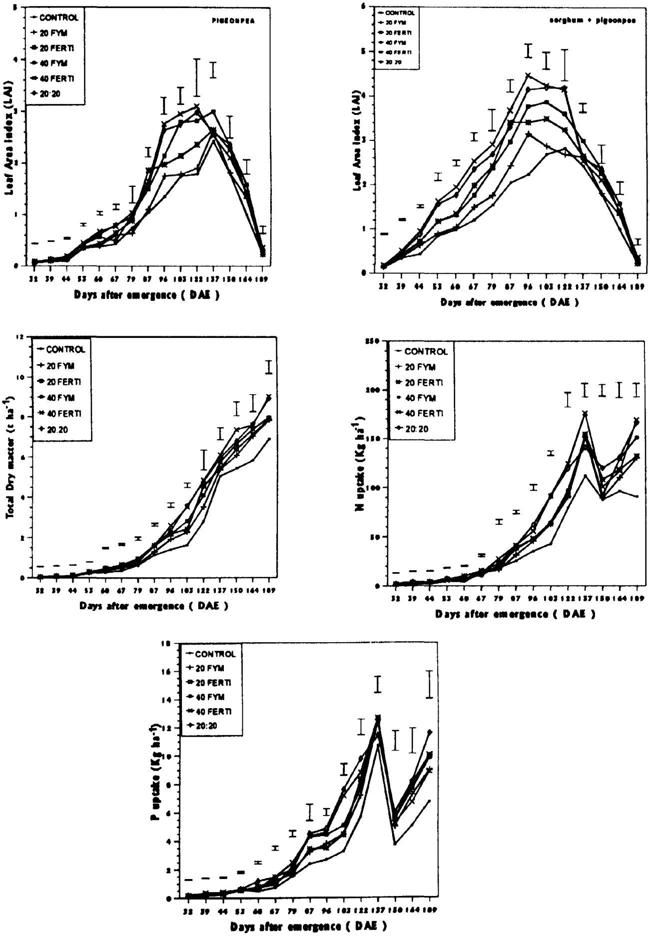
4.2.4.2 LAI of intercrop Pigeonpea

Leaf area index (LAI) was increased up to 2.64 at flowering stage and then it reduced and reached to a minimum value of 0.27 at maturity stage (Fig 7; Appendix 1.9). In vegetative stage of crop growth, LAI was influenced significantly due to N application. Application of 40 kg N ha^{-1} irrespective of source, increased the LAI (2.75 to 2.95) significantly compared to control (1.75) and 20 kg N ha^{-1} (FYM or fertilizer N) (1.75 to 2.14). Among 40 kg N ha^{-1} treatments, though not significantly, maximum LAI (2.95) was observed due to application of N as fertilizer source alone. The increase in LAI due to 40 kg N ha^{-1} was 62 and 44 % more than control and 20 kg N ha^{-1}. Application of fertilizer N alone, increased the LAI by 11 % more than that of FYM application alone irrespective of level of N. At flowering stage, though LAI was not influenced due to N application, maximum LAI (3.10) was observed due to 40 kg N ha^{-1} fertilizer N source alone. At pod development and maturity stage alone N application failed to influence LAI significantly.

4.2.4.3 Dry matter production of intercrop Pigeonpea

The dry matter production increased with the age of crop, i.e., from vegetative stage (47.5 to 2710 kg ha^{-1}) to flowering stage (4095 to 5611 kg ha^{-1}) and to pod development and maturity (7301 to 8097 kg ha^{-1}) (Fig 7; Appendix 1.10). During all stages of crop growth, N application influenced the dry matter production significantly. At the end of vegetative growth, significantly maximum dry matter production was recorded due to application of 40 kg N ha^{-1} either as fertilizer source alone or as FYM + fertilizer N. The dry matter production due to 40 kg N ha^{-1} (FYM) was found to be significantly more than that of the 20 kg N ha^{-1} (FYM or fertilizer N) and control treatments. At 20 kg N ha^{-1} no significant difference in dry matter production was observed between the sources of N. The increase in dry matter production due to 40 kg N ha^{-1} irrespective of source of N, was 103 and 41 % more than control and 20 kg N ha^{-1} respectively. At flowering stage, significantly ($P \leq 0.05$) more dry matter production (6098 kg ha^{-1}) was obtained due to 40 kg N ha^{-1} (fertilizer N) than control (5050 kg ha^{-1}). Between 20 and 40 kg N ha^{-1} (irrespective of source of N) no significant difference in dry matter production was observed. The increase in dry matter production due to 40 kg N ha^{-1} and 20 kg N ha^{-1} over control was 17 and 7 % respectively. At pod development and maturity stage, significantly maximum dry matter production was attained due to 40 kg N ha^{-1} (fertilizer N) than other treatments, however, it was on par with 40 kg N ha^{-1} (FYM + fertilizer N) treatment. The dry matter production was not significantly different between 20 kg N ha^{-1} (FYM or fertilizer N) and 40 kg N ha^{-1} (FYM). The increase in dry matter production due to 40 kg N ha^{-1} and 20 kg N ha^{-1} (irrespective of source of N) over control was 25 and 14 % respectively.

Figure 7.Growth and N & P uptake of Pigeonpea intercropped with Sorghum 1996



4.2.4.4 Nitrogen uptake by intercrop Pigeonpea

The uptake of N increased from vegetative stage to (1.78 to 69.3 kg ha^{-1}) to flowering stage (100.2 to 147.9 kg ha^{-1}). At pod development and maturity stage, the uptake of N was reduced (due to leaf fall) to 99.6 and further it increased up to 139.7 kg ha^{-1}. During all stages of crop growth, the uptake N was significantly influenced due to N application (Fig 7; Appendix 1.11). At vegetative stage, significantly maximum N uptake (91.2; 91.4 kg ha^{-1}) was observed due to 40 kg N ha^{-1} as fertilizer source alone or as FYM:fertilizer N than other treatments. The uptake of N (62.9 to 64.3) was not significantly differed due to 20 kg N ha^{-1} either fertilizer N alone or FYM alone and 40 kg N ha^{-1} as FYM alone treatments. The uptake of N was found to be lowest in control (0 N) . The increase in uptake of N due to 40 kg N ha^{-1} and 20 kg N ha^{-1} irrespective of source of N over control was 93% and 48 % respectively.

4.2.4.5 Phosphorus uptake of intercrop Pigeonpea

The uptake of P increased from vegetative stage (0.16 to 5.34 kg ha^{-1}) to flowering stage (7.91 to 12.05 kg ha^{-1}) (Fig 7; Appendix 1.12). However the P uptake was reduced at pod development stage (5.17 kg ha^{-1}) but it reached a peak of 9.35 kg ha^{-1} at maturity. During all the stages of crop growth, P uptake was influenced significantly due to N application. At vegetative stage, due to application of N at 40 kg ha^{-1} either as fertilizer N alone or FYM:fertilizer N significantly ($P \leq 0.05$) more uptake of P (7.18; 7.61 kg ha^{-1}) was observed than all other treatments. At 20 kg N ha^{-1} either through fertilizer or FYM sources not influenced the P uptake was not influenced significantly, however, the uptake was more than that of control treatment. At maturity, all N applied treatments irrespective of source and level of N, had significantly ($P \leq 0.05$) more P uptake (8.91 to 11.6 kg ha^{-1}) than that of control (6.75 kg ha^{-1}).

4.2.4.6 Potassium uptake of intercrop Pigeonpea

A mean K uptake of 60.0 kg ha^{-1} was observed, which was influenced due to N application significantly ($P \leq 0.05$) N application improved the K uptake (55.4 to 66 kg ha^{-1}) compared to control (51.3 kg ha^{-1}). Application of 40 kg N ha^{-1} recorded more uptake of K (63 kg ha^{-1}) than 20 kg N ha^{-1} (59.7 kg ha^{-1}) and control (51.3 kg ha^{-1}) (Appendix 2.9).

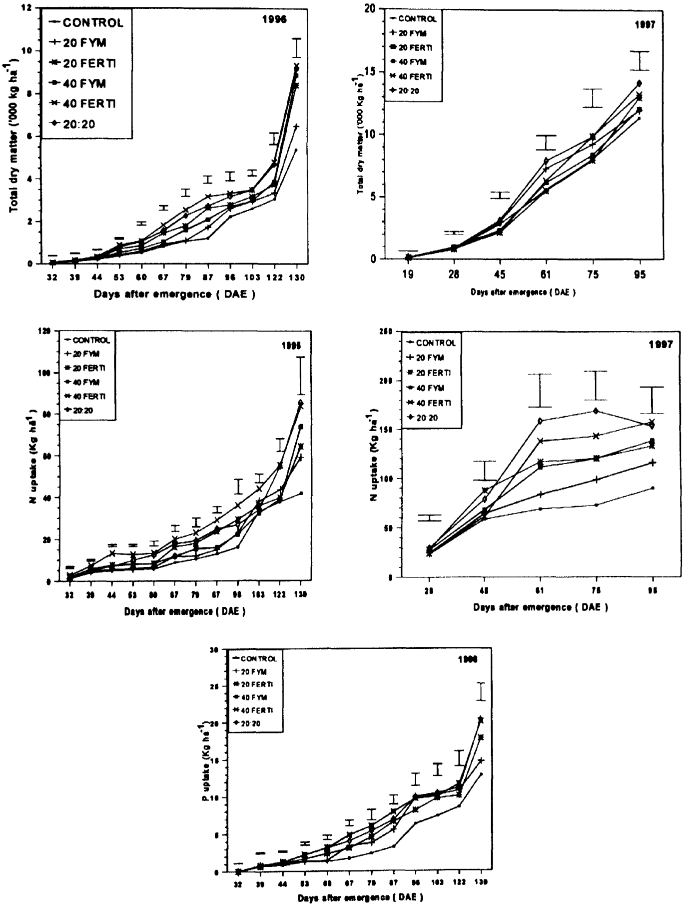
4.2.4.7 Dry matter production Sorghum

The dry matter production increased with the crop age i.e. from vegetative stage (45.5 to 811 kg ha^{-1}) to panicle initiation stage (1276 to 2262 kg ha^{-1}) and to seed development and maturity (2805 to 7952 kg ha^{-1}) (Fig 8; Appendix 1.14). The N application influenced the dry matter production significantly at all stages of crop growth. At all growth stages, the dry matter production was significantly higher due to application of 40 kg N ha^{-1} either through fertilizer N or FYM:fertilizer N. The increase in dry matter production due to 40 kg N ha^{-1} and 20 kg N ha^{-1} (irrespective of source of N) over control was 81%, 38%; 121%, 80% and 70% and 38 % at vegetative, panicle initiation and seed development and maturity stages respectively.

4.2.4.8 Nitrogen uptake by Sorghum

The uptake of N increased with the age of crop i.e. from vegetative stage (1.69 to 9.21 kg ha^{-1}) to panicle initiation (14.4 to 20.27 kg ha^{-1}) and to seed development and maturity (25.6 to 68.1 kg ha^{-1}) (Fig 8; Appendix 1.15). During the entire crop growth period, the N uptake by different treatments differed significantly due to N application. At all the stages of

Figure 8. Growth and N,P uptake by sorghum 1996 & 1997



crop growth, due to application of 40 kg N ha^{-1} either as fertilizer N or as FYM:fertilizer N significantly ($P \leq 0.05$) increased N uptake. The increase in uptake of N due to 40 kg N ha^{-1} and 20 kg N ha^{-1} (irrespective of source of N) over control was 97%, 28%; 80%, 50%; 94%, 48 % respectively at vegetative, panicle initiation and seed development and maturity.

4.2.4.9 Phosphorus uptake by Sorghum

With the age of crop, mean phosphorus uptake increased i.e. from vegetative stage (0.02 to 2.26 kg ha^{-1}), panicle initiation stage (3.36 to 6.02 kg ha^{-1}) and to seed development and maturity (8.63 to 17.73 kg ha^{-1}) (Fig 8; Appendix1.16). The N application at different sources and levels influenced the P uptake significantly. At all the stages of crop growth, control (no N) and 20 kg N ha^{-1} (FYM) recorded significantly lower P uptake than other treatments. At panicle initiation stage, and at maturity the increase in P uptake due to 40 kg N ha^{-1} and 20 kg N ha^{-1} (irrespective of source of N) over control was 58% and 27 % respectively.

4.2.4.10 Potassium uptake by Sorghum

The mean uptake of K by at harvest was 23.2 kg ha^{-1} (range 16.8 to 32.4 kg ha^{-1}). Nitrogen application did not significantly affect K uptake by sorghum (Appendix 1.16).

4.3 GROWTH AND DEVELOPMENT OF CROPS DURING 1997

4.3.1 Sole Soybean

4.3.1.1 Leaf area index (LAI)

The leaf area index (LAI) increased with the crop age until flowering (1.68) and reduced to 1.41 at maturity (Fig 9; Appendix 2.1). Except at the time of maturity, N application did not influence the LAI significantly. At maturity, application of N irrespective of source and level of N significantly increased the LAI (1.42 to 1.51) over control (1.06).

4.3.1.2 Dry matter production

The dry matter production of sole soybean increased with the crop age i.e., from vegetative stage (154 to 780 kg ha^{-1}) flowering stage (1379 to 2453 kg ha^{-1}) to maturity (3380 kg ha^{-1}) (Fig 9; Appendix 2.2). Nitrogen application did not influence the dry matter production significantly throughout crop growth period. However, N application at 20 kg ha^{-1} and 40 kg ha^{-1} irrespective of source of N increased the dry matter production by 15% and 8 % respectively over control (0 N) treatment.

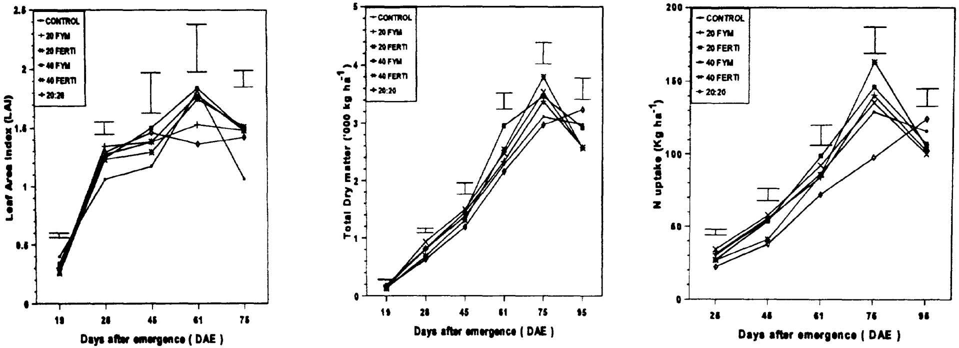
4.3.1.3 Nitrogen uptake

The mean uptake of N increased with the stage of crop growth i.e., from vegetative stage (29 to 50 kg ha^{-1}) and flowering stage (87 kg ha^{-1}) to maturity (135 kg ha^{-1}) (Fig 9; Appendix 2.3). The uptake of N during crop growth period was not influenced significantly due to N application. However, at maturity stage, N application @ 20 kg N ha^{-1} (fertilizer N) recorded maximum N uptake (163 kg ha^{-1}).

4.3.1.4 Phosphorus and Potassium uptake

The uptake of P at harvest was in the range of 8.63 to 11.04 kg ha^{-1} which was not influenced significantly due to N application. The mean uptake of K by soybean was found to be 52.8 kg ha^{-1} which was not influenced significantly due to N application (Appendix 2.3).

Figure 9 Growth and uptake of N by Soybean 1997



4.3.2 Soybean/Sunflower

4.3.2.1 Leaf area index of Soybean/Sunflower

Leaf area index (LAI) increased with time i.e. from 0.38 at vegetative stage to 1.71 at flowering stage, further it reduced to 1.41 at maturity. Only at maturity, N application affected the LAI significantly (Fig 10; Appendix 2.4). At maturity the LAI was maximum due to 20 kg N ha^{-1} (irrespective of source of N) than control and 40 kg N ha^{-1}. The response to N application was observed upto 20 kg N ha^{-1}.

4.3.2.2 LAI of intercrop Soybean

LAI increased from 0.26 to 1.01 (vegetative stage to pod development stage) and further it declined to 0.88 (maturity) (Fig 10; Appendix 2.1). Only at maturity LAI was varied significantly due to N fertilization. Significantly ($P \leq 0.05$) higher LAI was observed due to N application (irrespective of source and level of N) over control (0 N).

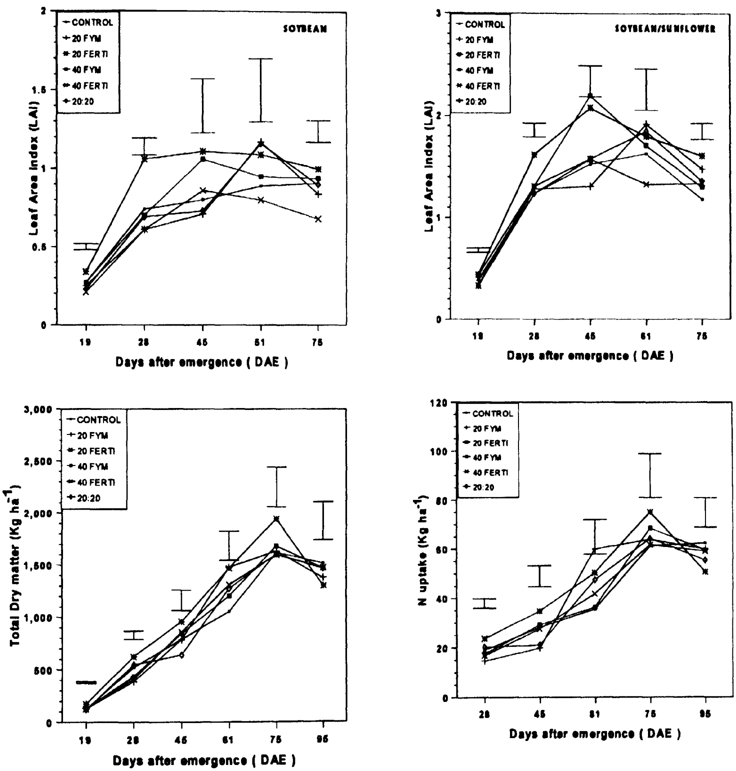
4.3.2.3 Dry matter production of intercrop Soybean

The mean dry matter production increased with age of crop i.e. from vegetative stage to maturity (133 to 1679 kg ha^{-1}), further it lowered to 1435 kg ha^{-1} at harvest (Fig 10; Appendix 2.2). There was no response to nitrogen in dry matter production of soybean at any growth stage.

4.3.2.4 Nutrient uptake by intercrop Soybean

Mean uptake of N was increased from 18.7 kg ha^{-1} at vegetative stage to 65.9 kg ha^{-1} at maturity (physiological), further the uptake was lowered to 58 kg ha^{-1} at harvest. Mean uptake of P and K at the time of harvest was 5.4 and 28.2 kg ha^{-1} respectively. N application failed to influence the nutrient uptake of intercropped soybean significantly (Fig 10; Appendix 2.3).

Figure 10.Growth and N uptake in Soybean intercropped with Sunflower 1997



4.3.2.5 Dry matter production of Sunflower

Dry matter production increased with the crop age from 61.4 kg ha^{-1} at vegetative stage to 1981 kg ha^{-1} at maturity, further the DMP was lowered to 1865 kg ha^{-1} at harvest . N application did not influence the dry matter production of sunflower at all crop growth stages (Fig 5; Appendix 2.5).

4.3.2.6 Nutrient uptake by Sunflower

Accumulation of N by sunflower was observed as 17.5 to 57 kg ha^{-1} from vegetative stage to maturity. Further, it reduced to 32 kg ha^{-1} at the time of harvest (Fig 5; Appendix 2.5). Mean uptake of phosphorus and potassium recorded as 4.8 and 5.2 kg ha^{-1} respectively (Appendix 2.5). N application did not influence the nutrient uptake by sunflower.

4.3.3 Pigeonpea

4.3.3.1 Leaf area index (LAI)

The mean leaf area index (LAI) reached a peak at flowering stage (4.08) and attained a minimum (0.06) at maturity stage. N application did not influence the LAI of pigeonpea throughout crop growth period except at flowering stage (Fig 11; Appendix 2.6). LAI was significantly ($P \leq 0.05$) more due to application of N at 40 kg N ha^{-1} (fertilizer N) (5.51) than that of any other treatment. Application of 40 kg N ha^{-1} either as FYM or FYM + fertilizer N, did not affect LAI significantly compared to 20 kg N ha^{-1} treatments, but significantly higher than that of control treatment. During pod development and maturity, N application did not influence the LAI significantly.

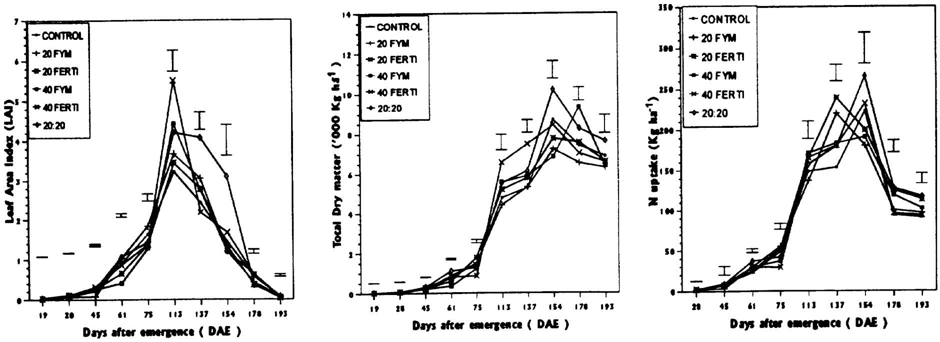
4.3.3.2 Dry matter production

The dry matter production increased till pod development stage (8210 kg ha^{-1}) and then started decline and reached to 6750 kg ha^{-1} at maturity (Fig 11; Appendix 2.7). During vegetative stage, significantly ($P \leq 0.05$) higher dry matter production was found higher with 20:20 kg N ha^{-1} (FYI + fertilizer N) than other treatments. The increase in dry matter production due to 40 kg N ha^{-1} was 30 % more than the control at vegetative stage. At flowering, significantly ($P \leq 0.05$) higher dry matter production was found with 40 kg N ha^{-1} (fertilizer N) (7508 kg ha^{-1}) than all other treatments. The increase in dry matter production due to 40 and 20 kg N ha^{-1} irrespective of source of N was 23 and 5 % more than that of control (no N) treatment. At pod development significantly ($P \leq 0.05$) higher dry matter production was observed due to 40 kg N ha^{-1} either as fertilizer N alone or FYM:fertilizer N than other treatments. At the time of maturity, N application did not influence the dry matter production significantly.

4.3.3.3 Nitrogen uptake

The mean N uptake increased up to pod development stage (215.7 kg ha^{-1}) then it dropped to 102.7 kg ha^{-1} at maturity stage (Fig 11; Appendix 2.8). During vegetative and flowering stages the uptake of N was not affected by N application, but at maturity, N uptake differed significantly ($P \leq 0.05$). At maturity, compared to control treatment (91.3 kg ha^{-1}) significantly higher N uptake (114.6 kg ha^{-1}) was observed due to 40 kg N ha^{-1} (FYM:fertilizer N), however, among different N applied treatments N uptake did not differ significantly. N application improved the uptake of N by 15 % compared to control treatment.

Figure 11. Growth and uptake of N in Pigeonpea 1997



4.3.3.4 Phosphorus and potassium uptake

At maturity, mean uptake of phosphorus at maturity was 8.59 kg ha^{-1}. Nitrogen application @ 40 kg N ha^{-1} (FYM:fertilizer N) significantly increased P uptake (9.5 kg ha^{-1}) compared to control (7.57 kg ha^{-1}). However, among N fertilized treatments irrespective of source and level of N there was no significant difference in P uptake. The increase in P uptake due to N fertilization was 16 % more than that of control. The uptake of K which ranged from 48.7 to 60.4 kg ha^{-1}, was influenced significantly due to N application. Significantly ($P \leq 0.05$) greater uptake of K (60.4 kg ha^{-1}) was observed due to 40 kg N ha^{-1} (fertilizer N) application, compared to control (48.7 kg ha^{-1}). However, among N fertilized treatments irrespective of source and level of N, there was little difference in K uptake. The mean K uptake due to N fertilization (58.1 kg ha^{-1}) was more than the control treatment (48.7 kg ha^{-1}) (Appendix 2.9).

4.3.4 Sorghum/Pigeonpea

4.3.4.1 Leaf area index of Sorghum/Pigeonpea

The leaf area index (LAI) increased from 0.25 to 2.97 till harvest of sorghum crop. Only at maturity of sorghum, N application influenced the LAI of sorghum/pigeonpea significantly (Fig 12; Appendix 2.10). LAI of sorghum/pigeonpea was significantly higher (3.67) due to application of N at 40 kg N ha^{-1} (fertilizer N) than that of control. However, no significant difference in LAI was observed between different N treatments at maturity stage of sorghum.

4.3.4.2 Leaf area index (LAI) of intercrop Pigeonpea

Leaf area index (LAI) was increased from vegetative stage (0.03 to 1.49) to flowering stage (4.08) and then it decreased during pod development and maturity stage (1.66 to 0.06).

Only at flowering stage, N application influenced the LAI significantly ($P \le 0.05$) (Fig 12; Appendix 2.6). N applied @ 20 kg ha^{-1} (fertilizer N) recorded significantly higher LAI (1.72) than control (no N) treatment, however, no significant difference on LAI was observed between different levels and sources of N. The increase in LAI, due to application of N irrespective of source and level of N was 75 % more than that of control (no N).

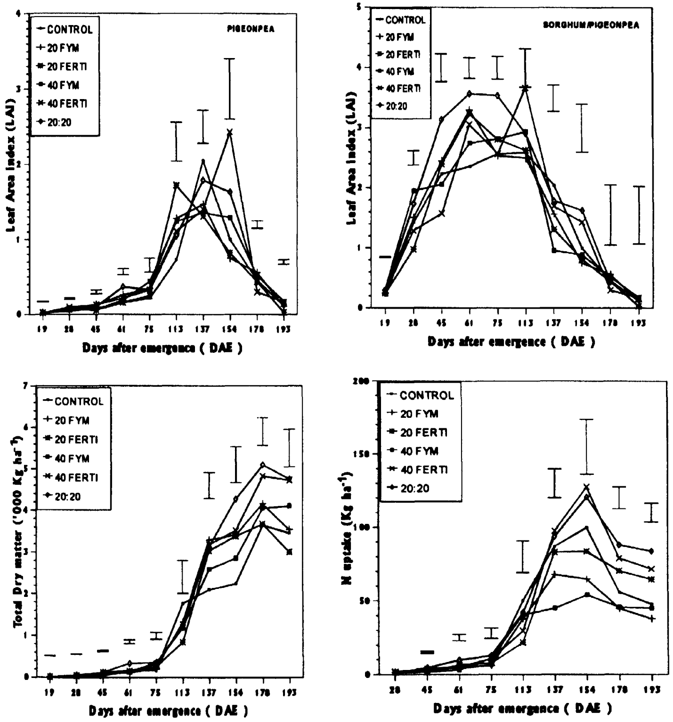
4.3.4.3 Dry matter production of intercrop Pigeonpea

The dry matter production increased till pod development stage (4242 kg ha^{-1}), and slight decline was observed at maturity (3935 kg ha^{-1}) (Fig 12; Appendix 2.7). At vegetative stage, significantly maximum dry matter production was observed due to 40 kg N (FYM + fertilizer N) treatment (336 kg ha^{-1}) than all other treatments (118 to 178 kg ha^{-1}). At flowering, due to application of N at 40 kg N ha^{-1} either as fertilizer or FYM:fertilizer N significantly increased the dry matter production compared to control. The increase in dry matter production due to application of N @ 40 kg N and 20 kg N ha^{-1} irrespective of source of N was 41 and 50 % more than that of control. At pod development stage, significantly maximum dry matter production was observed due to 40 kg N ha^{-1} (FYM:fertilizer N) treatment (4270 kg ha^{-1}) than that of control (2231 kg ha^{-1}). However, within N treatments, no significant difference in dry matter production was observed.

4.3.4.4Nitrogen uptake

The N uptake was increased till pod development stage (92 kg ha^{-1}) and then it dropped to 64 kg at maturity. During vegetative and flowering stages N application did not influence the uptake of N significantly (Fig 12; Appendix 2.8). At maturity, due to application of N at 40 kg N ha^{-1} (FYM + fertilizer N) recorded significantly ($P \le 0.05$) higher uptake of N

Figure 12. Growth and N uptake of Pigeonpea intercropped with Sorghum 1997



(77.8 kg ha^{-1}) compared to control (47.8 kg ha^{-1}). However, application of N irrespective of source and level of N failed to influence the uptake of N significantly. The increase in mean N uptake due to N application was 41 % more than that of control.

4.3.4.5 Phosphorus and potassium uptake at maturity

Phosphorus uptake was significantly ($P \leq 0.05$) more due to application of N @ 40 kg N ha^{-1} (fertilizer N) (5.7 kg ha^{-1}) than control (3.59 kg ha^{-1}). However, between N applied treatments levels & sources, the phosphorus uptake did not differ significantly. Potassium uptake was significantly higher due to 40 kg N ha^{-1} (FYM:fertilizer N) application than that of control (18 kg ha^{-1}). However, between N treatments (irrespective of sources and levels of N) K uptake did not differ significantly ((Appendix 2.12).

4.3.4.6 Dry matter production Sorghum

With the age of crop dry matter production increased due to application of N, i.e. from vegetative stage (126 to 872 kg ha^{-1}) to panicle initiation (2612 to 6480 kg ha^{-1}) and to seed development and maturity (8932 to 12676 kg ha^{-1}) (Fig 8; Appendix 2.11). Throughout crop growth period N application did not influence the dry matter production significantly. At maturity the increase in dry matter production due to 40 kg N ha^{-1} and 20 kg N ha^{-1} (irrespective of source of N) over control was 16 and 10 % respectively.

4.3.4.7 Nitrogen uptake

The mean uptake of N increased with the age of the crop and attained a maximum of 131.4 kg ha^{-1} at maturity (Fig 8; Appendix 2.12). Only at maturity stage, significantly ($P \leq 0.05$) maximum uptake of N was observed due to application of N at 20 kg N ha^{-1} and 40 kg N ha^{-1}

(irrespective of source of N) compared to control. However, there was no significant difference in N uptake of sorghum due to different sources and levels of N.

4.3.4.8 Phosphorus and Potassium uptake

At maturity, neither phosphorus uptake nor potassium uptake was influenced due to application of N at different sources and levels of N (Appendix 2.12).

4.4 NODULATION AND NITROGENASE ACTIVITY OF SOYBEAN AND PIGEONPEA DURING 1996

4.4.1 Number of nodules

In soybean mean nodule number plant^{-1} was increased from 4 at 48 DAE to 30 at 83 DAE, however in pigeonpea mean nodule number increased from 44 nodules plant^{-1} at 48 DAE to 52 nodules plant^{-1} at 83 DAE (Table 1 and 2). N application did not influence the nodule number plant^{-1} significantly at 48 and 83 DAE. Crops varied significantly ($P \leq 0.01$) in respect of nodule number plant^{-1}. The highest number of nodules plant^{-1} were observed for pigeonpea intercropped with sorghum followed by sole pigeonpea at 48 and 83 DAE. Sole crops and intercrops of soybean and pigeonpea did not differ significantly in respect of nodule number plant^{-1}. At 48 and 83 DAE mean nodule number per plant was marginally reduced due to application of 20 and 40 kg n ha^{-1} as that of control (0 N) treatment.

4.4.2 Weight of nodules

Mean nodule weight plant^{-1} was increased from 48 to 83 DAE by two times in soybean and three times in pigeonpea. At 48 DAE crops and nitrogen application influenced the nodule weight plant^{-1} significantly ($P \leq 0.01$), whereas at 83 DAE only crops influenced the nodule weight significantly ($P \leq 0.01$) (Table 1 and 2). At 48 DAE, 20 kg N and 40 kg N ha^{-1} as

Table 1. Number of nodules (no. plant^{-1}) and Weight of nodules (mg plant^{-1}) at 48 DAE 1996

Treatment	Sole Soybean	Intercrop Soybean	Sole Pigeonpea	Intercrop Pigeonpea	Mean
Number of nodules					
Control	2.1	2.5	55.2	48.8	27.2
20 kg N ha^{-1} (FYM)	1.8	3.2	47.5	38.5	22.8
20 kg N ha^{-1} (Fertlizer)	2.6	4.7	31.8	58.5	24.4
40kg N ha^{-1} (FYM)	2.7	7.5	39.3	48.2	24.4
40kg N ha^{-1} (Fertlizer)	6.5	2.9	39.2	37.8	21.6
20:20 kg N ha^{-1} (FYM:Fertlizer)	2.8	5.2	33.2	50.3	22.9
Mean	3.1	4.3	41.0	47.0	
Weight of nodules					
Control	18.9	16.9	123.3	138.3	74.4
20 kg N ha^{-1} (FYM)	8.2	22.9	110.0	200.0	85.3
20 kg N ha^{-1} (Fertlizer)	8.9	21.8	60.0	65.0	38.9
40kg N ha^{-1} (FYM)	9.3	34.2	133.3	125.0	75.5
40kg N ha^{-1} (Fertlizer)	10.3	8.0	66.7	45.0	32.5
20:20 kg N ha^{-1} (FYM:Fertlizer)	6.9	32.2	108.3	120.0	66.9
Mean	10.4	22.7	100.3	115.6	

	N[2]	*C*	*NC*
Number of nodules			
SE±	2.98	4.0	8.99
C.D (0.05)[1]	9.39 NS	13.71**	30.81 NS
Weight of nodules			
SE±	31.5	31.9	74.7
C.D (0.05)	99.0*	109.0**	256.0**

*1 * = (P≤0.05); ** = (P≤0.01); NS = Nonsignificant*

2. N = Nitrogen levels; C = Crops; NC = Interaction effect between nitrogen and crops

Table 2. Number of nodules (no. plant^{-1}) and Weight of nodules (mg plant^{-1}) at 83 DAE 1996

Treatment	Sole Soybean	Intercrop Soybean	Sole Pigeonpea	Intercrop Pigeonpea	Mean
Number of nodules					
Control	40.4	33.0	43.3	38.5	38.8
20 kg N ha^{-1} (FYM)	45.2	11.1	39.8	45.0	35.3
20 kg N ha^{-1} (Fertlizer)	38.6	16.1	26.2	61.8	35.7
40kg N ha^{-1} (FYM)	27.8	23.0	50.0	56.2	39.2
40kg N ha^{-1} (Fertlizer)	36.3	29.4	56.8	49.2	42.9
20:20 kg N ha^{-1} (FYM:Fertlizer)	26.6	28.1	55.3	95.8	51.5
Mean	35.8	23.5	45.3	57.8	
Weight of nodules					
Control	133	131	267	223	189
20 kg N ha^{-1} (FYM)	200	82	228	188	175
20 kg N ha^{-1} (Fertlizer)	121	93	157	197	142
40kg N ha^{-1} (FYM)	148	111	310	377	236
40kg N ha^{-1} (Fertlizer)	131	97	162	190	145
20:20 kg N ha^{-1} (FYM:Fertlizer)	96	97	207	225	156
Mean	138	102	222	233	

	N[2]	*C*	*NC*
Number of nodules			
SE±	8.98	7.82	18.87
C.D (0.05)[1]	28.3 NS	26.8*	64.67 NS
Weight of nodules			
SE±	26.7	20.4	50.9
C.D (0.05)	84 NS	70**	174 NS

 # 1, 2. Refer Table 4

fertilizer nitrogen significantly reduced in comparison to all other treatments. Nodule weight reduction was 90 and 126 % in 20 kg N (fertilizer N) and 40 kg N (fertilizer N) respectively than control (0 N) at 48 DAE. In respect of different sources of N, the percentage reduction in module weight was 126 in treatments which received fertilizer source of N alone than the treatments which received N as FYM. At 48 DAE mean nodule weight was significantly ($P \leq 0.05$) varied due to rate and source of N application. Application of 20 kg N ha^{-1} as FYM increased mean nodule weight significantly whereas 20 kg N as fertilizer N significantly reduced nodule weight than that of nodule weight in control treatment. In case of 40 kg N ha^{-1} as FYM, nodule weight was on par with that of control treatment, whereas in case of 40 kg N ha^{-1} through fertilizer N, nodule weight was reduced to over half than that of control and 40 kg N as FYM treatments. Application of 40 kg N ha^{-1} through fertilizer N + FYM had no effect on nodule weight as compared to the nodule weight of control (no N) plants. Among the crops, at 48 DAE soybean intercropped with sunflower recorded higher nodule weight $plant^{-1}$ than sole soybean and in case of pigeonpea plots the nodule weight $plant^{-1}$ was maximum in sole pigeonpea than pigeonpea intercropped with sorghum. Sole crops and intercrops of soybean and pigeonpea did not differ in nodule weight $plant^{-1}$ significantly at 83 DAE. Interaction effect between crops and N application on nodule weight was found to be significant at 48 DAE. In soybean intercropped with sunflower the nodule weight was lowest when it received 40 kg N through fertilizer source. In sole and intercropped pigeonpea, the lowest nodule weight was observed when crops received N through fertilizer source alone (20 kg N and 40 kg N).

4.4.3 Nitrogenase activity

Mean nitrogenase activity was increased by five folds from 48 to 83 DAE (0.92 to 4.9 μ mol C_2H_4 plant^{-1} h^{-1}) in soybean and not much increase (7 to 9 μ mol C_2H_4 plant^{-1} h^{-1}) was seen in pigeonpea. Nitrogenase activity varied significantly ($P \leq 0.05$) with N application and due to cropping systems at 48 and 83 DAE (Table 3 and 4). At 48 DAE, mean nitrogenase activity was not significantly ($P \leq 0.05$) reduced due to application of N at 20 and 40 kg N ha^{-1} through FYM. However application at 20 and 40 kg N ha^{-1} as fertilizer significantly reduced nitrogenase activity as that of control treatments. At 48 DAE, mean nitrogenase activity decreased from 2.17 m mom C_2H_4 plant^{-1} h^{-1} in 20 kg N (fertilizer source) to 1.91 μ mol C_2H_4 plant^{-1} h^{-1}) in 40 kg N (fertilizer source). At 48 DAE mean nitrogenase activity was reduced by 15, 6_2 and 30 % with FYM, fertilizer and FYM + fertilizer sources respectively than control (0 N) treatments. At 83 DAE, significantly ($P \leq 0.05$) highest nitrogenase activity (10.31 μ mol C_2H_4 plant^{-1} h^{-1}) was observed with 40 kg N (FYM). At 48 DAE mean nitrogenase activity was three fold higher in case of intercropped soybean than that of sole soybean. Similarly, in pigeonpea also, higher nitrogenase activity (1.25 folds) was observed in intercropped pigeonpea than in case of sole pigeonpea. In case of soybean a maximum nitrogenase activity of 0.70 μ mol C_2H_2 plant^{-1} h^{-1} was recorded in case of 20 kg N ha^{-1} FYM as against of 0.41 μ mol C_2H_4 plant^{-1} h^{-1} in control. Whereas a maximum activity of 2.47 μ mol C_2H_4 plant^{-1} h^{-1} was recorded in case of 40 kg N ha^{-1} as fertilizer N and FYM. In case of sole pigeonpea maximum nitrogenase activity of 11.88 μ mol C_2H_4 plant^{-1} h^{-1} was recorded in case of control treatments, whereas in intercropped pigeonpea a maximum nitrogenase activity of 11.59 μ mol C_2H_4 plant^{-1} h^{-1} was recorded in case of 40 kg n ha^{-1} as FYM.

4.4.4 Specific nitrogenase activity

Mean specific nitrogenase activity from 48 to 83 DAE was decreased from to 43 μ mol C_2H_4 g^{-1} nodules h^{-1} in soybean and from 62 to 41 μ mol C_4H_4 g^{-1} nodules h^{-1} in pigeonpea (Table 3 and 4). Mean specific nitrogenase activity was not significantly varied due to nitrogen application and cropping systems at 48 DAE. At 48 DAE, in sole soybean maximum specific nitrogenase activity was observed with 20 kg N application as FYM (89.5 μ mol C_2H_4 g^{-1} nodules h^{-1}) followed by 40 Kg N ha^{-1} (FYM : fertilizer source) (86.0 m and C_2H_4 g^{-1} nodules h^{-1}). In case of pigeonpea, maximum activity was observed with control (0 N) in sole pigeonpea, whereas in intercropped pigeonpea, maximum specific nitrogenase activity was observed in case of 40 kg N ha^{-1} as FYM application. At 83 DAE, the mean specific nitrogenase activity varied significantly due to N application and cropping systems maximum activity was found due to 40 kg N (fertilizer source) application followed by 40 kg N (FYM) application. The specific nitrogenase activity was mere in pigeonpea intercropped with sorghum (49 μ mol C_2H_4 g^{-1} nodules h^{-1}) than that of sole pigeonpea. No appreciable differences were found between sole soybean and intercropped soybean. In case of pigeonpea, intercropped pigeonpea due to application of 40 kg N (FYM or fertilizer source alone) recorded maximum specific nitrogenase activity.

Table 3. Nitrogenase activity (μ mol C_2H_4 plant^{-1} h^{-1}) and Specific nitrogenase activity (μ mol C_2H_4 g^{-1} nodules h^{-1}) at 48 DAE 1996

	Sole Soybean	Intercrop Soybean	Sole Pigeonpea	Intercrop Pigeonpea	Mean
Nitrogenase activity					
Control	0.41	0.60	11.88	9.04	5.48
20 kg N ha^{-1} (FYM)	0.70	1.38	6.59	9.16	4.46
20 kg N ha^{-1} (Fertlizer)	0.36	1.17	3.10	4.06	2.17
40kg N ha^{-1} (FYM)	0.51	2.29	5.23	11.51	4.88
40kg N ha^{-1} (Fertlizer)	0.30	0.37	4.36	2.59	1.91
20:20 kg N ha^{-1} (FYM:Fertlizer)	0.53	2.47	4.29	8.09	3.85
Mean	0.47	1.38	5.91	7.41	
Specific nitrogenase activity					
Control	25.9	39.9	98.9	65.5	57.5
20 kg N ha^{-1} (FYM)	89.5	61.9	61.1	45.0	64.4
20 kg N ha^{-1} (Fertlizer)	39.6	53.0	50.3	63.4	51.6
40kg N ha^{-1} (FYM)	63.1	66.5	40.9	91.9	65.6
40kg N ha^{-1} (Fertlizer)	38.3	81.7	63.9	57.6	60.4
20:20 kg N ha^{-1} (FYM:Fertlizer)	86.0	77.9	39.7	68.2	67.9
Mean	57.1	63.5	59.1	65.3	

	N^2	C	NC
Nitrogenase activity			
SE±	0.53	0.35	0.91
C.D (0.05)^1	1.68**	1.19**	3.11**
Specific nitrogenase activity			
SE±	8.61	5.4	14.3
C.D (0.05)	27.1^{NS}	18.5^{NS}	49.3**

 # 1, 2. Refer Table 4

Table 4. Nitrogenase activity (μ mol C_2H_4 plant^{-1} h^{-1}) and Specific nitrogenase activity (μ mol C_2H_4 g^{-1} nodules h^{-1}) at 83 DAE 1996

Treatment	Sole Soybean	Intercrop Soybean	Sole Pigeonpea	Intercrop Pigeonpea	Mean
Nitrogenase activity					
Control	4.9	3.4	9.7	13.0	7.8
20 kg N ha^{-1} (FYM)	6.4	3.2	10.5	6.4	6.6
20 kg N ha^{-1} (Fertlizer)	4.8	5.3	2.4	10.0	5.6
40kg N ha^{-1} (FYM)	5.7	5.4	4.4	25.8	10.3
40kg N ha^{-1} (Fertlizer)	5.9	5.5	9.1	12.3	8.2
20:20 kg N ha^{-1} (FYM:Fertlizer)	5.1	3.2	7.0	8.3	5.9
Mean	5.5	4.3	7.2	12.6	
Specific nitrogenase activity					
Control	33.8	27.5	38.9	45.6	36.5
20 kg N ha^{-1} (FYM)	39.7	39.8	40.3	33.2	38.2
20 kg N ha^{-1} (Fertlizer)	44.6	58.3	15.3	50.2	42.1
40kg N ha^{-1} (FYM)	41.2	48.7	16.6	79.1	46.4
40kg N ha^{-1} (Fertlizer)	44.5	52.5	56.2	87.9	60.3
20:20 kg N ha^{-1} (FYM:Fertlizer)	52.6	33.5	32.5	34.8	38.3
Mean	42.7	43.4	33.3	52.0	

	N[2]	*C*	*NC*
Nitrogenase activity			
SE±	1.05	0.78	1.97
C.D (0.05)[1]	3.31*	2.7**	6.7**
Specific nitrogenase activity			
SE±	4.9	4.4	10.6
C.D (0.05)	15.5*	15.1**	36.3*

 # 1, 2. Refer Table 4

4.5 NODULATION AND NITROGENASE ACTIVITY OF SOYBEAN AND PIGEONPEA DURING 1997

4.5.1 Number of nodules

Mean nodule number plant^{-1} was increased from 18 at 43 DAE to 63 at 80 DAE in soybean. The nodule number was not varied significantly due to N application at both 43 and 80 DAE. Cropping systems influenced the nodule number plant^{-1} significantly ($P \leq 0.05$) at both 43 and 80 DAE (Table 5 and 6). At both stages mean nodule number was highest in sole soybean than intercropped soybean, but in pigeonpea not much difference was observed between sole and intercrops.

4.5.2 Weight of nodules

In soybean mean nodule weight increased from 32 mg plant^{-1} at 43 DAE to 124 mg plant^{-1} at 80 DAE. Nodule weight varied significantly ($P \leq 0.05$) due to N application at 43 DAE but at 80 DAE similar differences were not observed (Table 5 and 6). Amongst the treatments lowest nodule weight was observed ($P \leq 0.05$) in case of 20 kg or 40 kg N applied as FYM source alone. Cropping systems had no significant effect on nodule weight at 43 DAE but at 80 DAE, cropping systems influenced the nodule weight significantly ($P \leq 0.01$). Significantly greater nodule weight was found in sole soybean than that of soybean intercropped with sunflower, whereas in pigeonpea no specific differences were observed at 80 DAE under sole and intercropped situations.

Table 5. Number of nodules (no. plant^{-1}) and Weight of nodules (mg plant^{-1}) at 43 DAE 1997

Treatment	Sole Soybean	Intercrop Soybean	Sole Pigeonpea	Intercrop Pigeonpea	Mean
Number of nodules					
Control	18.3	21.5	7.8	20.5	17.1
20 kg N ha^{-1} (FYM)	26.7	13.7	11.5	8.3	15.0
20 kg N ha^{-1} (Fertlizer)	21.2	14.7	18.5	18.8	18.3
40kg N ha^{-1} (FYM)	18.6	11.3	13.8	11.8	13.9
40kg N ha^{-1} (Fertlizer)	20.2	11.1	17.3	23.0	17.9
20:20 kg N ha^{-1} (FYM:Fertlizer)	21.3	17.0	25.0	12.0	18.9
Mean	21.1	14.9	15.7	15.8	
Weight of nodules					
Control	37.1	43.3	25.0	31.7	34.3
20 kg N ha^{-1} (FYM)	40.5	22.9	25.0	23.3	27.9
20 kg N ha^{-1} (Fertlizer)	38.6	37.6	38.3	33.3	37.0
40kg N ha^{-1} (FYM)	21.4	19.0	40.0	15.0	23.9
40kg N ha^{-1} (Fertlizer)	23.3	21.0	31.7	58.3	33.6
20:20 kg N ha^{-1} (FYM:Fertlizer)	32.9	22.9	46.7	43.3	36.4
Mean	32.3	27.8	34.4	34.2	

	N[2]	*C*	*NC*
Number of nodules			
SE±	2.5	1.37	3.82
C.D (0.05)[1]	7.8 ^{NS}	4.7*	13.1*
Weight of nodules			
SE±	2.81	2.14	5.34
C.D (0.05)	8.9*	7.3 ^{NS}	18.3**

 # 1,2. Refer Table 4

Table 6. Number of nodules (no. plant^{-1}) and Weight of nodules (mg plant^{-1}) 80 DAE 1997

Treatment	Sole Soybean	Intercrop Soybean	Sole Pigeonpea	Intercrop Pigeonpea	Mean
Number of nodules					
Control	63.0	71.3	13.0	6.8	38.5
20 kg N ha^{-1} (FYM)	86.0	55.9	11.8	4.5	39.6
20 kg N ha^{-1} (Fertlizer)	64.4	61.0	6.8	5.5	34.4
40kg N ha^{-1} (FYM)	75.2	47.6	11.7	2.3	34.2
40kg N ha^{-1} (Fertlizer)	60.7	45.1	14.7	7.8	32.1
20:20 kg N ha^{-1} (FYM:Fertlizer)	72.9	25.5	2.7	2.0	25.8
Mean	70.4	51.1	10.1	4.8	
Weight of nodules					
Control	123.3	96.7	48.3	5.0	68.3
20 kg N ha^{-1} (FYM)	163.3	102.4	51.7	5.0	80.6
20 kg N ha^{-1} (Fertlizer)	94.3	92.4	6.7	5.0	49.6
40kg N ha^{-1} (FYM)	154.3	87.1	48.3	5.0	73.5
40kg N ha^{-1} (Fertlizer)	88.6	61.0	38.3	31.7	54.9
20:20 kg N ha^{-1} (FYM:Fertlizer)	119.0	42.4	10.0	43.3	53.7
Mean	124	80.3	33.9	15.8	

	N[2]	*C*	*NC*
Number of nodules			
SE±	5.5	3.4	9.1
C.D (0.05)[1]	17.2^{NS}	11.7**	31.1^{NS}
Weight of nodules			
SE±	6.91	7.42	17.2
C.D (0.05)	21.8^{NS}	25.4**	58.9^{NS}

 # 1,2. Refer Table 4

4.5.3 Nitrogenase activity

Mean nitrogenase activity increased by 27 folds from 43 to 80 DAE (0.181 to 4.86 μ mol C_2H_4 plant^{-1} h^{-1}) in soybean and around two folds increase in pigeonpea (0.34 to 0.62 μ mol C_2H_4 plant^{-1} h^{-1}). Nitrogenase activity varied significantly due to N application and due to cropping systems at both 48 and 80 DAE (Table 7 and 8). At 43 DAE, significantly ($P \leq 0.05$) higher mean nitrogenase activity was observed due to application of 20 kg N ha^{-1} as FYM than that of 20 kg N ha^{-1} as fertilizer source and 40 kg N ha^{-1} (FYM : fertilizer source) application. At 80 DAE, mean nitrogenase activity did not significantly ($P \leq 0.05$) differ due to application of N at 20 kg N (fertilizer source) and 40 kg N ha^{-1}) FYM : fertilizer source) compared to control. Significantly ($P \leq 0.05$) higher mean nitrogenase activity was observed due to FYM application (20 and 40 kg N ha^{-1}) and lowest activity was observed due to 40 kg N ha^{-1} (fertilizer source) application. At 80 DAE mean nitrogenase activity was reduced by 27 and 44 % due to 40 kg N ha^{-1} (fertilizer source) compared to control and FYM application (20 kg or 40 kg N ha^{-1}).

At 43 DAE, mean nitrogenase activity was not varied significantly ($P \leq 0.05$) between sole and intercrops of soybean. However, in case of pigeonpea significantly ($P \leq 0.05$) higher nitrogenase activity was observed in sole pigeonpea than that of intercropped pigeonpea. In pigeonpea, the mean nitrogenase activity was two folds more than that of soybean at 43 DAE. Contrastingly at 80 DAE, significantly higher nitrogenase activity was found in sole soybean than that of intercropped soybean, however in case of pigeonpea, significant differences were not observed between sole and intercrops. Mean nitrogenase activity in soybean was 8 folds more than that of pigeonpea.

Table 7. Nitrogenase activity (μ mol C_2H_4 plant^{-1} h^{-1}) and Specific nitrogenase activity (μ mol C_2H_4 g^{-1} nodules h^{-1}) at 43 DAE, 1997.

Treatment	Sole Soybean	Intercrop Soybean	Sole Pigeonpea	Intercrop Pigeonpea	Mean
Nitrogenase activity					
Control	0.410	0.260	0.144	0.194	0.252
20 kg N ha^{-1} (FYM)	0.251	0.191	0.518	0.297	0.314
20 kg N ha^{-1} (Fertlizer)	0.255	0.211	0.201	0.180	0.212
40kg N ha^{-1} (FYM)	0.146	0.172	0.708	0.199	0.306
40kg N ha^{-1} (Fertlizer)	0.104	0.071	0.261	0.545	0.245
20:20 kg N ha^{-1} (FYM:Fertlizer)	0.082	0.012	0.456	0.355	0.226
Mean	0.208	0.153	0.381	0.295	
Specific nitrogenase activity					
Control	11.14	6.14	5.97	7.18	7.61
20 kg N ha^{-1} (FYM)	5.99	8.47	21.43	20.77	14.2
20 kg N ha^{-1} (Fertlizer)	6.84	5.87	5.33	5.38	5.9
40kg N ha^{-1} (FYM)	7.25	8.90	17.79	14.76	12.2
40kg N ha^{-1} (Fertlizer)	4.06	4.34	8.74	9.53	6.7
20:20 kg N ha^{-1} (FYM:Fertlizer)	2.67	0.54	9.94	9.87	5.8
Mean	6.3	5.7	11.5	11.3	

	N[2]	*C*	*NC*
Nitrogenase activity			
SE±	0.018	0.019	0.043
C.D (0.05)[1]	0.062*	0.063**	0.148**
Specific nitrogenase activity			
SE±	1.13	1.10	2.60
C.D (0.05)	3.56**	3.77**	8.89 ^{NS}

 # 1,2. Refer Table 4

Table 8. Nitrogenase activity (μ mol C_2H_4 plant^{-1} h^{-1}) and Specific nitrogenase activity (μ mol C_2H_4 g^{-1} nodules h^{-1}) at 80 DAE 1997

Treatment	Sole Soybean	Intercrop Soybean	Sole Pigeonpea	Intercrop Pigeonpea	Mean
Nitrogenase activity					
Control	7.65	2.46	0.28	0.37	2.69
20 kg N ha^{-1} (FYM)	6.80	4.75	1.94	0.79	3.57
20 kg N ha^{-1} (Fertlizer)	4.95	3.20	0.34	0.28	2.19
40kg N ha^{-1} (FYM)	6.83	5.76	0.94	0.27	3.45
40kg N ha^{-1} (Fertlizer)	0.84	5.95	0.67	0.38	1.96
20:20 kg N ha^{-1} (FYM:Fertlizer)	6.01	3.09	0.37	0.77	2.56
Mean	5.51	4.20	0.76	0.48	
Specific nitrogenase activity					
Control	68.7	29.1	6.5	74.7	44.8
20 kg N ha^{-1} (FYM)	56.5	49.0	38.5	158.4	75.6
20 kg N ha^{-1} (Fertlizer)	55.0	36.8	54.1	55.6	50.4
40kg N ha^{-1} (FYM)	44.8	71.7	19.6	54.8	47.7
40kg N ha^{-1} (Fertlizer)	9.9	109.2	16.4	11.9	36.9
20:20 kg N ha^{-1} (FYM:Fertlizer)	55.4	79.9	43.9	21.2	50.1
Mean	48.4	62.6	29.9	62.7	

	N^2	C	NC
Nitrogenase activity			
SE±	0.27	0.24	0.58
C.D (0.05)[1]	0.85**	0.83**	1.98**
Specific nitrogenase activity			
SE±	9.3	5.4	14.7
C.D (0.05)	29.2 ^{NS}	18.3**	50.2**

 # 1,2. Refer Table 4

4.5.4 Specific nitrogenase activity

Mean specific nitrogenase activity increased from 8.71 μ mol C_2H_4 g^{-1} nodules h^{-1} at 43 DAE to 51.9 M mol C_2H_4 g^{-1} nodules at 80 DAE. Specific nitrogenase activity varied significantly ($P \leq 0.05$) due to N application at 43 DAE, but at 83 DAE, the activity was not varied (Table 7 and 8). Significantly highest nodule activity was observed due to FYM application alone (20 kg and 40 kg N). At 43 DAE, sole crop of soybean and pigeonpea was not differed with intercrops in respect of specific nitrogenase activity. But at 83 DAE, significantly highest nodule activity was observed with intercrops of soybean and pigeonpea than the respective sole crops.

4.6 GRAIN YIELDS DURING 1996

4.6.1 Soybean

Grain yield of sole soybean which ranged from 757 to 1133 kg ha^{-1} was significantly ($P \leq 0.01$) influenced by levels and sources of N (Fig 13; Table 9). Application of N improved the grain yield. Significantly ($P \leq 0.05$) higher yield was obtained due to 40 kg N ha^{-1} (fertilizer N) application than all other treatments. The grain yield recorded by 20:20 kg N ha^{-1} (FYM:fertilizer N) was significantly ($P \leq 0.05$) higher than that of 40 kg N ha^{-1} (FYM), 20 kg N ha^{-1} (FYM) and control treatments, however it was on par with 20 kg N ha^{-1} (fertilizer N). Among the 20 kg N ha^{-1} treatments, the treatment which received N through fertilizer source recorded significantly ($P \leq 0.05$) higher yield than that of FYM source and control (no N) treatments. Irrespective of source of N, 40 kg N ha^{-1} treatments recorded 12 and 27 % higher yield than that of 20 kg N ha^{-1} (FYM or fertilizer N) and control treatments.

Table 9 Grain yields (kg ha^{-1}) of Soybean and Sunflower 1996 & 1997.

Treatment	1996			1997		
	Soybean	Soybean/sunflower		Soybean	Soybean/Sunflower	
		Soybean	Sunflower		Soybean	Sunflower
1. Control (0N)	769	549	90	770	729	367
2. 20 kg N ha^{-1} (FYM)	757	551	122	969	674	366
3. 20 kg N ha^{-1} (fertlizer)	999	711	153	1093	612	376
4. 40 kg N ha^{-1} (FYM)	820	723	188	1080	741	386
5. 40 kg N ha^{-1} (fertilizer)	1133	843	301	998	605	463
6. 20:20 kg N ha^{-1} (FYM : fertilizer)	981	788	275	1021	672	419
7. Mean	910	694	188	989	672	396

	Soybean (1996)				Sunflower (1996)	Soybean (1997)				Sunflower (1997)
	N[2]	*C*	*NC*	*CN*	*N*	*N*	*C*	*NC*	*CN*	*N*
SE±	38	15	45	35	14	43	25	61	61	25
C.D (0.05)[1]	119**	45**	135 NS	109	44**	135 NS	77**	178 NS	187	79 NS

Table 9 Grain yields (kg ha^{-1}) of pigeonpea and sorghum 1996 & 1997.

Treatment	1996			1997		
	Pigeonpea	Pigeonpea/Sorghum		Pigeonpea	Pigeonpea/Sorghum	
		Pigeonpea	Sorghum		Pigeonpea	Sorghum
1. Control (0 N)	1164	906	324	1268	594	3214
2. 20 kg N ha^{-1} (FYM)	1402	1083	330	1339	556	3563
3. 20 kg N ha^{-1} (Fertilizer)	1512	1310	687	1514	717	3307
4. 40 kg N ha^{-1} (FYM)	1458	1301	561	1379	516	3823
5. 40 kg N ha^{-1} (Fertilizer)	1819	1613	1076	1345	641	3762
6. 20:20 kg N ha^{-1} (FYM : Fertlizer)	1649	1533	800	1329	699	3679
7. Mean	1500	1291	630	1362	620	3558

	Pigeonpea (1996)				Sorghum (1996)	Pigeonpea (1997)				Sorghum (1997)
	N[2]	*C*	*NC*	*CN*	*N*	*N*	*C*	*NC*	*CN*	*N*
SE±	60	33	83	81	63	106	42	129	104	187
C.D(0.05)[1]	188**	102**	243 NS	249	197**	334 NS	130**	382 NS	319	589 NS

1 # C.D. at (0.05) ; ** = (P < 0.01) ; * = (P< 0.05) ; NS = nonsignificant ; 2 # N=Nitrogen levels & sources; C=Crop/s; NC=Interaction between nitrogen & crops;

Figure 13. Seed yields of Soybean and Sunflower,1996 & 1997

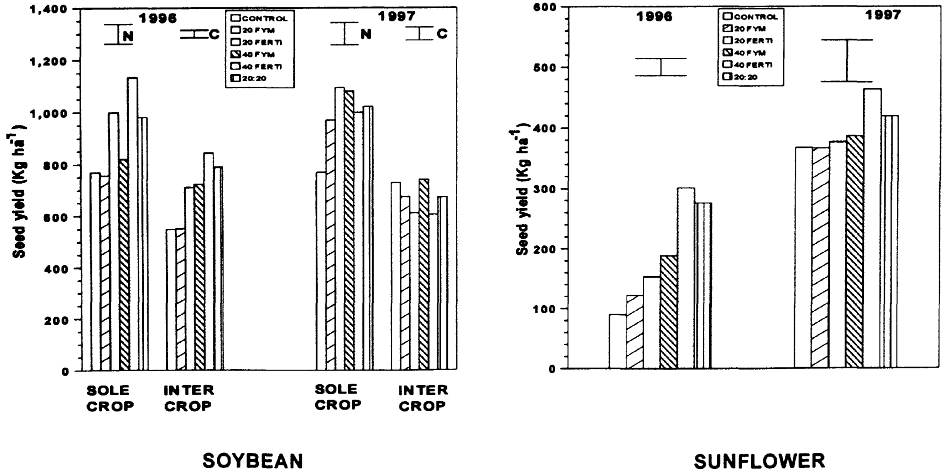
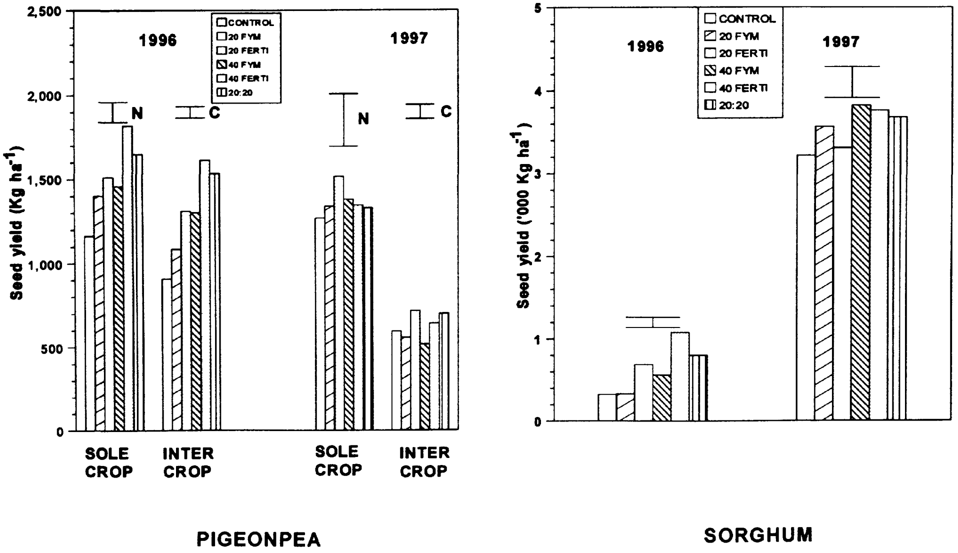


Figure 14. Seed yields of Pigeonpea and Sorghum 1996 & 1997



Grain yield of intercropped soybean which ranged from 549 to 843 kg ha^{-1} was significantly ($P \leq 0.01$) influenced by levels and sources of N application. Similar to sole soybean, N application improved the grain yield of intercropped soybean. Significantly ($P \leq 0.05$) maximum grain yield was obtained due to 40 kg N ha^{-1} (fertilizer N) application followed by 20:20 kg N ha^{-1} (FYM: fertilizer N) treatment. Significantly higher yield was attained by 20 kg N ha^{-1} which received N through fertilizer source than that of FYM and control treatments. The yield improvement over control (no N) treatments by 20 kg N ha^{-1} (FYM or fertilizer N) and 40 kg N ha^{-1} (FYM or/and fertilizer N) was 15 and 43 % respectively.

The grain yield of intercropped soybean was found to be significantly ($P \leq 0.01$) lower than the sole soybean crop. The reduction in yield of soybean due to sunflower intercropping was 31 %.

4.6.2 Sunflower

The seed yield of sunflower which ranged from 90 to 301 kg ha^{-1} was significantly ($P \leq 0.01$) influenced due to N application (Fig 13; Table 9). Significantly higher yields were obtained due to 40 kg N ha^{-1} as fertilizer source alone or fertilizer N + FYM than all other treatments. The yield increase due to 20 kg N ha^{-1} and 40 kg N ha^{-1} irrespective of source of N was 53 and 183 % compared to control (no N).

4.6.3 Pigeonpea

Mean grain yield of 1500 kg ha^{-1} was obtained by sole pigeonpea and it was significantly ($P \leq 0.01$) influenced due to N application (Fig 14; Table 9). Significantly ($P \leq 0.05$) maximum seed yield was recorded due to 40 kg N ha^{-1} (fertilizer N) than all other treatments, but it was on par with 20:20 kg N ha^{-1} (FYM:fertilizer N) treatment. No significant difference was observed due to 20 kg N ha^{-1} with either source of N but yield was significantly higher than the control (no N) treatment. The yield improvement over control due to 20 kg N ha^{-1} (FYM or fertilizer N) and 40 kg N ha^{-1} irrespective of source of N was 25 and 41 % respectively.

Grain yield which ranged from 906 to 1613 kg ha^{-1} was significantly ($P \leq 0.01$) influenced by N application. Due to application of N @ 40 kg N ha^{-1} as fertilizer N or fertilizer N + FYM, significantly higher yield was obtained than all other treatments. Amongst 20 kg N ha^{-1} treatments, maximum yield was obtained due to fertilizer N application than that of FYM and control treatments. The yield increase due to 20 kg N ha^{-1} and 40 kg N ha^{-1} irrespective of source of N over control was 32 and 64 % respectively.

Sole pigeonpea and intercropped pigeonpea yields differed significantly ($P \leq 0.01$). The yield recorded by intercropped pigeonpea was 16 % lower than that of sole crop.

4.6.4 Sorghum

Mean grain yield of 630 kg ha^{-1} was recorded during 1996 crop season. The N application significantly ($P \leq 0.01$) favored the grain yield of sorghum (Fig 14; Table 9). Significantly greater grain yield (1076 kg ha^{-1}) was attained due to 40 kg N ha^{-1} (fertilizer N) than all other treatments. The yield improvement over control by 20 kg N ha^{-1} and 40 kg N ha^{-1} irrespective of source of N was 57 and 151 % respectively.

4.7 GRAIN YIELDS DURING 1997

4.7.1 Soybean

Mean grain yield of 989 kg ha^{-1} was obtained during 1997 crop season. The yield which ranged from 770 to 1093 kg ha^{-1} was not significantly influenced due to N application (Fig 13; Table 9). However maximum grain yield (1093 kg ha^{-1}) was obtained due to 20 kg N ha^{-1} (fertilizer N). Lowest yield was recorded with control (no N) treatment.

Similar to of sole soybean, the grain yield of intercropped soybean was not significantly influenced by N application.

Grain yield of soybean intercropped with sunflower was significantly ($P \leq 0.01$) lower than that of sole soybean. The reduction in yield due to sunflower intercropping was 47 % than sole soybean.

4.7.2 Sunflower

Mean seed yield of 396 kg ha^{-1} was recorded during 1997 season. But the seed yields were not significantly influenced by N application (Fig 13; Table 9). However, maximum yield was observed with 40 kg N ha^{-1} (fertilizer N) which was 26 % higher than the control (no N).

4.7.3 Pigeonpea

During 1997, the pigeonpea grain yields under sole and intercrop situations was not significantly affected by N application (Fig 14; Table 9). However maximum seed yield was obtained due to 20 kg N ha^{-1} (fertilizer N) application in both sole and intercrops of pigeonpea. But yield of sole and intercropped pigeonpea differed significantly ($P \leq 0.01$). The reduction in pigeonpea yield due to intercropping with sorghum was 120 %.

4.7.4 Sorghum

Grain yield of sorghum which ranged from 3214 to 3823 kg ha^{-1} was not significantly influenced due to N application. However, N application improved the seed yield compared to control (0 N)(Fig 14; Table 9).

4.8.1 ABSCISED DRY MATTER DURING 1996

4.8.1.1 Soybean

The total abscised dry matter of both sole and intercrops of soybean was not significantly influenced by N application (Fig 15; Table 10). And the cropping systems (sole and intercrop) also did not differ significantly in respect of abscised dry matter. Mean abscised dry matter by soybean in sole crop and intercrop conditions was 1060 and 1000 kg ha^{-1} respectively.

4.8.1.2 Pigeonpea

The abscised dry matter was in the range of 1830 to 2030 kg ha^{-1} in case of sole pigeonpea and 1070 to 1640 kg ha^{-1} in case of pigeonpea intercropped with sorghum (Fig 15; Table 10). The mean abscised dry matter was 1960 kg ha^{-1} in sole pigeonpea and 1250 kg ha^{-1} in pigeonpea intercropped with sorghum. N application had no significant influence on abscised dry matter both in sole and intercrops of pigeonpea. But sole and intercrops differed significantly ($P \leq 0.01$), the abscised dry matter was found to be more in sole crop than that of intercropped pigeonpea. The percentage reduction in abscised dry matter in case of intercropped pigeonpea than sole pigeonpea was 57 %. The interaction between crops and N application was found to be nonsignificant.

4.8.2 N AND P CONTENT OF ABSCISED DRY MATTER DURING 1996

4.8.2.1 Soybean

The N content of fallen leaf of soybean was in the range of 6.3 to 8.3 kg ha^{-1} in case of sole crop and 5.8 to 7.9 kg ha^{-1} in case of intercropped soybean (Fig 15; Table 11). The mean N content of fallen leaf of sole soybean was 7.6 kg ha^{-1} and 6.9 kg ha^{-1} in case of intercropped soybean. Neither N application nor cropping systems had influenced the N content of fallen

Table 10 Asbcised dry matter (kg ha^{-1}) of soybean and pigeonpea 1996 & 1997.

		1996				1997			
		Soybean		Pigeonpea		Soybean		Pigeonpea	
	Treatment	Sole crop	Intercrop	Sole crop	Intercrop	Sole crop	Intercrop	Sole crop	Intercrop
1.	Control (0 N)	872	837	1829	1232	1234	512	1804	136
2.	20 kg N ha^{-1} (FYM)	1101	909	1972	1636	1072	465	2250	273
3.	20 kg N ha^{-1} (Fertilizer)	1058	1019	2000	1325	1031	537	2284	290
4.	40 kg N ha^{-1} (FYM)	1024	973	2021	1077	1174	476	2686	360
5.	40 kg N ha^{-1} (Fertilizer)	1167	1152	1920	1066	1107	502	2597	363
6.	20:20 kg N ha^{-1} (FYM)	1152	1112	2026	1161	1093	566	2547	382
	Mean	1062	1000	1961	1250	1119	510	2363	301
		SE±	*C.D (0.05)*[1]	*SE±*	*C.D (0.05)*	*SE±*	*C.D (0.05)*	*SE±*	*C.D (0.05)*
	N[2]	62	195 NS	76	240 NS	101	319 NS	231	726*
	C	29	88 NS	51	157**	44	136**	116	356**
	NC	79	234 NS	116	342 NS	127	375 NS	305	899*
	CN	70	216	125	384	108	334	283	873

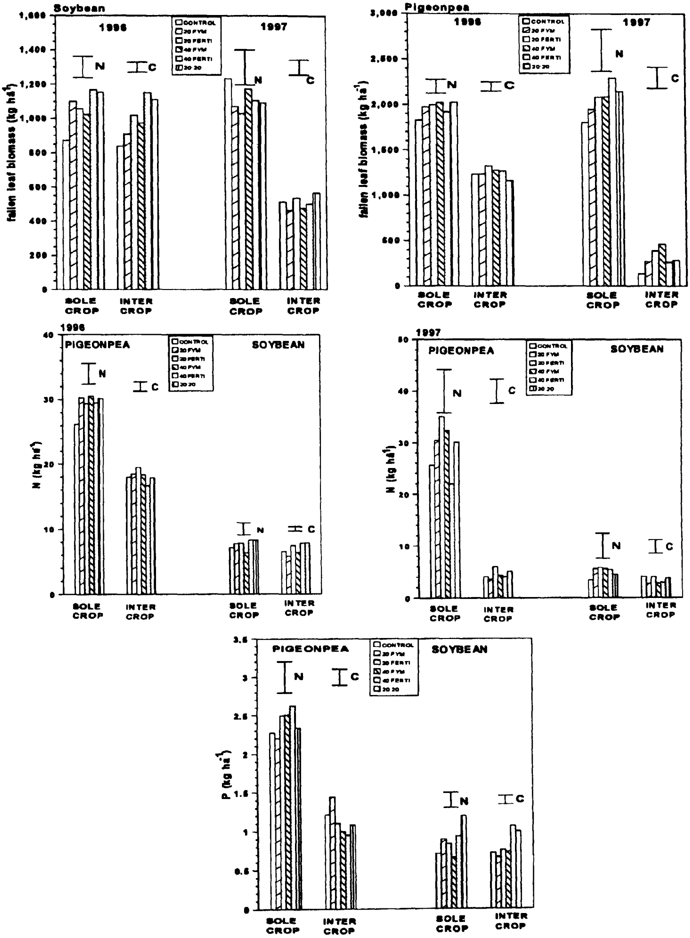
1 # C.D. at (0.05) ; ** = (P < 0.01) ; * = (P< 0.05) ; NS = nonsignificant ; 2 # N=Nitrogen levels & sources; C=Crop/s; NC=Interaction between nitrogen & crops;

Table 11 Nitrogen & Phosphorus content of abscised dry matter of soybean & pigeonpea 1996 & 1997.

	1996								1997			
	Soybean				Pigeonpea				Soybean		Pigeonpea	
	N		P		N		P		N		N	
Treatment	Sole crop	Inter crop	Sole crop	Inter crop	Sole crop	Inter crop	Sole crop	Inter crop	Sole crop	Inter crop	Sole crop	Inter crop
1. Control (0 N)	7.1	6.5	0.71	0.72	26.2	18.0	2.2	1.1	8.4	4.1	25.6	2.1
2. 20 kg N ha^{-1} (FYM)	7.7	5.8	0.89	0.67	30.3	23.5	2.4	1.0	7.6	5.8	40.5	3.6
3. 20 kg N ha^{-1} (Fertilizer)	7.8	7.4	0.84	0.76	29.4	18.5	2.4	1.1	9.8	4.0	35.1	8.0
4. 40 kg N ha^{-1} (FYM)	6.3	6.3	0.66	0.74	30.5	16.3	2.4	1.3	8.6	3.8	42.4	4.3
5. 40 kg N ha^{-1} (Fertilizer)	8.3	7.8	0.94	1.07	29.5	15.7	2.4	1.3	8.4	3.0	32.0	2.1
6. 20:20 kg N ha^{-1} (FYM : Fertlizer)	8.3	7.9	1.20	1.00	30.2	16.9	2.6	1.2	9.5	3.8	37.7	7.1
7. Mean	7.6	6.9	0.87	0.82	29.3	18.1	2.4	1.1	8.7	4.1	35.6	4.5
	SE±	*C.D^1 (0.05)*	*SE±*	*C.D (0.05)*	*SE±*	*C.D (0.05)*	*SE±*	*C.D (0.05)*	*SE±*	*C.D (0.05)*	*SE±*	*C.D (0.05)*
N^2	0.9	2.9^{NS}	0.10	0.31^{NS}	1.58	5.0^{NS}	0.20	0.64^{NS}	2.4	7.6^{NS}	4.2	13.2^{NS}
C	0.3	1.1^{NS}	0.06	0.17^{NS}	0.73	2.2**	0.10	0.32**	1.5	4.5**	2.3	7.1**
NC	1.1	3.3^{NS}	0.14	0.40^{NS}	2.02	6.0^{NS}	0.27	0.80^{NS}	3.5	10.3^{NS}	5.8	16.9^{NS}
CN	0.8	2.6	0.14	0.42	1.79	5.5	0.26	0.79	3.6	11.1	5.6	17.4

1 # C.D. at (0.05) ; ** = (P < 0.01) ; * = (P< 0.05) ; NS = nonsignificant ; 2 # N=Nitrogen levels & sources; C=Crop/s; NC=Interaction between nitrogen & crops;

Figure 15.Abscised dry matter and N & P content in soybean and pigeonpea 1996 & 1997



leaf. The P content of fallen leaf was in the range of 0.66 to 1.20 kg P ha^{-1} in sole soybean and 0.67 to 1.07 kg P ha^{-1} in intercropped soybean. The mean P content of fallen leaf added to the soil by sole soybean was 0.87 kg P ha^{-1}, and 0.82 kg P ha^{-1} in case of intercropped soybean. Neither N application nor crops had significantly influenced the P content of fallen leaf.

4.8.2.2 Pigeonpea

The mean N content of fallen leaf was not influenced significantly by N application. But, sole crop recorded significantly ($P \leq 0.05$) higher N content in fallen leaf (29.3 kg ha^{-1}) than that of intercropped pigeonpea (18.1 kg ha^{-1}) (Fig 15; Table 11). The P content of fallen leaf was also not significantly influenced by N application. Sole pigeonpea recorded significantly higher P content in fallen leaf (2.40 kg ha^{-1}) than the intercropped pigeonpea (1.13 kg ha^{-1}). The P content of fallen leaf was two fold more in sole pigeonpea than that of intercropped pigeonpea.

4.9.1 ABSCISED DRY MATTER DURING 1997

4.9.1.1 Soybean

Mean total abscised dry matter in sole and intercrops of soybean was 1120 and 510 kg ha^{-1} (Fig 15; Table 10). The abscised dry matter of soybean under sole and intercrop conditions was not significantly influenced due to N application. But sole soybean recorded significantly ($P \leq 0.01$) more abscised dry matter (1119 kg ha^{-1}) than intercropped soybean (510 kg ha^{-1}).

4.9.1.2 Pigeonpea

The abscised dry matter was in the range of 1804 to 2686 kg ha^{-1} in case of sole pigeonpea and 136 to 380 kg ha^{-1} in case of pigeonpea intercropped with sorghum (Fig 15; Table 10). Nitrogen application influenced the abscised dry matter significantly ($P \leq 0.05$).

Significantly more abscised dry matter was recorded due to 40 kg N ha^{-1} irrespective of source of N than the control (no N) in both sole and intercropped pigeonpea plots. The mean abscised dry matter was significantly ($P \leq 0.01$) more in sole crop (2360 kg ha^{-1}) than that of intercropped pigeonpea (300 kg ha^{-1}). The interaction between N application and crops was found to be significant ($P \leq 0.05$). The intercropped pigeonpea did not respond to N application in abscised dry matter, however, it was maximum at higher level of N application (40 kg N ha^{-1}).

4.9.2 N AND P CONTENT OF ABSCISED DRY MATTER DURING 1997

4.9.2.1 Soybean

The N content of fallen leaf was in the range of 7.6 to 9.8 kg ha^{-1} in sole crop and 3.0 to 5.8 kg ha^{-1} in intercropped soybean. The N content of fallen leaf of sole soybean (8.7 kg ha^{-1}) was two fold more than the intercropped soybean (4.1 kg ha^{-1}) (Fig 15; Table 11). Nitrogen application did not influence the N content of fallen leaf, but only sole and intercrops differed significantly. Significantly ($P \leq 0.01$) higher N content in fallen leaf was recorded in sole soybean than that of intercropped soybean.

4.9.2.2 Pigeonpea

The amount of N added to the soil through fallen leaf was nearly 8 times more in sole crop (35.6 kg ha^{-1}) than that of the intercropped pigeonpea (4.5 kg ha^{-1}). But N application had not influenced the N content of fallen leaf added to the soil (Fig 15; Table 11).

4.10 COMPARISON BETWEEN SOLE AND INTERCROPS OF SOYBEAN AND PIGEONPEA during 1996 AND 1997

4.10.1 Crop growth rate (CGR)

Crop growth rate was calculated from 30 days after emergence (DAE) to harvest of the crop. Between the sources at same level of N, no considerable difference in CGR was observed (data not shown), so different levels of N influence on CGR was presented.

4.10.1.1Soybean

In 1996, both sole soybean and soybean intercropped with sunflower, the CGR was increased with increase in level of N, i.e., 2.48 to 3.48 g m^{-2} d^{-1} in case of sole soybean and 2.13 to 2.85 g $m^{-2}d^{-1}$ in soybean intercropped with sunflower (Table 12). The mean crop growth rate of 2.99 g m^{-2} d^{-1} in sole soybean and 2.52 gm^{-2} g^{-1} in intercropped soybean. The percentage reduction in crop growth rate of soybean due to intercropping of sunflower was 16 compared to sole soybean. The increase in CGR of sole soybean due to N fertilization at 40 kg N ha^{-1} and 20 kg N ha^{-1} was 40 and 21 % respectively, compared to control, whereas in intercropped soybean due to N fertilization 34 and 21 percent more crop growth rate was observed than that of control (0 N) crop.

In 1997, mean crop growth rate of 4.24 g m^{-2} d^{-1} in case of sole soybean and 2.06 gm^{-2} d^{-1} in intercropped soybean was recorded. The reduction in crop growth rate in soybean due to intercropping with sunflower was 51 %. During this season, the crop growth rate was maximum at 20 kg N ha^{-1} (4.6 g m^{-2} d^{-1} in sole soybean; 2.18 gm^{-2} d^{-1} in intercropped soybean) which was 18 and 10 % higher than that of control in sole soybean and intercropped soybean respectively.

Table 12 Crop growth rate (CGR) ($gm^{-2}\ d^{-1}$) of Soybean and Pigeonpea in 1996 & 1997

Treatment	1996				1997			
	Soybean		Pigeonpea		Soybean		Pipeonpea	
	Solecrop	Intercrop	Solecrop	Intercrop	Solecrop	Intercrop	Solecrop	Intercrop
Control (0 N)	2.48	2.13	4.64	4.37	3.89	1.99	4.45	1.28
20 kg N ha^{-1}	3.02	2.58	5.40	4.99	4.60	2.18	4.62	1.86
40 kg N ha^{-1}	3.48	2.85	6.43	5.47	4.24	2.01	5.08	2.08
Mean	2.99	2.52	5.49	4.94	4.24	2.06	4.72	1.74

Table 13 Nitrogen accumulation rate (NAR) ($mg\ m^{-2}\ d^{-1}$) of Soybean and pigeonpea in 1996 & 1997

Treatment	1996				1997			
	Soybean		Pigeonpea		Soybean		Pipeonpea	
	Solecrop	Intercrop	Solecrop	Intercrop	Solecrop	Intercrop	Solecrop	Intercrop
Control (0 N)	90	90	90	60	150	60	130	60
20 kg N ha^{-1}	120	80	110	80	180	80	120	50
40 kg N ha^{-1}	140	120	130	100	150	80	140	60
Mean	120	100	110	80	160	70	130	60

4.10.1.2Pigeonpea

In 1996 the mean crop growth rate in sole pigeonpea was, 5.49 g m^{-2} d^{-1}, whereas in intercropped pigeonpea it was 4.94 g m^{-2} d^{-1} only (Table 12). In both crops (sole and intercrops), N fertlization increased the crop growth rate compared to control (no N). The crop growth rate due to 40 kg N ha^{-1} was 39 and 19 % more than that of control and 20 kg N ha^{-1}, however in intercropped pigeonpea, the crop growth rate increase due to 40 kg N ha^{-1} application was 25 and 10 % more than control and 20 kg N ha^{-1} application.

In 1997, the mean crop growth rate was nearly 2.7 times more in sole pigeonpea compared to intercropped pigeonpea. In both crops (sole and intercrops), crop growth rate was increased with increase in level of N application. The percentage increase was 14, 10 and 63, 12 more due to N application at 40 kg N ha^{-1} compared to control and 20 kg N ha^{-1} treatments in sole pigeonpea and intercropped pigeonpea respectively.

4.10.2 Nitrogen accumulation rate (NAR)

Nitrogen accumulation rate (NAR) was calculated from vegetative stage to harvest stage of crop. As no significant differences were observed between the sources of N at same level of N application, the means for 20 kg N ha^{-1} and 40 kg N ha^{-1} were calculated and presented in the table.

4.10.2.1Soybean

In 1996 the mean nitrogen accumulation rate (NAR) was 120 mg m^{-2} d^{-1} in case of sole soybean and 100 mg m^{-2} d^{-1} in intercropped soybean (Table 13). As increase in level of N from 20 to 40 kg N ha^{-1} the NAR increased from 120 to 140 mg m^{-2} d^{-1} in sole crop and 80 to 120 mg m^{-2} d^{-1} in intercropped soybean. Compared to control, the increase in NAR due to 40 kg N

ha^{-1} application was 56 and 17, 33 and 50 % higher in sole crop and intercropped soybean respectively.

In 1997, the mean rate of N accumulation was higher in sole crop (160 mg m^{-2} d^{-1}) compared to intercropped soybean (70 mg m^{-2} d^{-1}). The response to nitrogen accumulation rate was observed only up to 20 kg N ha^{-1}. Compared to control, the NAR due to 20 kg N ha^{-1} was 20 and 33 % higher in sole soybean and intercropped soybean respectively.

4.10.2.2Pigeonpea

In 1996 rainy season, the mean nitrogen accumulation rate (NAR) of sole pigeonpea (110 mg m^{-2} d^{-1}) was higher than that of intercropped pigeonpea (80 mg m^{-2} d^{-1}) (Table 13). In both the situations, with increase in level of N, the NAR was also increased. Compared to control, the NAR due to 40 kg N ha^{-1} was 44, 18 and 67, 25 % higher than control and 20 kg N ha^{-1} in sole pigeonpea and intercropped pigeonpea respectively.

In 1997, the mean NAR of sole pigeonpea was 2.25 folds more than intercropped pigeonpea. No consistent difference was observed between 20 and 40 kg N ha^{-1} compared to control.

4.11 EFFICIENCY OF THE CROPPING SYSTEMS

4.11.1 Canopy light interception

4.11.1.1 Canopy light interception during 1996

Sole soybean

Canopy light interception (LI) of soybean was increased till flowering and pod development stage of the crop and declined gradually until maturity. During vegetative stage, the light intercepted by crop increased from 18 to 60% in case of control (no N) from 29 to

63% due to 20 kg N ha^{-1} (FYM or fertilizer N) and from 34 to 66% due to 40 kg N ha^{-1} (irrespective of source of N) (Fig 16). At flowering stage, canopy light interception due to 40 kg N ha^{-1} was 11 % greater than that of control (no N), at maturity also, higher interception of light was observed due to 40 kg N ha^{-1} (46%) than that of 20 kg N ha^{-1} (39%) and control (33%).

Soybean/Sunflower

Maximum canopy light interception (LI) of soybean/sunflower was attained at flowering stage of crops in all treatments (Fig 16). Application of N influenced favorably, light interception and found to be maximum due to 40 kg N ha^{-1} treatments irrespective of source of N (81%) than that of control (63%) and 20 kg N ha^{-1} treatments (64%). Even at the time of maturity, fertilized crops intercepted more light than that of control (no N) crop.

Sole pigeonpea

The canopy light interception by pigeonpea crop increased till flowering stage of the crop and then started declining till maturity of the crop. The amount of light intercepted by crop increased with increase in N application (Fig 16). Between the sources of N at same level of N, no significant differences were observed. At peak point of light interception, the amount of light intercepted by crop due to N application (irrespective of rate and source of N) was 6 % more than control treatment (0 N). At this stage, between 20 kg N and 40 kg N ha^{-1}, no significant differences were observed.

Sorghum/pigeonpea

The canopy light interception was increased in the system till the harvest of sorghum and sudden decline in interception was observed (Fig 16). Throughout crop growth period, N fertilization favored the crop in intercepting more light. At 126 DAE, the amount of light intercepted by system in the control plot was 7 and 8 % less than that of 20 kg N ha^{-1} and 40 kg N ha^{-1} (irrespective of source) respectively.

4.11.1.2 Canopy light interception during 1997

Soybean

The canopy light interception (LI) of soybean increased upto flowering and pod development stage (90%) and declined gradually (40%) (Fig 17). Application of N favored in intercepting more light by crop. Between levels and sources of N, no considerable difference was observed. At flowering stage the increase in light interception by crop due to N application was 6 % compared to control (no N).

Soybean/Sunflower

The canopy light interception by system increased (89%) till harvest of sunflower, and declined thereafter (44%). No considerable difference in amount of light intercepted by crop was observed between levels and sources of N (Fig 17). However, at 67 DAE N application (irrespective of source and levels of N) increased the canopy light interception by 11 % compared to control.

Pigeonpea

The canopy light interception (LI) by pigeonpea was increased upto pod development stage (138 DAE) (92%) and declined gradually to 42% at maturity (Fig 17). At initial stages (23 to 67 DAE) of crop growth, the N fertilized crop intercepted more light than that of control (no N), however at later stages of crop growth, no considerable influence of N application on canopy light interception was observed.

Figure 16. Light interception,1996

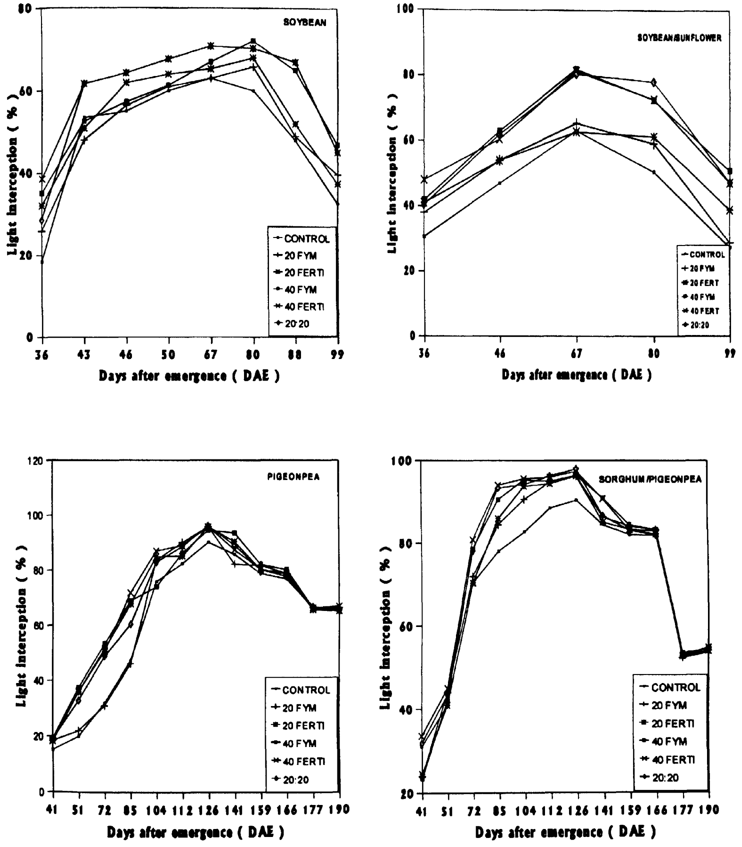
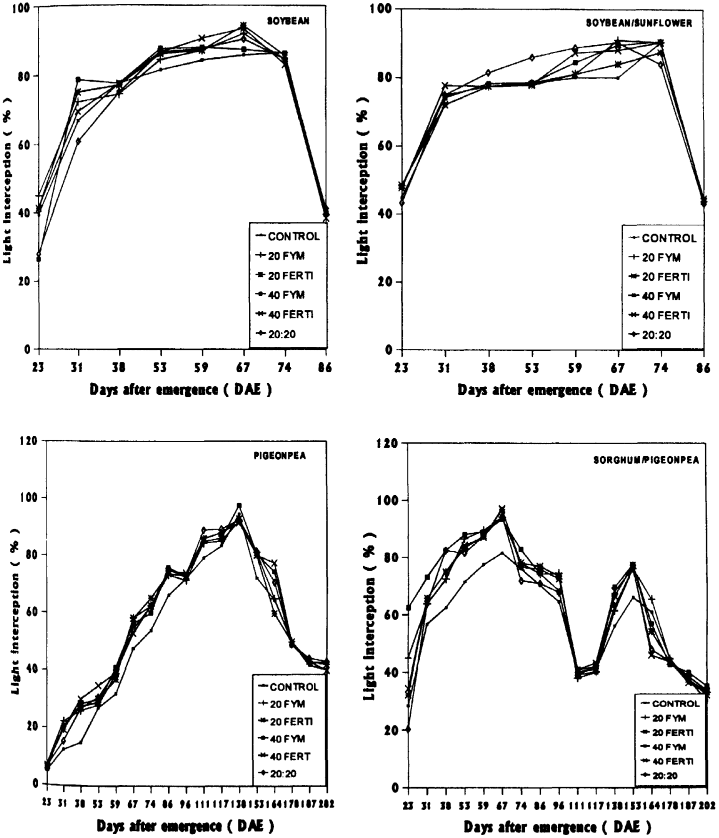


Figure 17. Light interception 1997



Sorghum/Pigeonpea

The interception of light by the sorghum/pigeonpea system was increased upto 67 DAE (94%) and then declined until maturity (33%) (Fig 17). No considerable influence of N application was observed on the amount of light interception by the system throughout crop/s growth period.

4.11.2 Radiation use efficiency of crops

Radiation use efficiency (RUE) increased due to N fertilization. In 1996, RUE was varied due to N treatments and it was in the range of 0.33 to 0.38 g MJ^{-1} in soybean, 0.44 to 0.57 g MJ^{-1} soybean/sunflower, 0.47 to 0.63 g MJ^{-1} in pigeonpea and 0.67 to 0.91 g MJ in case of sorghum/pigeonpea (Table 14). The increase in RUE due to N application (irrespective of rate and source of N) over control was, 12, 23, 17 and 27 % in soybean, soybean/sunflower, pigeonpea and sorghum/pigeonpea respectively.

In 1997, the RUE was in the range of 0.42 to 0.49 g MJ^{-1} in soybean, 0.45 to 0.52 g MJ^{-1} in soybean/sunflower, 0.45 to 0.68 g MJ^{-1} in pigeonpea and 0.82 to 1.14 g MJ^{-1} in sorghum/pigeonpea systems (Table 14). On an average, the increase in RUE due to N application over control was, 10, 4, 6 and 18 % in soybean, soybean/sunflower, pigeonpea and sorghum/pigeonpea respectively.

4.11.3 Nitrogen use efficiency

In 1996, among the four systems tried viz., sole soybean, soybean/sunflower, sole pigeonpea and sorghum/pigeonpea, the mean nitrogen use efficiency (NUE) (kg biomass $kg^{-1}N$ applied) was highest in sorghum/pigeonpea (143) followed by sole pigeonpea (67). The NUE was more in intercropping situations i.e. soybean/sunflower (25), sorghum/pigeonpea (143)

Table 14 Radiation use efficiency (RUE) (g MJ^{-1}) of sole and intercropping systems 1996 & 1997

	1996				1997			
	Soybean	Soybean/ Sunflower	Pigeonpea	Sorghum/ Pigeonpea	Soybean	Soybean/ Sunflower	Pigeonpea	Sorghum/ pigeonpea
Control (0 N)	0.33	0.44	0.47	0.67	0.42	0.47	0.50	0.82
20 kg N ha^{-1} (FYM)	0.36	0.50	0.51	0.76	0.44	0.51	0.49	0.89
20 kg N ha^{-1} (fertilizer)	0.37	0.52	0.50	0.86	0.49	0.52	0.51	0.96
40 kg N ha^{-1} (FYM)	0.35	0.53	0.54	0.87	0.47	0.48	0.45	0.83
40 kg N ka^{-1} (fertilizer)	0.38	0.56	0.63	0.91	0.46	0.45	0.54	1.01
20:20 kg N ha-1 (FYM: fertilizer)	0.38	0.57	0.56	0.87	0.42	0.50	0.68	1.14
Mean								

Table 15 Nitrogen harvest index (NHI) of soybean and pigeonpea 1996 & 1997

Treatment	1996				1997			
	Soybean	Soybean/ Sunflower	Pigeonpea	Sorghum/ Pigeonpea	Soybean	Soybean/ Sunflower	Pigeonpea	Sorghum/ Pigeonpea
Control (0 N)	0.81	0.73	0.39	0.47	0.62	0.53	0.32	0.53
20 kg N ha^{-1} (FYM)	0.82	0.77	0.43	0.52	0.60	0.60	0.34	0.40
20 kg N ha^{-1} (fertilizer)	0.80	0.73	0.40	0.54	0.65	0.57	0.34	0.49
40 kg N ha^{-1} (FYM)	0.80	0.76	0.45	0.56	0.61	0.53	0.32	0.34
40 kg N ka^{-1} (fertilizer)	0.84	0.76	0.42	0.59	0.62	0.58	0.30	0.39
20:20 kg N ha^{-1} (FYM: fertilizer)	0.83	0.74	0.46	0.57	0.64	0.53	0.32	0.47
Mean	0.82	0.75	0.43	0.54	0.62	0.55	0.32	0.44

systems compared to respective sole crops (20; 67) (Fig 18). In all systems, among the N levels and sources applied, the biomass produced per kg of N applied was more when crop received N as fertilizer source alone at respective levels of N. The increase in NUE due to fertilizer N alone irrespective of level of N, was 67 % more in sole soybean, 45 % in soybean/sunflower, 69 % in pigeonpea and 63 % in sorghum/pigeonpea compared to the respective cropping systems which received N as FYM alone.

During 1997 crop season, biomass produced per kg of N was maximum in sorghum/pigeonpea and minimum in soybean/sunflower systems (Fig 18). The NUE was greater in sole soybean and sorghum/pigeonpea, at lower level of (20 kg N ha^{-1}) of N application (fertilizer source alone), however in sole pigeonpea at higher level of N application i.e. 40 kg N ha^{-1} (fertilizer source alone).

4.11.4 Agronomic efficiency (AE)

During 1996, among the four systems studied, the agronomic efficiency (kg grain produced kg^{-1} N applied) was maximum in sorghum/pigeonpea system (Fig 19). The agronomic efficiency of the crops is greater in intercropping systems than that of respective sole crops. In all the four systems, the efficiency was more due to the application of fertilizer N alone compared to FYM alone. Also at lower level of N (20 kg ha^{-1}) the agronomic efficiency was more than that of higher level of N (40 kg N ha^{-1}) in all four systems.

In 1997, the mean agronomic efficiency was more in sorghum/pigeonpea system. In sole soybean, the efficiency was high due to 20 kg N ha^{-1}(fertilizer source) application, whereas in soybean/sunflower, no appreciable differences were observed (Fig 19). In sole pigeonpea, the efficiency was high due to 20 kg N ha^{-1} (fertilizer source), whereas in sorghum/pigeonpea, no considerable differences were observed.

4.11.5 Nitrogen harvest index (NHI)

Whether the crop was net exploiter or net contributor of the soil will be known with NHI. In 1996 and 1997, the proportion of N in seed was more in sole soybean (0.82; 0.62) and soybean/sunflower (0.75; 0.55) than that of sole pigeonpea (0.43; 0.32) and sorghum/pigeonpea (0.54; 0.44) (Table 15). This indicated that the proportion of N left over in residues was less in sole soybean, whereas in pigeonpea the proportion of N left over in residues was high. During both the years of study, no appreciable differences were observed due to different levels and sources of N application.

4.11.6 Apparent Recovery of N

In 1996, the apparent recovery of N (%) by soybean was 60 to 130 in sole crop and 73 to 153 in soybean/sunflower systems, 19 to 299 in sole pigeonpea and 231 to 321 in sorghum/ pigeonpea system. In intercropping situations, the apparent recovery was more than sole crop situations of respective crops. Among different sources of N application, percentage recovery of N was high when crop received N through fertilizer N (irrespective of level of N) in all the systems (Fig 20). Among different N levels tried, the recovery of N was more in 20 kg N ha^{-1} (fertilizer N) (130%) in sole soybean, whereas in soybean/sunflower system, the recovery of N was more due to 40 kg N ha^{-1} (fertilizer N) (153%). However in pigeonpea, the apparent recovery of N was more due to 20 kg N ha^{-1} (fertilizer N) in both sole crop and intercropping systems.

In 1997, in soybean and soybean/sunflower, no appreciable differences were observed, however, the recovery of N (%) was more due to 20 kg N ha^{-1} as fertilizer source in sole soybean (171%) and soybean/sunflower (49%) compared to all other treatments (Fig 20). Whereas in pigeonpea and sorghum/pigeonpea systems, the recovery of N was more when crop received N as fertilizer source compared to FYM. When comparison was made between levels of N, at lower level of N (20 kg N ha^{-1}) the apparent recovery was more in sole pigeonpea (213%) and sorghum/pigeonpea system compared to all other treatments.

4.12 BIOLOGICAL AND CHEMICAL PROPERTIES OF SOIL

4.12.1 Pre-sowing soil sample analysis

Soil samples up to a depth of 120 cm were collected from each main plot and analyzed for chemical and biological properties (Table 16). Biological and chemical properties of soil samples varied with soil depth ($P \leq 0.01$). A maximum fertilizer N content of 3.83 mg N g^{-1} soil was observed up to 15 cm soil depth and it was followed by 15 to 30 cm (2.5 mg N g^{-1} soil) $\geq$ 30-60 (1.9 mg N g^{-1} soil) $\geq$ 60-90 (1.8 mg N g^{-1} soil) and 90-120 cm (1.6 mg N g^{-1} soil) depth (Table 16). The highest net N mineralization of 1.35 mg N g^{-1} soil 10 d^{-1} was observed for 60-90 cm depth samples followed by $\geq$ 15-30 $\geq$ 90-120 $\geq$ 30-60 and 0-15 cm depths. A maximum amount of C (252.9 mg C g^{-1} soil 10^{-1}) was respired from 0-15 cm depth samples followed by 15-30 cm $\geq$ 30-60 cm $\geq$ 60-90 cm and 90-120 cm depth samples. A maximum microbial biomass C content (284.8 mg C g^{-1} soil) and N content (45 mg N g^{-1} soil) were observed in 0-15 cm surface soil samples and biomass C and N content decreased with the increase in soil depth up to 120 cm (Table 16). Similarly surface 15 cm soil samples contained highest organic carbon (6.4 mg kg^{-1} soil) followed by 15-30 cm $\geq$ 60-90 cm $\geq$ 30-60 cm $\geq$ 90-120 cm depth of soil. Available phosphorus was maximum in 15-30 cm

Table 16. Biological and Chemical properties of soil samples collected prior to sowing 1996

	Details	Soil depth (cm) 0-15	15-30	30-60	60-90	90-120	Mean	SE±	C.D (0.05)
1.	mineral N ($\mu g\ g^{-1}$ soil)	3.8	2.5	1.9	1.8	1.6	2.3	0.07	0.14**
2.	Net N mineralization ($\mu g\ Ng^{-1}$ soil 10 d^{-1})	0.7	1.3	1.1	1.4	1.1	1.1	0.08	0.16**
3.	Soil respiration ($\mu g\ C\ g^{-1}$ soil 10 d^{-1})	252.9	231.0	193.7	158.4	125.9	192.4	1.93	3.95**
4.	Microbial biomass C ($\mu g\ C\ g^{-1}$ soil)	284.8	219.5	167.5	131.9	120.0	184.7	7.00	14.3**
5.	Microbial biomass N ($\mu g\ N\ g^{-1}$ soil)	45.0	34.7	26.5	20.9	19.0	29.2	1.12	2.29**
6.	Organic carbon ($g\ kg^{-1}$ soil)	6.4	4.4	3.6	3.7	3.2	4.3	0.10	0.20**
7.	Available P ($mg\ kg^{-1}$ soil)	0.77	0.10	0.10	0.10	0.10	0.23	0.11	0.22**
8.	Available K ($mg\ kg^{-1}$ soil)	180	109	157	159	169	155	3.89	7.96**

** = ($P \leq 0.01$)

followed by 0-15 cm soil depth. The highest available K content was observed at 0-15 cm soil depth followed by 90-120 cm ≥ 60-90 cm ≥ 30-60 and 15-30 cm soil depth.

4.12.2 Crops and N influence on soil biological and chemical properties during 1996

4.12.2.1 Mineral N

Mean mineral N (NH^+_4 + NO^-_3) content in the surface (0-30 cm) soil samples was influenced significantly ($P \leq 0.01$) due to nitrogen application (Table 17). Mean mineral N content increased significantly from 3.16 mg N g^{-1} soil at presowing to 7.88 mg N g^{-1} soil at 112/198 days after emergence (DAE) [soil samples collected after harvest of soybean (112 DAE) and pigeonpea (198 DAE)]. The mean mineral N content in the soil at 37 DAE was nearly five folds more than that of mineral N at presowing stage across the N treatments. Significantly more amount of mineral N content in soil was observed with 40 kg N ha^{-1} treatments irrespective of source of N. Amongst the 40 kg N ha^{-1} treatments, mean mineral N content is 10 and 9 % more in 40 kg N ha^{-1} (FYM) and 40 kg N ha^{-1} (fertilizer N) than FYM + fertilizer N. In case of 20 kg N ha^{-1} treatments, significantly more mineral N content was observed in case of FYM applied plots. During crop growth period, significantly more amount of fertilizer N was observed with 40 kg N ha^{-1} (FYM) and 40 kg N ha^{-1} (fertilizer N) than all other treatments. Mineral N content in the soil was not influenced by cropping systems (Table 17). In sole soybean and soybean/sunflower cropping systems mineral N content in the soil was significantly ($P \leq 0.01$) more than the sole pigeonpea and sorghum/pigeonpea cropping systems in the soil samples collected after harvest of soybean and pigeonpea (112/198 DAE). Similar results were not observed at 37 and 78 DAE. There was no significant interaction of cropping systems and N treatments for soil mineral N content.

Table 17. Mineral N (NH_4^+ + NO_3^- - N) and Net N mineralization in surface soil samples (0-30 cm) 1996

Treatment	Presowing	Days after emergence 37	78	112/198[1]	Mean
Mineral N (µg g^{-1} soil)					
Control	3.7	10.6	4.9	4.6	5.9
20 kg N ha^{-1} (FYM)	3.8	14.3	5.3	7.5	7.7
20 kg N ha^{-1} (Fertlizer)	2.5	13.8	5.2	6.7	7.1
40kg N ha^{-1} (FYM)	2.6	16.6	8.6	10.1	9.5
40kg N ha^{-1} (Fertlizer)	2.9	16.8	8.5	9.4	9.4
20:20 kg N ha^{-1} (FYM:Fertlizer)	3.4	15.5	6.3	9.1	8.6
Soybean	3.2	14.6	6.4	8.6	8.2
Soybean/Sunflower	3.2	14.4	6.3	8.7	8.1
Pigeonpea	3.2	14.9	6.6	7.0	7.9
Sorghum/Pigeonpea	3.2	14.5	6.7	7.2	7.9
Mean	3.2	14.6	6.5	7.9	
Net N Mineralization (µg g^{-1} soil 10 d^{-1})					
Control	1.8	2.9	11.3	2.5	4.6
20 kg N ha^{-1} (FYM)	0.8	4.0	12.7	2.5	5.0
20 kg N ha^{-1} (Fertlizer)	1.5	3.6	12.7	1.7	4.9
40kg N ha^{-1} (FYM)	1.1	5.5	13.4	2.6	5.6
40kg N ha^{-1} (Fertlizer)	0.6	4.7	13.0	2.1	5.1
20:20 kg N ha^{-1} (FYM:Fertlizer)	0.2	4.9	12.7	2.3	5.0
Soybean	1.0	4.0	12.4	1.9	4.8
Soybean/Sunflower	1.0	4.9	12.8	2.1	5.2
Pigeonpea	1.0	4.2	12.7	2.4	5.1
Sorghum/Pigeonpea	1.0	3.9	12.5	2.7	5.0
Mean	1.0	4.3	12.6	2.3	

	N[3]	*C*	*T*	*NT*	*CT*	*NC*	*NCT*
Mineral N							
SE±	0.13	0.12	0.12	0.29	0.24	0.29	0.58
C.D (0.05)	0.42**	0.37^{NS}	0.33**	0.79**	0.66**	0.89^{NS}	1.61**
Net N Mineralization							
SE±	0.12	0.10	0.10	0.24	0.20	0.25	0.49
C.D (0.05)	0.38**	0.32^{NS}	0.28**	0.67**	0.56**	0.77^{NS}	1.36*

1. *Soil samples collected after soybean harvest (112 DAE) and after pigeonpea harvest (198 DAE)*
2. ** = (P0≤05); ** = (P≤0.01); NS=Not significant*
3. *N = Nitrogen levels; C = Crop/s; T = Time; NT = Interaction between Nitrogen levels & time; CT = Interaction between crop/s and time; NC = Interaction between nitrogen & crop/s; NCT = Interaction between nitrogen, crop/s and time.*

4.12.2.2 Net N mineralization

Mean net N mineralization in surface soil samples (0-30 cm) varied significantly ($P \leq 0.01$) with N application but cropping systems did not influence net N mineralization in the soil (Table 17). Mean net N mineralization in the soil increased significantly from 1.0 mg N g^{-1} soil 10 d^{-1} at presowing to 2.33 mg N g^{-1} soil 10^{-1} at the time of harvest of soybean and pigeonpea (112/198 DAE). Mean net N mineralization was 4.25 times more at 37 DAE, 12.6 times more at 78 DAE and 2.3 times more at 112/198 DAE as compared to net N mineralization at presowing stage. Mean net N mineralization was significantly higher due to 40 kg N ha^{-1} (FYM) followed by 40 kg N ha^{-1} (fertilizer N fertilizer) treatments and lowest with 0 N control treatment. Mean net N mineralization in soil samples was not influenced significantly ($P \leq 0.05$) due to cropping systems. At 37 and 78 DAE net N mineralization was highest in case of soybean/ sunflower system (Table 17). However, at 112/198 days after emergence of crops the mean net N mineralization was highest in sorghum/pigeonpea system followed by sole pigeonpea. The interaction effect between N application and crops on net N mineralization was not significant.

4.12.2.3 Soil respiration

The amount of C respired from the surface (0-30 cm) soil samples varied significantly with N application, cropping systems and sampling times during the crop growing period (Table 18). Mean amount of soil respiration was nearly 3 times less at crop harvest than that at presowing. Mean soil respiration across the N treatments was significantly ($P \leq 0.01$) more at presowing than at 37 DAE. It increased significantly ($P \leq 0.01$) at 78 DAE than at 37 DAE and then it decreased significantly at harvest stage (112/198 DAE) cropping systems influenced the soil respiration

Table 18. Soil respiration in surface soil samples (0-30 cm) 1996

Treatment	Days after emergence				Mean
	Presowing	37	78	112/198[1]	
Control	245	156	268	60	182
20 kg N ha^{-1} (FYM)	242	143	295	75	189
20 kg N ha^{-1} (Fertlizer)	236	155	297	93	195
40kg N ha^{-1} (FYM)	243	140	303	101	197
40kg N ha^{-1} (Fertlizer)	245	146	306	89	196
20:20 kg N ha^{-1} (FYM:Fertlizer)	240	146	292	99	194
Soybean	242	139	276	68	181
Soybean/Sunflower	242	147	289	83	190
Pigeonpea	242	145	296	84	192
Sorghum/Pigeonpea	242	158	314	109	206
Mean	242	147	294	86	

	N[3]	*C*	*T*	*NT*	*CT*	*NC*	*NCT*
SE±	1.74	0.77	1.01	2.75	1.90	2.38	4.89
C.D (0.05)	5.55**	2.4**	2.79**	7.63**	5.28**	7.35**	13.5**

 # 1,2,3. Refer Table 17

significantly ($P \leq 0.01$). The mean amount of carbon respired from the soil was 5 and 7 % higher in intercropping systems of soybean and pigeonpea than respective sole crops. Significantly higher amount of carbon was respired in sorghum/pigeonpea system and lowest was recorded due to sole soybean at all stages of crop growth. The amount of carbon respired in sole pigeonpea and sorghum/pigeonpea systems due to 40 kg N ha^{-1} (FYM) was 8 and 12 % higher than (0 N) control treatment (Table 20).

4.12.2.4 Microbial biomass C

Mean microbial biomass C content in surface soil samples (0-30 cm) was influenced significantly ($P \leq 0.01$) by N application and cropping system across the time of soil sampling (Table 19). Significantly ($P \leq 0.05$) higher mean microbial biomass C content in the soil was observed due to 40 kg N ha^{-1} treatments irrespective of source of N than 20 kg N ha^{-1} and control (0 N) treatments. Mean microbial biomass content across N levels and sources and cropping systems was significantly increased from presowing (252 mg C g^{-1} soil) to 78 DAE (317 mg C g^{-1} soil) and then it decreased at the time of harvest of crops (132 mg C g^{-1} soil). Mean microbial biomass C content was nearly 17 % more at 78 DAE than that at presowing stage, but at the time of harvest of crops, 48 % reduction was observed compared to the microbial biomass C content at presowing stage. Significantly higher microbial biomass C content across N treatments was observed in sorghum/pigeonpea plots (232 mg C g^{-1} soil) followed by soybean/sunflower plots (224 mg C g^{-1} soil). Compared to sole crops of soybean and pigeonpea microbial biomass C content was nearly 10 % more in systems of soybean/sunflower and sorghum/pigeonpea (Table 20).

Table 19. Microbial biomass C and N content in surface soil samples (0-30 cm) 1996

Treatment	Presowing	Days after emergence 37	78	112/198[1]	Mean
Microbial biomass C (μg C g^{-1} soil)					
Control	296	171	214	78	190
20 kg N ha^{-1} (FYM)	282	173	253	82	197
20 kg N ha^{-1} (Fertlizer)	234	184	278	127	206
40kg N ha^{-1} (FYM)	254	204	340	167	241
40kg N ha^{-1} (Fertlizer)	214	216	320	163	228
20:20 kg N ha^{-1} (FYM:Fertlizer)	234	219	358	172	246
Soybean	252	174	270	112	202
Soybean/Sunflower	252	215	301	128	224
Pigeonpea	252	184	287	131	213
Sorghum/Pigeonpea	252	204	317	156	232
Mean	252	204	317	132	
Microbial biomass N (μg N g^{-1} soil)					
Control	46.7	27.1	33.9	12.3	30.0
20 kg N ha^{-1} (FYM)	44.6	27.4	39.9	12.9	31.2
20 kg N ha^{-1} (Fertlizer)	37.0	29.1	44.0	20.1	32.6
40kg N ha^{-1} (FYM)	40.1	32.3	53.8	26.4	38.2
40kg N ha^{-1} (Fertlizer)	33.8	34.1	50.7	25.8	36.1
20:20 kg N ha^{-1} (FYM:Fertlizer)	37.0	34.6	56.7	27.3	38.9
Soybean	39.9	27.5	42.8	17.7	32.0
Soybean/Sunflower	39.9	34.0	47.7	20.2	35.5
Pigeonpea	39.9	29.1	45.3	20.7	33.8
Sorghum/Pigeonpea	39.9	32.3	50.2	24.6	36.8
Mean	39.9	30.8	46.5	20.8	

	N[3]	*C*	*T*	*NT*	*CT*	*NC*	*NCT*
Microbial biomass C							
SE±	4.29	1.65	2.05	6.1	3.91	5.54	10.29
C.D (0.05)	13.5**	5.1**	5.7**	16.9**	10.8**	15.3*	28.5^{NS}
Microbial biomass N							
SE±	0.68	0.26	0.32	0.97	0.62	0.88	1.63
C.D (0.05)	2.1**	0.8**	0.90**	2.7**	1.7**	2.7*	4.5^{NS}

1,2,3 Refer Table 17

Table 20. Interaction effect between N levels & sources and cropping systems on soil respiration, microbial biomass C and N in surface soil samples (0-30 cm) 1996

Treatment	Soybean	Soybean/ Sunflower	Pigeonpea	Sorghum/ Pigeonpea	Mean
Soil respiration (μg C g^{-1} soil 10 d^{-1})					
Control	168	180	185	194	182
20 kg N ha^{-1} (FYM)	180	190	188	196	189
20 kg N ha^{-1} (Fertlizer)	188	195	188	211	195
40kg N ha^{-1} (FYM)	180	189	201	218	197
40kg N ha^{-1} (Fertlizer)	185	193	195	213	196
20:20 kg N ha^{-1} (FYM:Fertlizer)	186	195	192	203	194
Mean	181	190	192	206	
Microbial biomass C (μg C g^{-1} soil)					
Control	181	192	185	201	190
20 kg N ha^{-1} (FYM)	186	198	194	211	197
20 kg N ha^{-1} (Fertlizer)	187	215	201	220	206
40kg N ha^{-1} (FYM)	218	241	239	267	241
40kg N ha^{-1} (Fertlizer)	215	242	220	236	228
20:20 kg N ha^{-1} (FYM:Fertlizer)	225	257	241	260	246
Mean	202	224	213	232	
Microbial biomass N (μg N g^{-1} soil)					
Control	28.7	30.3	29.2	31.7	30.0
20 kg N ha^{-1} (FYM)	29.4	31.3	30.7	33.4	31.2
20 kg N ha^{-1} (Fertlizer)	29.6	34.1	31.7	34.9	32.6
40kg N ha^{-1} (FYM)	34.1	38.3	34.8	37.3	36.1
40kg N ha^{-1} (Fertlizer)	34.5	38.2	37.9	42.2	38.2
20:20 kg N ha^{-1} (FYM:Fertlizer)	35.7	38.3	38.1	41.1	38.9
Mean	32.0	35.5	33.8	36.8	

	N[3]	*C*	*NC*
Soil respiration			
SE±	1.74	0.77	2.38
C.D (0.05)	5.48**	2.3**	7.35**
Microbial biomass C			
SE±	4.29	1.65	5.54
C.D (0.05)	13.5**	5.1**	15.3*
Microbial biomass N			
SE±	0.68	0.26	0.97
C.D (0.05)	2.1**	0.8**	2.7*

 # 2,3 Refer Table 17

4.12.2.5 Microbial biomass N

Mean microbial biomass N content was influenced significantly ($P \leq 0.01$) due to N application and cropping systems. Mean microbial biomass N content across N levels and cropping systems was significantly ($P \leq 0.01$) increased from presowing (39.9 mg N g^{-1} soil) to 78 DAE (46.5 mg N g^{-1} soil) and then it decreased at the time of harvest of crops (20.8 mg N g^{-1} soil) (Table 19). The increase in microbial biomass N at 78 DAE was 17 % more than that of presowing and 55 % more than that of at the time of harvest of crops. Significantly ($P \leq 0.05$) higher microbial biomass N content was observed due to 40 kg N ha^{-1} treatments irrespective of source of N than 20 kg N ha^{-1} treatments and control (0 N). The mean microbial biomass N content due to 40 kg N ha^{-1} treatments (irrespective of source of N) was 19 % more than that of 20 kg N ha^{-1} (irrespective of source of N) and 27 % more than the control treatments (0 N) respectively. Mean microbial biomass N content was significantly ($P \leq 0.05$) more in sorghum/pigeonpea and soybean/sunflower plots (35.5 to 36.8 mg N g^{-1} soil) than sole crops of pigeonpea and soybean (32 to 33.8 mg N g^{-1} soil). In sole crops of soybean and pigeonpea, the microbial biomass N content was 9 % less than that of intercropped plots (soybean/sunflower and sorghum/pigeonpea) (Table 20).

4.12.3 Crops and N influence on soil biological and chemical properties during 1997

4.12.3.1 Mineral N

Mineral N (NH^+_4 + NO^-_3) content in surface soil samples up to 30 cm depth varied significantly during crop growth stages with application of N and also due to cropping systems (Table 21). Mean minerai N content in soil samples increased significantly ($P \geq 0.01$) till 83 DAE. Mineral N content in soil at 83 DAE was greater than the mineral N content in soil samples collected prior to sowing. Mean soil mineral N content across the sampling time increased significantly ($P \geq 0.05$) due to application of N irrespective of source of N. Mineral N content in case of 20 kg N ha^{-1} treatment was one and half fold more than that of 0 N control treatment. In case of 20 kg N ha^{-1} treatments soil fertilizer N content was similar in case of FYM or fertilizer N source. However, at 40 kg N ha^{-1} treatment significantly ($P \leq 0.01$) higher mineral N content in soil was observed in case of FYM or FYM + fertilizer N treatments than that of mineral content at 40 kg N ha^{-1} fertilizer N treatment. Significant interaction between N treatments and sampling times was observed for soil mineral N content. Soil samples collected prior to sowing showed one and half times more mineral N content in case of 40 kg N as FYM than that mineral N content in soil with 40 kg N ha^{-1} as fertilizer. However during subsequent sampling such differences for mineral N content reduced for FYM and fertilizer N treatments. Mean mineral N content in surface soil samples across the N treatments increased significantly ($P \leq 0.01$) up to 37 DAE and then decreased up to 83 DAE. mineral N content of soil in sole pigeonpea plots was significantly more than that of from pigeonpea/sorghum intercrop treatments. In case of control (0 N) and 40 kg N as FYM treatments significantly higher mineral N content in soil under sole pigeonpea plots than that of sole soybean plots was recorded. In case of sorghum/pigeonpea plots significantly maximum soil mineral N content was recorded in case of control (0 N) than in soil under sorghum/pigeonpea plots (Table 22).

4.12.3.2 Net N mineralization

Net N mineralization in the surface soil samples up to 30 cm depth varied significantly during crop growth stages with the application of N and also due to cropping system. Mean net N mineralized at 1997 season presowing stage was 3.58 times more than that of the mean net N mineralized at 1996 presowing stage. Mean net N mineralization in the soil was significantly

Table 21. Mineral N (NH_4^++NO_3^- - N) and Net N Mineralization in surface soil samples (0-30 cm) 1997

Treatments	Presowing	Days after emergence 37	65	83	Mean
Mineral N (µg g^{-1} soil)					
Control	2.1	4.0	4.9	5.0	4.0
20 kg N ha^{-1} (FYM)	5.3	6.6	6.0	6.9	6.2
20 kg N ha^{-1} (Fertlizer)	5.6	7.2	6.2	6.2	6.3
40kg N ha^{-1} (FYM)	10.3	12.6	8.2	8.3	9.8
40kg N ha^{-1} (Fertlizer)	7.1	12.2	8.1	7.1	8.7
20:20 kg N ha^{-1} (FYM:Fertlizer)	7.8	12.5	8.5	7.7	9.1
Soybean	6.1	9.2	6.6	6.8	7.2
Soybean/Sunflower	6.0	9.2	6.6	6.5	7.1
Pigeonpea	7.1	9.3	7.8	7.0	7.8
Sorghum/Pigeonpea	6.3	9.2	6.9	7.2	7.4
Mean	6.4	9.2	7.0	6.9	
Net N Mineralization (µg N g^{-1} soil 10 d^{-1})					
Control	1.2	2.0	2.3	3.3	2.2
20 kg N ha^{-1} (FYM)	2.4	2.0	2.9	4.0	2.8
20 kg N ha^{-1} (Fertlizer)	2.4	2.1	2.7	4.7	3.0
40kg N ha^{-1} (FYM)	5.7	4.7	3.5	5.4	4.8
40kg N ha^{-1} (Fertlizer)	4.9	5.4	3.8	5.3	4.8
20:20 kg N ha^{-1} (FYM:Fertlizer)	4.9	4.4	4.0	5.5	4.7
Soybean	3.5	3.2	3.3	5.0	3.8
Soybean/Sunflower	3.3	3.3	3.4	4.8	3.7
Pigeonpea	3.6	3.7	2.8	4.7	3.7
Sorghum/Pigeonpea	3.9	3.5	3.4	4.2	3.7
Mean	3.6	3.4	3.2	4.7	

	N[3]	*C*	*T*	*NT*	*CT*	*NC*	*NCT*
Mineral N							
SE±	0.12	0.10	0.09	0.23	0.19	0.24	0.45
C.D (0.05)	0.38**	0.30**	0.25**	0.63**	0.51*	0.66*	1.26**
Net N Mineralization							
SE±	0.10	0.10	0.09	0.21	0.18	0.23	0.44
C.D (0.05)	0.31**	0.29 NS	0.24**	0.59**	0.50**	0.7 NS	1.21**

 # 2,3 Refer Table 17

Table 22. Interaction effect between N levels & sources and cropping systems on mineral N content in surface soil samples (0-30 cm) 1997

Treatment			Soybean	Soybean/ Sunflower	Pigeonpea	Sorghum/ Pigeonpea	Mean
Control			3.6	3.6	4.4	4.3	4.0
20 kg N ha^{-1} (FYM)			6.5	5.9	6.4	6.1	6.2
20 kg N ha^{-1} (Fertlizer)			6.6	5.8	6.3	6.5	6.3
40kg N ha^{-1} (FYM)			9.5	9.4	10.9	9.6	9.8
40kg N ha^{-1} (Fertlizer)			9.1	8.7	8.3	8.6	8.7
20:20 kg N ha^{-1} (FYM:Fertlizer)			9.6	9.4	8.5	9.0	9.1
Mean			7.2	7.1	7.8	7.4	
	N^3	*C*	*T*				
SE±	0.13	0.09	0.24				
C.D (0.05)	0.40**	0.28**	0.66**				

 # 2,3 Refer Table 17

increased ($P \leq 0.01$) from 3.58 mg N g^{-1} 10 d^{-1} at presowing stage to 4.69 mg g^{-1} 10 d^{-1} at 83 DAE. (Table 21). Net N mineralized in the soil across the sampling time increased significantly ($P \leq 0.01$) due to application of N irrespective of source of N. Net N mineralized at 40 kg N ha^{-1} treatment was 66 % more than the net N mineralized at 20 kg N kg^{-1} irrespective of source of N. Net N mineralized in 20 kg N ha^{-1} treatments was 33 % more than that of control treatment. Net N mineralized was similar in case of 20 kg N ha^{-1} with FYM or fertilizer N source. No significant ($P \leq 0.05$) differences were observed between sources of N (FYM or fertilizer N) at 20 kg N as well as 40 kg N treatments, however, marginally higher amount of net N mineralization was recorded in case of FYM source than the fertilizer N source. Significant interaction ($P \leq 0.01$) between nitrogen levels and sampling times was observed for net N mineralization. Net N mineralized in the soil at 87 DAE was nearly 3 times more than that of net N mineralization in the soil samples collected at presowing in case of 0 N control treatment. Application of FYM or fertilizer N at 20 kg N ha^{-1} increased net N mineralization at 87 DAE by 1.5 times and by 2 times more than the net N mineralization at presowing. Cropping systems did not influence mean net N mineralization in the soil significantly ($P \leq 0.05$). At 83 DAE, net N mineralization in sole soybean, soybean/sunflower and sole pigeonpea plots was significantly higher than that of net N mineralization in sorghum/pigeonpea plots. The interaction effect between cropping systems and nitrogen levels was found to be nonsignificant.

4.12.3.3 Soil respiration

The amount of carbon respired from the surface soil sampling varied significantly ($P \leq 0.05$) during crop growth period with the application of N and also due to cropping systems (Table 23). Mean amount of carbon respired increased significantly from 81 mg C g^{-1} soil 10 d^{-1} at presowing

Table 23. Soil respiration in surface soil samples (0-30 cm) 1997

Soil resperation (µg C g^{-1} soil 10 d^{-1})

Treatments			Presowing	Days after emergence 37	65	83	Mean
Control			69.3	100.1	60.6	82.1	78.0
20 kg N ha^{-1} (FYM)			75.0	114.6	66.5	87.3	85.8
20 kg N ha^{-1} (Fertlizer)			82.0	124.1	79.8	100.6	96.6
40kg N ha^{-1} (FYM)			88.0	128.9	96.0	104.9	104.4
40kg N ha^{-1} (Fertlizer)			86.9	125.1	103.2	109.4	106.2
20:20 kg N ha^{-1} (FYM:Fertlizer)			85.5	126.0	97.5	99.7	102.2
Soybean			83.9	118.0	80.4	94.4	94.1
Soybean/Sunflower			80.6	120.2	77.6	94.9	93.3
Pigeonpea			79.0	122.3	93.1	104.0	100.0
Sorghum/Pigeonpea			81.0	119.1	84.8	96.1	95.2
Mean			81.1	120.0	83.9	97.3	
	N[3]	*C*	*T*	*NT*	*CT*	*NC*	*NCT*
SE±	0.83	1.03	0.84	2.0	1.78	2.33	4.27
C.D (0.05)	2.6**	3.2**	2.3**	5.5**	5.0**	7.2^{NS}	11.8^{NS}

 # 2,3 Refer Table 17

stage to 97.33 mg C g^{-1} soil 10 d^{-1} at 83 DAE. The amount of carbon respired across sampling times increased significantly due to N application irrespective of source of N (Table 23). Significantly higher amount of carbon was respired due to 40 kg N treatments irrespective of source of N than 0 N control treatment and 20 kg N ha^{-1} (FYM or fertilizer N source) treatments. Among 40 kg N ha^{-1} treatments higher amount of carbon was respired due to application of N as fertilizer followed by FYM and FYM + fertilizer N. Among the 40 kg N ha^{-1} treatments, significantly higher amount of C was respired in case of fertilizer N treatment at 65 and 83 DAE. At all the stages of crop growth, for 20 kg N ha^{-1} treatments significantly ($P \leq 0.01$) higher soil respiration was observed when nitrogen was applied through fertilizer N source than that of N applied through FYM. Cropping systems influenced the soil respiration significantly ($P \leq 0.01$). The soil respiration at 83 DAE in sole pigeonpea plots was 10% more than sole soybean, 9% than soybean/sunflower and 8% than sorghum/pigeonpea plots respectively. During all crop growth stages the soil respiration was maximum in sole pigeonpea plots. The interaction effect between cropping systems and nitrogen levels was found to be nonsignificant.

4.12.3.4 Microbial biomass C

Application of nitrogen and due to cropping systems influenced the mean microbial biomass C in the soil significantly ($P \leq 0.05$). The microbial biomass C in the soil was significantly decreased from presowing to 83 DAE (Table 24). The microbial biomass C at 37 DAE was 35 % more than that of microbial biomass C at presowing. Across the sampling times, microbial biomass C due to 40 kg N treatments (irrespective of source of N) recorded significantly higher microbial biomass C than 20 kg N (FYM or fertilizer source) and 0 N control treatments, which was 22 and 47 % more than that of 20 kg N (FYM or fertilizer source) and 0 N control treatments. Among the 40 kg N treatments, significantly higher microbial biomass C was observed with the FYM + fertilizer source than FYM alone or fertilizer source alone at 65 DAE, however at 83 DAE significantly higher microbial biomass C content was observed with the N applied through FYM alone. During all crop growth stages, significantly ($P \leq 0.01$) higher microbial biomass C was found with fertilizer N than FYM at 20 kg N. Cropping systems influenced the mean microbial biomass C significantly ($P \leq 0.05$). No significant differences was observed between sole soybean, soybean/sunflower and sole pigeonpea plots in microbial biomass C content in the soil, however significantly higher microbial biomass C content in the soil was observed in sorghum/pigeonpea plots than sole pigeonpea plots. The interaction effects between sampling time and cropping systems was found to be nonsignificant.

4.12.3.5 Microbial biomass N

Significant influence on microbial biomass N with the application of nitrogen ($P \leq 0.01$) and due to cropping systems ($P \leq 0.05$) was observed (Table 24). The microbial biomass N content in the soil significantly decreased from presowing stage to 87 DAE by 29 %. At 37 days after emergence (DAE) the microbial biomass nitrogen was 35, 16 and 90 % more than that of microbial biomass nitrogen at presowing, 65 and 83 DAE. Across the sampling time, mean microbial biomass nitrogen content was significantly higher in 40 kg N plots irrespective of source of nitrogen than 20 kg N (FYM or fertilizer N) and control (0 N) treatments. Across the cropping systems, the microbial biomass nitrogen was significantly ($P \leq 0.01$) higher(48 $mgNg^{-1}$) at 65 DAE due to FYM + fertilizer N treatments. The microbial biomass N in the soil was significantly ($P \leq 0.05$) higher in sorghum/pigeonpea plots than that of sole soybean, soybean/sunflower and sole pigeonpea. The

Table 24. Microbial biomass C and N content in surface soil samples (0-30 cm) 1997

Treatments	Presowing	Days after emergence			Mean
		37	65	83	
Microbial biomass C (μg C g^{-1} soil)					
Control	144	237	174	108	166
20 kg N ha^{-1} (FYM)	165	252	186	129	183
20 kg N ha^{-1} (Fertlizer)	208	276	234	150	217
40kg N ha^{-1} (FYM)	224	297	268	176	241
40kg N ha^{-1} (Fertlizer)	239	298	256	158	238
20:20 kg N ha^{-1} (FYM:Fertlizer)	248	296	305	153	251
Soybean	204	266	242	150	216
Soybean/Sunflower	198	283	239	146	217
Pigeonpea	200	272	230	141	211
Sorghum/Pigeonpea	217	283	237	147	221
Mean	205	276	237	146	
Microbial biomass N (μg N g^{-1} soil)					
Control	22.8	37.5	27.4	17.1	26.2
20 kg N ha^{-1} (FYM)	26.1	39.8	29.5	20.4	29.0
20 kg N ha^{-1} (Fertlizer)	32.9	43.7	37.0	23.7	34.3
40kg N ha^{-1} (FYM)	35.5	47.0	42.4	27.8	38.2
40kg N ha^{-1} (Fertlizer)	37.8	47.2	40.5	25.0	37.6
20:20 kg N ha^{-1} (FYM:Fertlizer)	39.3	46.8	48.2	24.2	39.6
Soybean	32.2	42.1	38.3	23.7	34.1
Soybean/Sunflower	31.3	41.8	37.8	23.1	34.3
Pigeonpea	31.7	43.0	36.3	22.2	33.3
Sorghum/Pigeonpea	34.3	44.7	37.6	23.2	34.9
Mean	32.4	43.7	37.5	23.0	

	N[3]	*C*	*T*	*NT*	*CT*	*NC*	*NCT*
Microbial biomass C							
SE±	5.10	3.06	3.41	8.85	6.65	8.26	16.64
C.D (0.05)	16.1**	9.4**	9.5**	24.5**	18.4^{NS}	25.5^{NS}	46.1^{NS}
Microbial biomass N							
SE±	0.81	0.48	0.54	1.40	1.05	1.31	2.63
C.D (0.05)	2.5**	1.49*	1.5**	3.9**	2.9^{NS}	4.0^{NS}	7.3^{NS}

2,3. *Refer Table 17*

Table 25. Biological and chemical properties in surface soil samples (0-30 cm) taken after harvest of pigeonpea 1997

Treatment	N1[1]	N2	N3	N4	N5	N6	Mean
Mineral N (µg N g^{-1} soil)							
Pigeonpea	3.8	4.1	4.0	7.3	6.0	6.8	5.3
Sorghum/Pigeonpea	4.1	5.8	5.4	7.9	5.5	5.6	5.7
Mean	3.9	4.9	4.7	7.6	5.8	6.2	
Net N mineralization (µg N g^{-1} soil 10 d^{-1})							
Pigeonpea	2.3	3.6	4.1	6.0	5.5	4.3	4.3
Sorghum/Pigeonpea	1.3	1.8	3.4	6.6	4.5	3.8	3.6
Mean	1.8	2.7	3.8	6.3	5.0	4.1	
Soil respiration (µg C g^{-1} soil 10 d^{-1})							
Pigeonpea	77.0	92.0	93.1	139.8	131.8	127.3	110.2
Sorghum/Pigeonpea	74.9	87.5	88.0	120.2	125.2	114.2	101.7
Mean	76.0	89.8	90.5	130.0	128.5	120.7	
	N[3]	*C*	*NC*				
mineral N							
SE±	0.52	0.26	1.68				
C.D (0.05)	1.62 NS	0.79 NS	2.09 NS				
Net N mineralization							
SE±	0.52	0.27	0.7				
C.D (0.05)	1.64*	0.84 NS	2.2 NS				
Soil respiration							
SE±	1.88	1.64	3.4				
C.D (0.05)	5.9**	5.1*	10.5 NS				
Microbial biomass C (µg C g^{-1} soil)							
Pigeonpea	199	242	222	231	224	240	227
Sorghum/Pigeonpea	216	219	205	301	220	244	234
Mean	208	231	214	266	222	242	
Microbial biomass N (µg N g^{-1} soil)							
Pigeonpea	31.5	38.3	35.1	37.5	37.9	37.9	35.8
Sorghum/Pigeonpea	34.2	34.6	32.5	47.6	34.8	38.7	37.1
Mean	32.9	36.5	33.8	42.1	35.2	38.3	
	N[3]	*C*	*NC*				
Microbial biomass C							
SE±	10.4	3.64	12.12				
C.D (0.05)	32.6*	11.2 NS	37.4**				
Microbial biomass N							
SE±	1.64	0.58	1.92				
C.D (0.05)	5.2*	1.78 NS	5.9**				

 # 1 N1 = Control; N2 = 20 kg N ha^{-1} (FYM); N3 = 20 kg N ha^{-1} (Fertlizer); N4 = 40 kg N ha^{-1} (FYM); N5 = 40 kg N ha^{-1} (Fertlizer); N6 = 20:20 kg N ha^{-1} (FYM: Fertlizer)
 # 2,3. Refer Table 17.

interaction effect between sampling times vs. cropping systems and cropping systems vs. nitrogen application was found to be nonsignificant.

4.12.3.6 Biological properties of soil after pigeonpea harvest

Fertilizer N content in the soil was not influenced either by nitrogen application or by cropping systems (Table 25). Net N mineralization was significantly ($P \leq 0.05$) effected by N application. The net N mineralization was higher at 40 kg N (FYM) than all other treatments except with 40 kg N (fertilizer N). Similar effect on net N mineralization was observed with 40 kg N either with FYM alone or fertilizer source alone. The net N mineralized at 40 kg N (FYM) was nearly 3 times more than the net N mineralized at control (0 N). Nitrogen application influenced the soil respiration significantly ($P \leq 0.01$). In case of 40 kg N (FYM) and 40 kg N (fertilizer N) the amount of carbon respired was greater than all other treatments. Significantly lowest amount of carbon was respired with 0 N control treatment. The soil respiration was significantly ($P \leq 0.05$) maximum (110 mg C g^{-1}) in sole pigeonpea plots than intercropped pigeonpea plots (102 mg C g^{-1}).

Nitrogen application influenced the microbial biomass C and N content in the soil significantly ($P \leq 0.05$). The microbial biomass C and N was higher in 40 kg N as FYM or FYM + fertilizer N fertilizer treatments than all other treatments. Cropping systems have not influenced the microbial biomass C and N. But the interaction effect between nitrogen application and crops on microbial biomass C and N was found to be significant ($P \leq 0.01$). Significantly maximum microbial biomass C (301 mg C g^{-1}) and N (48 mg N g^{-1}) was observed in sorghum/pigeonpea with 40 kg N (FYM) treatment.

DISCUSSION

CHAPTER 5

DISCUSSION

To evaluate the impacts of N application on soybean and pigeonpea under sole and intercropping systems and on the chemical and biological properties of the soil, field experiments were conducted on a Vertisol during the rainy seasons of 1996 and 1997 at the ICRISAT center, Patancheru. The results of the experiments are discussed in this chapter.

5.1 Weather during 1996 and 1997

Well distributed rainfall of 1016 mm was recorded from Jun to Dec in 1996 and there was no soil moisture deficit. The annual amount of rainfall received in 1996 was 25per cent above the long-term average. Hence during the crop growth period the response of crops to N application was positive. In 1997, out of the 741 mm of rainfall recorded during the year, only 604 mm was received during the cropping season from Jun to Dec. In 1997, sowing of crops was delayed as the amount of rainfall received during the month of Jun was only 19 mm against an average of 118 mm. Although the annual total rainfall received during 1997 was 92per cent of the long-term average, a month long break in rainfall occurred from late July to the third week of in Aug which created moisture deficit for crops hence crops suffered from moisture deficiency during major part of crop growth period. It resulted in no to low response to N application. N fertilization to crops in the SAT is considered a risky investment because of unpredictable weather. The applied N remains unused in the soil as nitrate. We observed this feature of N application during 1997 due to erratic rainfall. Adu-Gyamfi *et al* (1996) also observed that soil nitrate-N can be left unused in the soil in the absence of adequate soil moisture during the crop growing season. In the subsequent rainy season this fraction of soil N is left with on set of rains.

5.2 Impact of N application on crop production

5.2.1 Sole Soybean

In 1996, observations on the growth attributes (LAI, dry matter), nutrient uptake and seed yield of sole soybean showed beneficial influence of N application when compared to the control treatment. Response to N was significantly higher when the crop received N through fertilizer N source compared to the application of FYM. In the present investigation, the higher level of fertilizer N @ 40 kg N ha^{-1} and FYM+fertilizer N treatments were found to be superior in increasing LAI, biomass production, nutrient uptake and seed yield. Asanuma *et al* (1992) observed the plants fed with N made greater growth compared with control (no N) treatments. They further found that soybean plants require greater energy for fixing N_2 ; and therefore N fertilization helped the plants to overcome the N deficiency which may occur before enough N is fixed. Greater growth in N fertilized plants also occurs due the priming effect of N fertilization improves the availability of soil nutrients. Thus there is no limitation of N during early crop growth period. The nutrient uptake in soybean crop is governed by both dry matter produced and thus the resultant nutrient concentration in plant. In most cases, increased nutrient concentration in plant results in increased uptake of nutrients. In our experiment, a higher uptake of N, P and K was observed due to N application at 40 kg N ha^{-1} (as fertilizer source alone or FYM + fertilizer N). It could be attributed to increased concentration of nutrients in the biomass and seeds. Sarkar and Tripathi (1996), Patel *et al* (1996), Sharma and Dixit (1987) and Patel and Chandravanshi (1996) have stated that application of N increased the N concentration in biomass and seed.

The seed yield of soybean recorded in our experiment with an application of 40 kg N ha^{-1} (fertlizer N) was higher than all other treatments and seed yield of soybean recorded with above said treatment was 12per cent and 27 per cent higher than that with 20 kg N ha^{-1} (FYM or fertilizer N) application and control (0 N). The increase in the crop yield due to N application was due to increased leaf area, higher levels of N in the plant. These growth parameters resulted in a better utilization of solar energy which led to increased synthesis of carbohydrates. Patel and Chandravanshi (1996) hold this view that though soybean is a leguminous crop it requires large quantity of N, especially during its initial growth. Therefore high positive correlation was observed by Asanuma *et al* (1992) between total top weight of the crop and the total amount of N removed by plants and seed yield. Similar increase in yield due to N application have been reported by Rahman *et al* (1992), Duong *et al* (1984), Lamb *et al* (1990), Dahatonde and Shiva (1992), Jadhav *et al* (1994), Krishna *et al* (1995), Haider *et al* (1995), Patel *et al* (1996), Sharma and Mishra (1997), and Patel and Chandravanshi (1996).

During 1997, no significant response to nitrogen application was observed with respect to LAI, dry matter production, nutrient uptake and yield of soybeans. This was the result of the drought stress that the crop suffered, the amount of rainfall received from Jun to Oct was 523 mm in 51 rainy days which was 70per cent of the total annual rainfall. During the major part of the grand growth cycle of soybean, the soil moisture was highly limited. Some moisture deficit continued to pod development and maturity stage. All these factors combined to reduce the growth of soybean in the experiment and led to masking of the response to N. The results of the this experiment show that in rainfed agriculture, N application will have to be synchronized with rain distribution and availability of moisture in the soil.

5.2.2 Soybean/Sunflower

In the 1996 experiment the application of N @ 40 kg ha^{-1} (fertilizer or FYM+fertilizer N) soybean/sunflower produced greater LAI than all other treatments. It could be attributed to rapid meristematic activity and enhanced total assimilating area which produced more assimilates.

As observed in sole soybean, in the intercropped soybeans also, greater LAI, dry matter production, nutrient uptake and yield were recorded with higher level of N application. Since there was no moisture stress during entire crop growth period during 1996, the application of N at higher level favoured vigorous growth of the plant, which in turn, increased the uptake of nutrients and yield.

Relatively low dry matter production, nutrient uptake and yield of sunflower in the present investigation was due to lower than normal plant population as only 1/3 of the sole sunflower crop population was maintained in while intercropping it with soybean. In addition, the flowering time of the crop coincided with the receipt of heavy rains which washed the pollens. However increased production of dry matter, nutrient uptake and yield of intercropped sunflower with the application of N @ 40 kg ha^{-1} (fertilizer source alone or FYM + fertilizer N) was observed. These results are in line with the observations reported by Gimenez *et al* (1994), Kharwara and Bindra (1992), and Mishra *et al* (1995) who found increased dry matter production with an increase in N application level in sole sunflower. Higher nutrient uptake was one to a greater availability of soil N which favoured vigorous growth of the plant. This has increased the nutrient uptake and seed yield. Pal *et al* (1996), Gimenez *et al* (1994), Ujjinaiah *et al* (1994), Wagh *et al* (1992), Kharwara and Bindra (1992), Patil *et al* (1992), Ogunremi (1996), Jagtap and Sabale (1994), Susheel Kumar *et al* (1995), Mishra *et al* (1995) and Megur *et al* (1993) reported similar response to N in case of sole sunflower.

In 1997 due to weather aberration, the crop suffered from severe moisture deficit during flowering and seed development stages of growth which reduced the absorption of nutrients by crop substantially. Seed filling was also affected adversely, which resulted in a poor seed yield.

5.2.3 Sole Pigeonpea

Positive effects of N application to pigeonpea were observed on its LAI, dry matter production, nutrient uptake and yield in the experiment conducted during 1996. At the vegetative growth stage of the crop, the LAI under the treatment N @ 40 kg ha^{-1} (irrespective of source of N) was 57per cent and 38 per cent more than that of control and 20 kg N ha^{-1} (FYM or fertilizer N) respectively. Matiwade and Sheelawantar (1992) observed that with increased N applied upto 50 kg ha^{-1}, the LAI of pigeonpea increased from 0.18 to 0.40 which was attributed to an increased surface area available for photosynthesis. Leaf expansion occurred due to the increased availability of plant nutrients from the soil together with applied N. In sole pigeonpea, the dry matter biomass at maturity, increased due to N application @ 40 kg N ha^{-1}. The relative increase was 19 and 39 per cent more than N application @ 20 kg N ha^{-1} and no N (control) respectively. Response of sole pigeonpea to N fertilization of a similar magnitude was observed by Matiwade and Sheelawantar (1992), Kumar Rao *et al* (1981), and Khan (1988). Beneficial effect of N fertilization on nutrient uptake was reflected in increased plant LAI, dry matter accumulation and increased nutrient content in the biomass. The yield improvement due to application of 20 and 40 kg N ha^{-1} (irrespective of source of N) over control (0 N) was 25per cent and 41 per cent. Jagadale and Dafatardar (1985), Muthuvel *et al* (1985) and Matiwade and Sheelawantar (190), Kumar Rao *et al* (1981), Kulkarni and Panwar (1981), Chittapur *et al* (1994) and Singh *et al* (1994) obtained similar results, these lend support to the data gathered in the of present investigation.

As pigeonpea is a deep rooted crop, it is able to extract moisture from deeper soil layers. Little response has been observed in terms of LAI, dry matter production and nutrient uptake. However the seed yields of sole and intercropped pigeonpea were not affected due to N application. Such results were obtained because of a severe outbreak of *Helicoverpa* experienced in the 1997 cropping season at the ICRISAT Patancheru center.

5.2.4 Sorghum/Pigeonpea

In the 1996 experiment, LAI of sorghum/pigeonpea and intercropped pigeonpea increased with increased level of N application. In sorghum/pigeonpea intercropping system the application of 40 kg N ha^{-1} (irrespective of source of N) was found superior than the other levels of N application and the LAI of the crop recorded in this treatment was 52per cent and 29 per cent more than the LAI observed in the control treatment (0 N) and 20 kg N ha^{-1} plots. Obviously an increased supply of nutrients lead to better plant growth. Application of N at 40 kg ha^{-1} as mineral source alone or as FYM+fertilizer N, was found to increase the dry matter production, nutrient uptake and seed yield, as observed in the case of sole pigeonpea. Reddy *et al* (1980) also observed increased dry matter production of pigeonpea intercropped with sorghum, with increased levels of applied N, but these authors observed negligible or no response to applied N on the seed yield of intercropped pigeonpea (Reddy *et al* 1980 and Tobita *et al* 1994).

The 1997 experiment showed that the LAI of sorghum/pigeonpea intercropping system and intercropped pigeonpea, did not differ due to N application. The response was similar in dry matter production, nutrient uptake and yield of intercropped pigeonpea. Whereas sorghum crop showed a clear response to N application (discussed in the next page), the pigeonpea growth and yield were unaltered. The more vigorous growth of sorghum with increasing N application may have stressed the pigeonpea crop and limitations of water and light were the associated features which resulted in lowering the yield of pigeonpea.

An increase in dry matter production, N and P uptake and grain yield of sorghum when 40 and 20 kg N ha^{-1} (irrespective of source of N) over control (0 N) was observed in the 1996 experiment. The results indicated that with increased level of N (irrespective of source) growth and nutrient uptake of sorghum were increased. The increased dry matter production, N and P uptake and grain yield of sorghum due to N application was however not significant. The results of the present study are in consonant with those reported by Ahlawat and Kumar (1988) and Tobita *et al* (1994). Similar results with regard to the response of sole sorghum to N application were reported by several authors (Rao *et al* 1995 ; Dashora and Porwal 1994 ; Sheik Mohammed *et al* 1993 ; Nimje and Gandhi 1993 ; Hirapara *et al* 1992 ;Powell and Hons 1992; Bhosekar and Raikhelkar 1990; Zweifel *et al* 1987 ; and Kasole *et al* 1994).

5.3 Impact of N fertilization on Nodulation and Nitrogenase activity

5.3.1 Soybean

A nodule weight reduction of 90 and 126 per cent in soybean treated with 20 kg N ha^{-1} (fertilizer N) and 40 kg N ha^{-1} (fertilizer N) respectively was observed as compared to the control treatment (0 N) treatment. With respect to different sources of N, the nodule weight reduction was 126 per cent in the treatments which received mineral N alone compared to the treatments which received N as FYM. All the N treatments recorded decreased nodule weight compared to the control (0 N) at both the stages of observation. The application of N has an inhibitory effect on the root hair infection by *Rhizobium* and subsequent formation of infection thread of nodules due to increased soil nitrate (Asanuma *et al* 1992 ; Hardson and Danso 1984 ; Katoch *et al* 1983 and Igor *et al* 1997). Among the different sources of N, organic N (FYM) had less effect than inorganic N. Wakimoto (1989) observed that the application of N without organic matter (compost) reduced the nodule weight, while the application of N with organic matter had relatively less inhibitory effect on nodulation in soybeans.

The observation on the reduction in nitrogenase activity at higher level of N (40 kg N ha^{-1} fertilizer source) application compared to control treatment could be attributed to the inhibitory effect of soil nitrates on nodulation as reflected on the activity of nodules. These results are in agreement with those of Hardson and Danso (1984) and Igor *et al* (1997) who also found that a rapid decline in nitrogenase activity when nodulated soybean plants were supplied with 10 μ mol m^{-3} nitrate at the vegetative stage. Hardson and Danso (1984) observed reduced nitrogenase activity of soybean was reduced from 11 to 9 μ mol $plant^{-1}$ h^{-1} when N dose was increased from 20 to 100 kg ha^{-1}. At 48 DAE, specific nitrogenase activity was less in treatments which received N through mineral source compared to the treatments that received N as FYM. This study clearly shows that (1) lesser inhibitory effect of organic N (FYM) on nodulation compared to inorganic N, (2) sole soybean and intercropped soybean did not differ in respect of weight and activity of nodules, and (3) the associated intercrop (sunflower) did not influence the soybean nodulation. The findings of present investigation were in accordance with those of Deshmukh et al (1996) who reported that nitrogenase activity of mung bean grown as intercrop with cotton was adversely affected due to the application of chemical fertilizer (50 kg N ha^{-1}) alone or in combination with organic sources, while 50 kg N ha^{-1} through *Leucaena* loppings had relatively less effect on nitrogenase activity compared with zero N applied treatment (Deshmukh *et al* 1996). Sole soybean and intercropped soybean did not differ in respect of weight and activity of nodules. It indicates that the associated intercrop (sunflower)did not have any adverse affect on the nodulation and nitrogenase activity of soybean.

The 1997 experiment showed that, weight of nodules (at 43 DAE) was found to be less at higher level of N application (irrespective of source of N) compared to control and 20 kg N ha^{-1} (FYM or fertilizer). A similar response of nodulation to N application in soybeans was observed by Hardson and Danso (1984) ; Katoch *et al* (1983) and Igor *et al* (1997).

Compared to the control treatment (0 N) during 1997, less nitrogenase activity and specific nitrogenase activity due to N application (irrespective of source and level of N) was observed. Wani *et al* (1997) had noted that, in soybean with increasing soil mineral N levels from 23 to 92 μg N g^{-1} soil, the nitrogenase activity decreased (from 1.0 to 0 μ mol C_2H_4 $plant^{-1}$ h^{-1}).

5.3.2 Pigeonpea

In the 1996 experiment, nodule number was not influenced significantly either by N application or by the system of cropping. However, the weight of nodules was reduced at both the stages of observation i.e., 48 and 83 DAE, where the crop received N through mineral source alone (20 or 40 kg N ha^{-1}). These results are in accord with those of Kumar Rao *et al* (1981) and Khan (1988) who observed a reduction in nodule number and weight with N application at rates ranging from 20 kg to 200 kg ha^{-1}. It is evident that soil nitrate have an inhibitory effect on the nodule formation and their development. At 48 DAE, in the soybean receiving N through mineral source [(20 or 40 kg N ha^{-1} or 20:20 (FYM + fertilizer N)] the nitrogenase activity of the nodules was observed to be less than that of control and FYM alone treated plots. This indicates that mineral N had more inhibitory effect on the nodulation in soybean than the organic sources of N. Fertilizer N at 25 ppm nitrate was found to reduce the nitrogenase activity of pigeonpea by Kumar Rao *et al* 1981.

In 1997, a deficient rainfall year, no definite conclusions could be drawn from the experimental results in respect of the influence of N application on nodulation and nitrogenase activity of sole and intercropped pigeonpea. Severe moisture deficient conditions, it is obvious, affect the crop growth as the rainfall was 585 mm against a normal of over 700 mm during the rainy cropping season. Further studies on interaction effect of moisture stress and nodulation of pigeonpea are indicated.

5.4 Abscised dry matter and its N and P content

The mean amount of abscised dry matter added to the soil by soybean was in the range of 750 to 1000 kg ha^{-1} which amounted to 6-10 kg N ha^{-1}. In case of pigeonpea, the mean amount of abscised dry matter added to the soil was 1800 to 3000 kg ha^{-1} which amounted to 20-24 kg N ha^{-1}. Sole crops added more biomass and N through leaf fall than when grown as intercrops. The amount of N added to the soil through the leaf fall was an additional bonus of N by the systems. It has been previously observed that the addition of abscised dry matter as well as N added through leaf fall corresponded well with the growth and duration of pigeonpea (Kumar Rao *et al* 1996; Narain *et al* 1980).

5.5 Impact of N fertilization on Biological and Chemical properties of soil

Microorganisms play an important role in keeping the soils in a productive state. They stimulate the underlying productivity of the soil and help sustain biological production on an enduring basis.

Research studies reported in this thesis, 1996 exemplified as good rainfall year (in rainfed agriculture in the semi arid regions, average to above normal rainfall years called as good rainfall years). Application of N at higher levels [at 40 kg ha^{-1} (irrespective of source)] showed a high mineral soil N content (8.6 to 9.5 mg N g^{-1} soil) and a net N mineralization of 5.0 to 5.6 mg N g^{-1} soil 10 d^{-1} compared to control (5.9; 4.6) and 20 kg N ha^{-1} (7.1 to 7.7; 4.9 to 5) was applied. The increase in mineral N and net N mineralization due to 40 kg N ha^{-1} application was 24per cent and 56 per cent respectively more than that of 20 kg N ha^{-1} and control (0 N) treatments. Higher values of mineral N and net N mineralization in fertilizer treatments compared to control were reported by Saran *et al* (1996) and Deshmukh *et al* (1996). The amount of C respired by soil microorganisms due to the application of 40 kg N ha^{-1} (irrespective of its source) was 2per cent and 8 per cent more than the plots receiving 20 kg N ha^{-1} and 0 N (control) respectively. Similarly Saran *et al* (1996) had also observed high soil respiration in soil amended with organic manures compared to control. The mean microbial biomass C content due to 40 kg N and 20 kg N ha^{-1} (irrespective of its source) was 41 % and 5 % greater than that of control (0 N). It was also noted that the microbial biomass N was 27per cent and 7per cent greater than that of control treatments respectively. These results of the present investigation are in accord with those of Ocio *et al* (1991), Singh (1993) and Singh and Singh (1993). In the deficit rainfall year in 1997 the impact of N application on soil biological properties was somewhat similar to the results obtained during 1996. However, the magnitude of the response differed widely. The mean mineral N (NH_4^++NO_3^--N) content of the soil increased at 40 kg N ha^{-1} (irrespective of source). It was 130per cent and 46 per cent more than that of control and 20 kg N ha^{-1} treatments, whereas, the net N mineralized was 118per cent and 66 per cent more than that of control and 20 kg N ha^{-1} (FYM or mineral N) treatments respectively. Due to the application of 40 kg N ha^{-1} (irrespective of source) the increase in soil respiration by soil microorganisms was 14per cent and 33 per cent more than that of plots which received 20 kg N ha^{-1} and 0 N (control) respectively. Similarly, microbial biomass C and N content due to 40 kg N ha^{-1} (irrespective of source) was 46per cent more than that of 0 N treatment. A significant positive correlation between grain yield of wheat and microbial nutrients content of the soil indicates that the microbial biomass contributes significantly to grain production (Srivastava and Lal, 1994).

Wani *et al* (1997) also observed that application of 25 kg N ha^{-1} to postrainy season sorghum increased mineral N concentration in soil by 2.6 times over the mineral concentration of treatments that did not receive any N for postrainy season sorghum. Application of fertilizer results in increased mineral N concentration in soil and the increase is directly related to the rate of fertilizer N application (Wani *et al* 1997)

The cropping systems influence soil respiration, microbial biomass C and N contents in the soil. In our study the amount of carbon respired and microbial biomass C & N content were found to be higher in intercropping systems of soybean and pigeonpea than that of their respective sole crops. The differences are due to the rooting patterns, nutrient extraction area per plant and intensity of nutrient absorption per unit area of the two crops. Wani et al (1997) also observed that crops influenced the mineral N and net N mineralization in the soil and growing legumes in rotation increases mineral N content in soil, compared with the cultivation of nonlegume crops.

5.6 Comparison of sole and intercrops of soybean and pigeonpea

In the research reported in this study, it was noted that the dry matter produced, N accumulated and seed yield of soybean and pigeonpea were less in the systems when these crops were grown as intercrops than when grown as sole crops. This is due to the competition effect caused by the component crops. The degree of competition for water and nutrients was more on soybean and pigeonpea during 1997 (a scarce rainfall year) compared to 1996 (a good rainfall year). Competition of crops for moisture and nutrients has influenced the growth of both soybean and pigeonpea crops negatively (especially in 1997). The yield reduction noted in soybean due to intercropping was 31per cent and 47 per cent compared to its sole crop yield in 1996 and 1997 respectively, whereas in pigeonpea crop, it was 16per cent and 104 per cent in the years 1996 and 1997 respectively. The competition for light, moisture and nutrients between crops depends on the nature of their growth habits and therefore the type of crop involved. Increased plant height with broad leaves as in sunflower and the soil nutrient exhaustive nature of sorghum crop in the sorghum /pigeonpea system were found to reduce growth (as evidenced by LAI, dry matter, and nutrient uptake) and the yields of soybean and pigeonpea under intercropping situations. The analysis of results from 80 experiments on sorghum/pigeonpea intercropping also revealed that the system provides 90per cent of the equivalent yield of sole sorghum and 52per cent of the sole pigeonpea (Ali, 1996).

5.7 Efficiency of the sole and intercropping systems

A comparison of the different cropping systems evaluated showed that N fertilization favoured higher interception of solar radiation in all the four cropping systems than that of control and 20 kg N ha^{-1} treatments, whereas, the net N mineralized was 118per cent and 66 per cent more than that of control and 20 kg N ha^{-1} (FYM or mineral N) treatments respectively. Due to the application of 40 kg N ha^{-1} (irrespective of source) the increase in soil respiration by soil microorganisms was 14per cent and 33 per cent more than that of plots which received 20 kg N ha^{-1} and 0 N (control) respectively. Similarly, microbial biomass C and N content due to 40 kg N ha^{-1} (irrespective of source) was 46per cent more than that of 0 N treatment. A significant positive correlation between grain yield of wheat and microbial nutrients content of the soil indicates that the microbial biomass contributes significantly to grain production (Srivastava and Lal, 1994).

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5.7 Efficiency of the sole and intercropping systems

A comparison of the different cropping systems evaluated showed that N fertilization favoured higher interception of solar radiation in all the four cropping systems evaluated viz. sole soybean, soybean/sunflower, sole pigeonpea and sorghum/pigeonpea, in both the years of study. In intercropping systems of soybean/sunflower and sorghum/pigeonpea, till the harvest of the intercrops viz, sunflower and sorghum, the amount of light intercepted was more than that of sole crops. After the harvest of intercrop decline in light interception was more at the higher level of N (40 kg N ha^{-1}) application when compared to the 20 kg N ha^{-1} application and the control (0 N) treated crops. Gimenez *et al* (1994) similarly reported a greater light interception in sunflower in N fertilized plots than in 0 N plots. The increase in the canopy light interception was attributed to a higher LAI and dry matter production at the higher levels of N application and in the intercropping systems. Hughes and Keatinge (1983) observed a linear relationship between the amount of dry matter accumulated by the pigeonpea and the amount of solar radiation intercepted by foliage during growth. Shinde *et al* (1996) suggested that it would be beneficial to adopt intercropping of sunflower either with groundnut or with soybean for more efficient conversion of light energy into chemical energy. Similarly Sivakumar and Virmani (1980) also reported that maize/pigeonpea canopy maintained higher levels of interception of solar radiation upto the time of maize harvest because of its higher LAI.

The radiation use efficiency (RUE) has recently been recognized as a more rational means of growth analysis than the traditional agronomic analysis. In this study results obtained in 1996 showed that the dry matter production (g) per MJ was 0.33 to 0.38 in soybean; 0.44 to 0.56 in soybean/sunflower; 0.47 to 0.63 in pigeonpea; and 0.67 to 0.91 in sorghum/pigeonpea. N application showed a beneficial effect in producing more dry matter per

MJ of solar radiation. Intercropping systems, generally, were found to be more efficient than the sole crops in both the years of study. Muchow and Davis (1988) had also reported that radiation use efficiency (RUE) was more responsive to N supply compared to radiation interception. This study confirms the previous observations on the large response of (RUE) to N in sunflower and is also in line with the data reported by Gimenez *et al* 1994.

In the present study the results of the comparison of different cropping systems evaluated showed that sorghum/pigeonpea intercropping was superior not only for the absorption of PAR but also in the conversion of absorbed PAR into dry matter due to its complementary effects in better use of natural resources like light, moisture and nutrients. Willey et al (1981) observed that on deep Vertisols of peninsular India, medium duration sorghum (200-220 days) and pigeonpea intercropping was highly productive.

Quantitatively, efficiency of fertilizer-N, whether measured from biomass stand point (kg biomass kg N^{-1} applied), agronomic point (kg yield kg N^{-1} applied) or N recovery values (proportion of fertilizer N absorbed by the crop), depended on the availability of N in the soil, crop growth (canopy type) and efficiency of crops in utilizing the applied N. In both the years of the study the efficiency of the intercropping system was more as compared to growing the components as sole crops. Higher use of natural resources and yields can be attributed to greater canopy coverage per unit area, which in turn increases the dry matter production and nutrient uptake. As the crops were not exposed to any moisture stress during the 1996 cropping season, the available soil nutrients were better utilized by the crops. Application of N in mineral sources was found to be superior than FYM in increasing the production and the recovery of N by crops. A significantly strong interaction between water and applied nutrients exists in rainfed crop production.

The proportion of N in the seed compared to total dry matter (nitrogen harvest index) was higher in the soybean than in the pigeonpea crops. It is due to greater N concentration (per cent) in the seeds of soybean than in the seeds of pigeonpea and also this may be related to the crop duration. The study also indicates that the amount of N left over in the crop residues was consequently less in soybean than in pigeonpea. Kundu et al (1996) in their research concluded that soybean apparently left a negative N balance in the soil; and the magnitude of soil N used by the crop could be still higher if the soybean straw is not returned to the soil.

In sum, some major inferences that can be drawn from research were:(1) in all the cropping systems tried eg. sole soybean, soybean/sunflower, sole pigeonpea and sorghum /pigeonpea, the application of N promoted growth, nutrient uptake and yield of the crops; (2) N application generally inhibited development of nodules in legume crops evaluated and their nitrogenase activity; (3) the growth of base crops viz., soybean and pigeonpea were reduced when these were grown in intercropping systems; (4) comparison of two intercropping systems showed that soybean/sunflower and sorghum/pigeonpea utilized the natural resources more efficiently; (5) considering the soil health and in order to maintain higher mineral N levels, net N mineralization, soil respiration, microbial biomass C and N contents it is recommended that higher levels of N application are needed (as an example 40 kg N ha^{-1} irrespective of source of N) to sustain vigorous crop growth and yields of crops.

SUMMARY AND CONCLUSION

CHAPTER 6

SUMMARY AND CONCLUSION

Soybean and pigeonpea are among the most important grain legumes grown as sole and/or intercrops in the Indian semi arid tropics (SAT). An analysis of the area and yield trend of soybean in India show that although the area expanded at a compound rate of 600 per cent, the productivity increase is negligible. The crop yield was low 862 kg ha^{-1}. Pigeonpea (*Cajanus cajan* (L) Millsp) is also an important grain legume crop of the Indian semi arid tropics (SAT). India is the major pigeonpea producing country accounting for over 90 per cent of the global pigeonpea production. The productivity of the crop in India is low 533 kg ha^{-1}. Amongst the abiotic constraints to increased productivity of soybean and pigeonpea in the semi-arid tropics (SAT), soil N is prominent. The SAT regions are usually low in organic matter (less than 1 per cent) as compared to the soils in temperate eco-environments (2-4 per cent). Because organic matter is the basic source of available-N in the soil, many soils in the SAT are incapable of maintaining N supply in adequate amounts; N fertilization, therefore, is necessary for obtaining reasonably high yields of soybeans and pigeonpea in SAT agriculture. In view of this, study was conducted with the twin objectives. (1) evaluating the soybean and pigeonpea under sole and intercropping systems and their response to N application, and (2) performance of the impact of N applicaton from various sources on biological and chemical properties of a Vertisol. The present investigation was carriedout during the rainy cropping seasons of 1996 and 1997 in an agricultural watershed at the ICRISAT center, Patancheru.

The experiment was laid out in split-plot design with N treatments in the main plots (N1 to N6) and cropping systems as subplots (C1 to C4), These treatments were replicated thrice. The valid conclusions of the study are presented here under :

During 1996, (a good rainfall year);

(1) Significant improvement in growth, nutrient uptake and yield were recorded in all the four cropping systems tried viz; sole soybean, sole pigeonpea, soybean /sunflower and sorghum /pigeonpea when N was applied.

(2) Application of N at 40 kg N ha^{-1} (fertilizer source alone or FYM + fertilizer N) excelled in improving the growth and yield of all the four cropping systems studied.

(3) Maximum yields of 1133 kg ha^{-1} and 843 kg ha^{-1} in sole soybean and intercropped soybean; 1819 kg ha^{-1} and 1613 kg ha^{-1} in sole pigeonpea and intercropped pigeonpea were obtained when 40 kg N ha^{-1} was sourced from fertilizer N.

(4) Due to the applicaton of N @ 40 kg ha^{-1}, 301 kg ha^{-1} and 1076 kg ha^{-1} yields of sunflower seed and sorghum grain were obtained.

(5) Seed yield of soybean was more in 20 kg N and 40 kg N ha^{-1} (irrespective of source of N) compared to the control 0 N treatment. The increase in yield was 15 per cent and 43 per cent respectively.

(6) Seed yield of pigeonpea increased when 20 N kg and 40 kg N ha^{-1} (irrespective of source of N) compared to control (0 N). The increase recorded was 25 and 41 per cent respectively.

(7) In soybean/sunflower intercropping system, intercrop sunflower seed yield increased with 20 kg N and 40 kg N ha^{-1} (irrespective of source of N) over 0 N treatment. The

increase was 53 per cent and 183 per cent respectively. In sorghum/pigeonpea intercropping system seed yield of sorghum increased due to application of 20 kg N and 40 kg N ha^{-1} over control (0 N) to the extent of 57 per cent and 151 per cent respectively.

(8) At 48 DAE, mean nodule weight reduction obtained was 90 per cent and 126 per cent in 20 kg N ha^{-1} (fertilizer N) and 40 kg N ha^{-1} (fertilizer N) treated plots respectively compared to the control (0 N) treatment. Among the different sources of N assessed, the nodule weight reduction was 126 per cent in treatments which received N from fertilizer sources alone compared to the treatments which received N from FYM.

(9) Mean nitrogenase activity of the nodules was reduced by 15 per cent, 62 per cent, and 30 per cent with application of FYM, fertilizer N and FYM + fertilizer sources (irrespective of level of N) respectively compared to control (0 N) treatment at 48 DAE.

(10) Greater activity of nitrogenase in the nodules was observed when soybean and pigeonpea were grown as intercrops compared to the respective sole crops.

(11) Higher level of N application (40 kg ha^{-1}) showed a maximum mineral N content (8.6 to 9.5 mg N g^{-1} soil) and net mineralization (5.0 to 5.6 mg N g soil 10 d^{-1}) in the soil compared to control (5.9; 4.7) and 20 kg N ha^{-1} (7.1 to 7.7; 4.9 to 5.0) treatments.

(12) The amount of carbon respired by microorganisms (soil respiration) due to the application of 40 kg N ha^{-1} was 2 and 8 per cent more than those treatments which received 20 kg N ha^{-1} and 0 N (control) respectively.

(13) Mean microbial biomass C content due to 40 kg N ha^{-1} and 20 kg N ha^{-1} was 41 per cent and 5 per cent greater than that of the control (0 N) treatment, mean

microbial biomass N content increased was 27 per cent and 7 per cent higher in the above said treatments compared to the control (0 N) treatment.

(14) Mean crop growth rate of the intercropped soybean (2.52 g m^{-2} d^{-1}) was less than that of sole soybean (2.99 g m^{-2} d^{-1}). Similarly mean crop growth rate of intercrop pigeonpea (4.94 g m^{-2} d^{-1}) was also less than that of sole pigeonpea (5.49 g m^{-2} d^{-1}).

(15) Mean nitrogen accumulation rate of sole soybean (120 mg m^{-2} d^{-1}) and pigeonpea (110 mg m^{-2} d^{-1}) were greater than respective intercrops (100; 80 mg m^{-2} d^{-1}).

(16) Radiation use efficiency (g MJ^{-1}) improved due to the application of N (irrespective of source and level of N) over control (0 N). The increase was 12 per cent in sole soybean, 23 per cent in soybean /sunflower , 17 per cent in pigeonpea and 27 per cent in sorghum/pigeonpea.

(17) Nitrogen use efficiency (kg biomass kg N^{-1} applied), agronomic efficiency (kg grain kg N^{-1} applied) and apparent recovery of N (per cent) were greater when crop received N through fertilizer source alone than when crop received N through FYM.

(18) Maximum nitrogen use efficiency (NUE) (kg biomass kg N^{-1}) was recorded in the treatments receiving an application of N at 20 kg ha^{-1}. The NUE was 26, 31, 75 and 202 in sole soybean, soybean/sunflower, sole pigeonpea and sorghum/pigeonpea respectively at an application of 40 kg ha^{-1}.

(19) Application of N at 20 kg ha^{-1} (fertilizer source) was found superior in respect of agronomic efficiency (AE) (kg grain kg N^{-1} applied). AE was 12, 11, 17 and 38 in sole soybean, soybean/sunflower, sole pigeonpea and sorghum/pigeonpea respectively when 20 kg N ha^{-1} was applied.

(20) The relative recovery of N increased by 130 per cent in sole soybean; 299 per cent in sole pigeonpea and 321 per cent sorghum/pigeonpea due to application of N at 20 kg ha^{-1} (fertilizer N); but in soybean/sunflower system, a higher recovery was observed when 40 kg N ha^{-1} (fertilizer N alone) was applied.

During 1997, (a deficit rainfall year);

(21) No significant effect was observed due to N application in respect of growth, nutrient uptake and yield were of sole soybean and soybean /sunflower cropping systems, while a little response was observed in sole pigeonpea and sorghum/pigeonpea cropping systems.

(22) Mean nitrogenase activity of the nodules increased 27 folds between 43 to 80 DAE (0.181 to 4.86 μ mol C_2H_4 $plant^{-1}$ h^{-1}) in soybean and around two folds in pigeonpea (0.34 to 0.62 μ mol C_2 H_4 $plant^{-1}$ h^{-1}). At 43 DAE, maximum nitrogenase activity was observed due to the application of 40 kg N ha^{-1} from FYM compared to 20 kg N ha^{-1} sourced as fertilizer and 40 kg N ha^{-1} (FYM + fertilizer source).

(23) Inhibitory effect of higher levels of N application on nodulation was recorded. Inhibition effect observed at higher level of N application was relatively less when the crop received N from FYM than when the crops received N through fertilizer N alone.

(24) Nitrogen application influenced the soil mineral N content, net N mineralization, soil respiration and microbial biomass C and N contents in the soil.

(25) The mean mineral N content of the soil increased when 40 kg N ha^{-1} was applied (irrespective of source). It was 130 per cent and 46 per cent more than control (0 N) treatment and with the 20 kg N ha^{-1} application. The net N mineralized was 118 per cent and

66 per cent more than that of control and 20 kg N ha^{-1} (FYM or fertilizer N) treatments respectively at 40 kg N ha^{-1}. Due to the application of 40 kg N ha^{-1} (irrespective of source) the increase in soil respiration (by soil microorganisms) was 14 per cent and 33 per cent more than in the plots which were treated with 20 kg N ha^{-1} or 0 N (control) respectively. Similarly, microbial biomass C and N contents in the 40 kg N ha^{-1} treatment (irrespective of source) was 46 per cent more than the control (0 N) treatment.

(26) The crop growth rate of intercropped soybean reduced two fold and that of pigeonpea by three folds when compared to the growth rates obtained under their production as sole crop.

(27) Nitrogen accumulation rate in the intercrop reduced two times in both soybean and pigeonpea crops when compared to their production as sole crops.

(28) Among the different levels and sources of N, application of N at 40 kg N ha^{-1} (fertilizer source alone) increased the amount of light intercepted by crop and the radiation use efficiency (g MJ^{-1}) in all the four systems.

(29) Among the four systems tried, sole soybean; soybean/sunflower; sole pigeonpea; and sorghum/pigeonpea, a greater amount of light was intercepted and biomass produced per MJ of solar radiation in the intercropping systems compared to the respective sole crops.

(30) The mean amount of abscised dry matter added to the soil by soybean was in range of 750 to 1000 kg ha^{-1} which amounted to 6-10 kg N ha^{-1} and 1.2 kg P ha^{-1}. In case of pigeonpea the mean amount of abscised dry matter added to the soil was 1800 to 3000 kg ha^{-1} which amounted to 20 to 24 kg N ha^{-1} and 2.4 kg P ha^{-1}.

(31) The yield of soybean reduced by 31 per cent and 47 per cent in 1996 and 1997 respectively when intercropped, while pigeonpea yields reduced by 16 per cent and 104 per cent in 1996 and 1997 respectively due to intercrop pressure.

(32) The degree of reduction in growth of soybean and pigeonpea was more in 1997 (a scarce rainfall year) compared to 1996 (a good rainfall year).

(33) In both the years of study, nitrogen harvest index (proportion of N in the seed) was found to be higher in soybean (0.82) than pigeonpea (0.43). It denotes that percentage of N added to the soil was less under soybean compared to the pigeonpea.

(34) The differential response to N application by all crops during 1996 and 1997 was mainly due to the distribution and amount of rainfall received. During 1996, the total annual rain recorded was 1062 mm which was 25 per cent above long-term average annual rainfall. Rain totaled 994 mm from Jun to Sep, 33 per cent above the long term seasonal average. In 1997, the total amount of annual rain was 741 mm which was 92 per cent of the long-term average annual rainfall. The total amount of rainfall received from Jun to Sep was (449 mm); it was 48 per cent less than the long term average.

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APPENDIX

Appendix 1.1

Leaf area index of sole soybean (S) and intercropped soybean (IC) 1996.

Treatment[3]	Vegetative stage									Flowering stage					
	32[1]			39			44			53			60		
	S	IC	Mean	S	IC	Mean	S	IC	Mean	S	IC	Mean	S	IC	Mean
N_1	0.19	0.17	0.18	0.29	0.27	0.28	0.48	0.40	0.44	0.71	0.62	0.72	0.80	0.75	0.78
N_2	0.23	0.20	0.22	0.52	0.47	0.49	0.62	0.57	0.60	0.86	0.70	0.78	1.03	1.00	1.02
N_3	0.28	0.19	0.23	0.49	0.45	0.47	0.71	0.70	0.71	1.00	0.89	0.95	1.07	1.00	1.04
N_4	0.29	0.25	0.27	0.50	0.40	0.45	0.68	0.60	0.64	1.10	1.06	1.08	1.02	0.91	0.97
N_5	0.31	0.30	0.31	0.52	0.48	0.50	0.87	0.85	0.86	1.16	1.09	1.13	1.13	1.03	1.08
N_6	0.38	0.24	0.31	0.48	0.46	0.47	0.85	0.83	0.84	1.17	1.04	1.11	1.08	1.01	1.05
Mean	0.28	0.23		0.47	0.42		0.70	0.66		1.00	0.90		1.02	0.95	
	SE±	*C.D*[2]		*SE±*	*C.D*		*SE±*	*C.D*		*SE±*	*C.D*		*SE±*	*C.D*	
N[4]	0.02	0.07**		0.03	0.10**		0.05	0.14**		0.08	0.25*		0.10	0.33^{NS}	
C	0.02	0.05*		0.01	0.04^{NS}		0.02	0.06^{NS}		0.07	0.22^{NS}		0.05	0.15^{NS}	
N at C	0.04	0.10^{NS}		0.04	0.11^{NS}		0.06	0.17^{NS}		0.15	0.43^{NS}		0.13	0.39^{NS}	
C at N	0.04	0.12		0.03	0.10		0.05	0.15		0.17	0.54		0.12	0.36	

Treatment[3]	Pod development & maturity stage														
	67			79			87			96			103		
	S	IC	Mean	S	IC	Mean	S	IC	Mean	S	IC	Mean	S	IC	Mean
N_1	0.79	0.71	0.75	0.66	0.54	0.60	0.55	0.53	0.54	0.50	0.45	0.47	0.12	0.07	0.09
N_2	0.87	0.76	0.82	0.75	0.64	0.69	0.61	0.57	0.59	0.54	0.56	0.55	0.19	0.08	0.13
N_3	0.91	0.83	0.87	0.73	0.74	0.74	0.65	0.61	0.63	0.53	0.62	0.58	0.25	0.14	0.20
N_4	0.96	0.76	0.86	0.87	0.73	0.80	0.71	0.64	0.67	0.60	0.62	0.61	0.22	0.10	0.16
N_5	1.21	0.93	1.07	1.17	0.94	1.06	1.14	0.75	0.95	0.75	0.72	0.73	0.32	0.19	0.26
N_6	0.94	0.95	0.95	0.92	0.89	0.91	0.90	0.71	0.80	0.88	0.78	0.83	0.15	0.10	0.13
Mean	0.95	0.83		0.85	0.75		0.76	0.63		0.63	0.63		0.21	0.11	
	SE±	*C.D*		*SE±*	*C.D*		*SE±*	*C.D*		*SE±*	*C.D*		*SE±*	*C.D*	
N	0.07	0.21^{NS}		0.10	0.32^{NS}		0.11	0.33^{NS}		0.09	0.29^{NS}		0.04	0.14^{NS}	
C	0.05	0.16^{NS}		0.04	0.12^{NS}		0.03	0.10*		0.04	0.13^{NS}		0.03	0.08*	
N at C	0.11	0.33^{NS}		0.12	0.36^{NS}		0.12	0.36^{NS}		0.12	0.35^{NS}		0.06	0.19^{NS}	
C at N	0.13	0.39		0.10	0.29		0.08	0.25		0.11	0.32		0.07	0.20	

Repeated measures analysis of variance(RMAV)

	N	*C*	*T*	*NC*	*NT*	*CT*	*NCT*
SE±	0.04	0.02	0.03	0.05	0.07	0.04	0.10
C.D.	0.11*	0.05^{NS}	0.08**	0.14^{NS}	0.20^{NS}	0.11^{NS}	0.28^{NS}

1. Days after emergence (DAE)
2. C.D. at (0.05) ; ** = ($P < 0.01$) ; * = ($P < 0.05$) ; NS = nonsignificant
3. N_1 = Control; N_2 = 20 kg N ha^{-1} (FYM); N_3 = 20 kg N ha^{-1} (fertlizer); N_4 = 40 kg N ha^{-1} (FYM); N_5 = 40 kg N ha^{-1} (fertilizer N); N_6 = 20:20 kg N ha^{-1} (FYM: fertilizer N)

4. *N=Nitrogen levels & sources; C=Crop/s; T=Time. NT=Interaction between nitrogen & time. NC=Interaction between nitrogen & crops. CT=Interaction between crops and time; NCT=Interaction between nitrogen, crop/s and time*

Appendix 1.2

Dry matter production (kg ha^{-1}) of soybean (S) and intercropped soybean (IC), 1996.

Treatment[3]	Vegetagive stage									Flowering stage					
	32			39			44			53			60		
	S	IC	Mean	S	IC	Mean	S	IC	Mean	S	IC	Mean	S	IC	Mean
N_1	84.1	81.4	82.8	174.2	140.7	157.5	286	232	259	527	476	502	668	585	626
N_2	105.3	98.4	101.8	221.8	181.7	201.7	337	279	308	601	442	522	805	756	780
N_3	118.2	100.9	181.6	246.1	239.4	242.7	435	374	405	729	598	664	936	707	821
N_4	140.9	129.4	140.1	231.5	217.1	224.3	383	348	365	704	735	720	878	784	831
N_5	145.2	136.5	139.9	312.2	293.7	303.0	519	440	480	891	793	842	1125	943	1034
N_6	141.9	132.0	133.0	289.6	265.7	277.6	456	418	437	752	688	720	1000	885	942
Mean		113.1		245.9	223.1		403	349		700.7	632		902	776.7	
	SE±	*C.D*		*SE±*	*C.D*		*SE±*	*C.D*		*SE±*	*C.D*		*SE±*	*C.D*	
N[4]	9.3	29.3*		9.9	31.3**		19.0	59.9**		124	392^{NS}		113	356^{NS}	
C	4.5	13.9^{NS}		6.1	18.9*		11.5	35.4*		93	287^{NS}		55	171^{NS}	
N at C	12.2	35.8^{NS}		14.5	42.6^{NS}		27.5	80.6^{NS}		204	598^{NS}		148	437^{NS}	
C at N	11.1	34.1		15.0	46.3		28.1	86.6		228	703		136	406	

Treatment[3]	Pod development & maturity stage														
	67			79			87			96			103		
	S	IC	Mean	S	IC	Mean	S	IC	Mean	S	IC	Mean	S	IC	Mean
N_1	990	884	937	1073	906	989	1414	1284	1349	1771	1470	1620	1842	1593	1717
N_2	1051	938	994	1405	1155	1280	1968	1406	1687	2181	1763	1972	2145	1939	2042
N_3	1143	986	1065	1555	1356	1456	2102	1545	1824	2275	1900	2088	2367	1933	2150
N_4	1059	976	1018	1595	1404	1499	2287	1609	1948	2440	2062	2251	2422	2031	2226
N_5	1292	1216	1254	1842	1578	1710	2393	1729	2061	2667	2123	2395	2785	2195	2490
N_6	1185	1101	1143	1718	1526	1622	2116	1845	1980	2518	2113	2315	2626	2244	2435
Mean	1120	1017		1531	1321		2047	1570		2309	1905		2364	1989	
	SE±	*C.D*		*SE±*	*C.D*		*SE±*	*C.D*		*SE±*	*C.D*		*SE±*	*C.D*	
N	60	189*		88	276*		227	716^{NS}		272	857^{NS}		170	535^{NS}	
C	64	196^{NS}		89	273^{NS}		125	385*		131	402^{NS}		59	183**	
N at C	126	372^{NS}		177	523^{NS}		314	921^{NS}		354	1042^{NS}		198	592^{NS}	
C at N	156	480		217	668		306	942		320	985		145	447	

Repeated measures analysis of variance(RMAV)

	N	*C*	*T*	*NC*	*NT*	*CT*	*NCT*
SE±	60.3	35.5	50.0	86.1	131.5	76.2	186.4
C.D.	189.8*	109.4^{NS}	138.6**	265.2^{NS}	364.4^{NS}	211.3*	516.5^{NS}

1,2,3 & 4. Refer Appendix 1.1

Appendix 1.3

Nitrogen uptake (kg ha^{-1}) by soybean (S) and intercropped soybean (IC), 1996.

Treatment[3]	Vegetative stage									Flowering stage					
	32[1]			39			44			53			60		
	S	IC	Mean	S	IC	Mean	S	IC	Mean	S	IC	Mean	S	IC	Mean
N_1	3.2	2.5	2.9	5.9	3.9	4.9	8.6	6.4	7.5	10.9	8.3	9.6	11.7	10.5	11.1
N_2	3.5	3.3	3.4	6.8	4.7	5.7	10.5	7.9	9.2	10.7	7.3	9.0	14.2	13.1	13.6
N_3	4.3	3.4	3.9	10.4	8.3	9.3	12.6	10.7	11.7	13.6	11.3	12.5	14.8	12.7	13.8
N_4	5.0	3.9	4.5	8.2	6.1	7.1	11.27	11.1	11.2	13.8	12.6	13.2	15.2	13.8	14.5
N_5	5.1	5.3	5.2	13.9	12.5	13.2	19.4	15.4	17.4	21.7	17.1	19.4	24.4	18.0	21.2
N_6	5.0	5.0	5.0	11.9	9.5	10.7	16.2	10.7	13.5	17.8	13.9	15.9	19.5	16.7	18.1
Mean	4.4	3.9		9.5	7.5		13.1	10.4		14.8	11.7		16.6	14.1	
	SE±	*C.D*[2]		*SE±*	*C.D*		*SE±*	*C.D*		*SE±*	*C.D*		*SE±*	*C.D*	
N[4]	0.45	1.42*		0.54	1.71**		0.86	2.72**		1.71	5.38*		2.29	7.20[NS]	
C	0.17	0.52[NS]		0.36	1.12**		0.73	2.24*		1.06	3.27[NS]		1.41	4.20[NS]	
N at C	0.54	1.60[NS]		0.83	2.44[NS]		1.53	4.49[NS]		2.51	7.36[NS]		3.35	9.81[NS]	
C at N	0.41	1.26		0.89	2.74		1.78	5.48		2.60	8.01		3.46	10.65	

Treatment[3]	Pod development & maturity stage														
	67			79			87			96			103		
	S	IC	Mean	S	IC	Mean	S	IC	Mean	S	IC	Mean	S	IC	Mean
N_1	22.9	17.0	19.9	31.4	24.2	27.8	39.9	37.4	38.6	64.9	55.7	59.0	68.9	66.1	67.5
N_2	23.4	17.1	20.2	43.9	28.5	36.2	54.0	30.3	42.1	80.3	66.6	73.5	82.3	77.4	79.8
N_3	20.6	21.0	20.8	32.3	35.3	33.8	59.2	43.1	51.2	88.9	75.6	82.3	93.9	76.3	85.1
N_4	28.0	20.8	24.4	40.9	38.0	39.4	62.9	44.5	53.7	93.0	80.2	86.6	94.0	83.7	88.9
N_5	29.5	25.8	27.6	42.8	42.8	42.8	66.2	53.7	59.9	99.6	93.3	98.1	113.6	98.5	106.1
N_6	23.4	24.1	23.8	37.3	35.8	36.6	57.3	47.6	52.3	101.5	86.6	94.1	109.4	92.8	101.1
Mean	24.6	21.0		38.1	34.1		56.6	42.7		88.0	76.3		93.7	82.5	
	SE±	*C.D*		*SE±*	*C.D*		*SE±*	*C.D*		*SE±*	*C.D*		*SE±*	*C.D*	
N	2.28	7.17[NS]		4.71	14.84[NS]		5.86	18.46[NS]		8.83	27.82[NS]		4.67	14.73**	
C	1.76	5.41[NS]		3.51	10.81[NS]		3.49	10.74*		3.36	10.37*		2.59	7.97*	
N at C	3.80	11.16[NS]		7.69	22.58[NS]		8.41	24.68[NS]		10.58	31.45[NS]		6.47	19.01[NS]	
C at N	4.30	13.25		8.59	26.48		8.54	26.31		8.24	25.39		6.34	19.53	

Repeated measures analysis of variance(RMAV)

	N	C	T	NC	NT	CT	NCT
SE±	1.80	0.96	1.58	2.45	4.09	2.33	5.75
C.D.	5.68*	2.95[NS]	4.38**	7.56[NS]	11.34[NS]	6.45[NS]	15.93[NS]

1,2,3 & 4. Refer Appendix 1.1

Appendix 1.4

Phosphorus and potassium uptake (kg ha^{-1}) by sole soybean (S) and intercropped soybean (IC), 1996.

Treat-ment[3]	Vegetative stage									Flowering stage					
	32[1]			39			44			53			60		
	S	IC	Mean	S	IC	Mean	S	IC	Mean	S	IC	Mean	S	IC	Mean
N_1	0.42	0.36	0.39	0.66	0.54	0.60	1.05	0.82	0.94	1.67	1.31	1.49	2.41	1.74	2.07
N_2	0.48	0.45	0.47	0.88	0.72	0.80	1.28	1.01	1.14	1.70	1.22	1.46	2.72	2.38	2.55
N_3	0.53	0.43	0.48	0.91	0.90	0.91	1.33	1.31	1.31	1.99	1.69	1.84	2.74	2.35	2.55
N_4	0.73	0.61	0.67	0.94	0.93	0.94	1.56	1.20	1.38	2.25	1.68	1.96	3.05	2.43	2.74
N_5	0.61	0.58	0.59	1.15	1.10	1.13	1.77	1.55	1.66	2.34	2.26	2.30	3.13	3.13	3.13
N_6	0.67	0.58	0.62	1.04	0.98	1.01	1.72	1.37	1.55	2.10	2.16	2.13	2.86	3.20	3.03
Mean	0.57	0.50		0.93	0.86		1.45	1.21		2.01	1.72		2.82	2.54	
	SE±	*C.D*[2]		*SE±*	*C.D*		*SE±*	*C.D*		*SE±*	*C.D*		*SE±*	*C.D*	
N[4]	0.04	0.12*		0.06	0.19*		0.08	0.26**		0.20	0.62^{NS}		0.41	1.29^{NS}	
C	0.03	0.08^{NS}		0.03	0.09^{NS}		0.06	0.19*		0.16	0.48^{NS}		0.20	0.63^{NS}	
N at C	0.06	0.17^{NS}		0.08	0.23^{NS}		0.13	0.39^{NS}		0.33	0.98^{NS}		0.54	1.59^{NS}	
C at N	0.06	0.19		0.07	0.23		0.15	0.45		0.38	1.17		0.50	1.54	

Treat-ment[3]	Pod development & maturity stage															K uptake at harvest		
	67			79			87			96			103					
	S	IC	Mean	S	IC	Mean	S	IC	Mean	S	IC	Mean	S	IC	Mean	S	IC	Mean
N_1	3.40	2.72	3.06	3.75	3.52	3.64	5.31	4.90	5.10	7.30	6.32	6.81	8.07	7.11	7.59	39.8	29.2	34.5
N_2	4.22	3.44	3.83	5.51	4.72	5.11	7.52	4.90	6.21	10.73	7.49	9.11	11.15	8.62	9.88	45.4	37.4	41.4
N_3	3.75	3.26	3.50	4.52	5.01	4.76	7.71	6.14	6.92	9.30	8.85	9.08	10.72	9.04	9.88	49.3	41.2	45.2
N_4	4.21	3.65	3.93	6.53	5.28	5.91	9.05	6.24	7.65	10.22	9.37	9.80	11.00	9.75	10.37	49.2	42.1	45.6
N_5	3.92	3.75	3.84	6.12	5.75	5.94	8.68	7.09	7.89	11.72	10.46	11.09	12.28	11.14	11.71	60.1	51.4	55.8
N_6	4.03	4.53	4.28	6.32	5.56	5.94	8.54	7.54	8.04	11.94	9.97	10.96	13.22	10.97	12.09	55.3	45.8	50.5
Mean	3.92	3.56		5.46	4.97		7.80	6.14		10.20	8.75		11.07	9.44		49.9	41.2	
	SE±	*C.D*		*SE±*	*C.D*		*SE±*	*C.D*		*SE±*	*C.D*		*SE±*	*C.D*		*SE±*	*C.D*	
N	0.34	1.06^{NS}		0.43	1.34*		0.89	2.79^{NS}		1.06	3.23^{NS}		0.58	1.84**		3.01	9.49**	
C	0.22	0.68^{NS}		1.41	1.26^{NS}		0.47	1.45*		0.57	1.75^{NS}		0.19	0.58**		1.29	3.98*	
N at C	0.51	1.49^{NS}		0.83	2.45^{NS}		1.20	3.54^{NS}		1.44	4.23^{NS}		0.67	2.01^{NS}		3.75	11.1^{NS}	
C at N	0.54	1.66		1.00	3.09		1.15	3.55		1.39	4.28		0.46	1.43		3.16	9.75	

Repeated measures analysis of variance(RMAV)

	N	*C*	*T*	*NC*	*NT*	*CT*	*NCT*
SE±	0.23	0.13	0.20	0.33	0.52	0.30	0.73
C.D.	0.74*	0.40^{NS}	0.55**	1.00^{NS}	1.43*	0.82*	2.01^{NS}

1,2,3 & 4. Refer Appendix 1.1

Appendix 1.5

Leaf area index (LAI) of sole soybean and soybean/sunflower (IC), 1996.

Treatment[3]	Vegetative stage									Flowering stage					
	32[1]			39			44			53			60		
	S	IC	Mean	S	IC	Mean	S	IC	Mean	S	IC	Mean	S	IC	Mean
N_1	0.19	0.21	0.20	0.29	0.36	0.32	0.48	0.59	0.54	0.71	0.95	0.83	0.80	1.18	0.99
N_2	0.23	0.27	0.25	0.52	0.63	0.57	0.62	1.08	0.80	0.86	1.15	1.00	1.03	1.68	1.35
N_3	0.28	0.25	0.27	0.49	0.67	0.58	0.71	1.25	0.98	1.00	1.57	1.28	1.07	1.88	1.48
N_4	0.29	0.35	0.32	0.50	0.62	0.56	0.68	1.14	0.91	1.10	1.75	1.43	1.02	1.72	1.37
N_5	0.31	0.49	0.40	0.52	0.88	0.70	0.87	1.72	1.29	1.16	2.02	1.59	1.13	1.97	1.55
N_6	0.38	0.35	0.37	0.48	0.77	0.63	0.85	1.51	1.18	1.17	1.92	1.55	1.08	1.91	1.50
Mean	0.28	0.32		0.48	0.65		0.70	1.22		1.00	1.56		1.02	1.72	
	SE±	*C.D*[2]		*SE±*	*C.D*		*SE±*	*C.D*		*SE±*	*C.D*		*SE±*	*C.D*	
N[4]	0.02	0.07**		0.05	0.16**		0.07	0.23**		0.09	0.27**		0.10	0.31	
C	0.02	0.05 NS		0.03	0.08**		0.03	0.08**		0.08	0.24**		0.06	0.18**	
N at C	0.04	0.10 NS		0.07	0.19 NS		0.09	0.25**		0.16	0.48 NS		0.14	0.41 NS	
C at N	0.05	0.12		0.06	0.19		0.06	0.20		0.19	0.60		0.14	0.43	

Treatment[3]	Pod development & maturity stage														
	67			79			87			96			103		
	S	IC	Mean	S	IC	Mean	S	IC	Mean	S	IC	Mean	S	IC	Mean
N_1	0.79	1.10	0.95	0.66	0.82	0.74	0.55	1.57	0.56	0.50	0.45	0.47	0.12	0.07	0.09
N_2	0.87	1.24	1.06	0.75	0.92	0.83	0.61	0.64	0.62	0.54	0.56	0.55	0.19	0.08	0.13
N_3	0.91	1.39	1.15	0.73	0.98	0.86	0.65	0.74	0.70	0.53	0.62	0.58	0.25	0.14	0.20
N_4	0.96	1.26	1.11	0.87	1.03	0.95	0.71	0.75	0.73	0.60	0.62	0.61	0.22	0.10	0.16
N_5	1.21	1.96	1.59	1.17	1.51	1.34	1.14	0.87	1.01	0.75	0.72	0.73	0.32	0.19	0.26
N_6	0.94	1.87	1.40	0.92	1.19	1.06	0.90	0.83	0.86	0.88	0.78	0.83	0.15	0.10	0.13
Mean	0.95	1.47		0.85	1.08		0.76	0.73		0.63	0.63		0.21	0.11	
	SE±	*C.D*		*SE±*	*C.D*		*SE±*	*C.D*		*SE±*	*C.D*		*SE±*	*C.D*	
N	0.07	0.23**		0.12	0.38**		0.11	0.34 NS		0.09	0.29 NS		0.04	0.14 NS	
C	0.05	0.17**		0.04	0.12**		0.04	0.11 NS		0.04	0.13 NS		0.03	0.08*	
N at C	0.12	0.35 NS		0.14	0.41 NS		0.13	0.37 NS		0.12	0.35 NS		0.06	0.19 NS	
C at N	0.13	0.41		0.10	0.29		0.09	0.27		0.11	0.32		0.07	0.20	

Repeated measures analysis of variance(RMAV)

	N	*C*	*T*	*NC*	*NT*	*CT*	*NCT*
SE±	0.04	0.02	0.03	0.05	0.09	0.05	0.12
C.D.	0.13**	0.06 NS	0.09**	0.16 NS	0.24*	0.13**	0.33 NS

1,2,3 & 4. Refer Appendix 1.1

Appendix 1.6

Dry matter production (kg ha^{-1}) of Sunflower 1996

Treatment[3]	32[1]	39	44	53	60	67	79	87	92
N_1	26	41	123	149	490	618	844	758	588
N_2	46	111	324	491	745	897	1139	1108	993
N_3	45	131	382	622	945	1179	1368	1400	1272
N_4	64	112	348	604	880	996	1206	1247	1006
N_5	98	265	506	929	1703	2085	2171	2127	1856
N_6	60	196	395	800	1611	1911	1986	2027	1661
Mean	57	143	346	599	1062	1281	1452	1444	1229
SE±	9.6	42	31	30	88	79	51	77	52
CD[2]	30**	132**	96**	96**	277**	249**	160**	243**	164**
Repeated measures analysis of variance(RMAV)									
	N[4]	*T*	*NT*	*TN*					
SE±	25	45	115	111					
CD	78**	63**	160**	153					

Appendix 1.7

Nitrogen uptake (kg ha^{-1}) of Sunflower, 1996.

Treatment[3]	32[1]	39	44	53	60	67	79	87	92
N_1	1.02	1.38	3.2	3.3	6.7	12.4	13.8	13.6	9.4
N_2	2.09	4.02	9.3	10.3	12.1	18.4	20.5	22.2	16.1
N_3	2.07	4.97	14.1	12.6	13..2	17.4	27.6	27.4	22.5
N_4	2.52	3.90	9.6	14.9	15.2	21.9	23.7	25.1	19.6
N_5	4.36	10.61	22.2	24.1	30.4	38.4	40.5	42.5	34.8
N_6	2.89	8.11	15.0	20.7	31.7	38.0	40.6	40.8	32.4
Mean	2.49	5.50	12.2	14.3	18.2	24.4	27.8	28.6	22.5
SE±	0.27	0.72	1.59	0.86	1.94	2.01	1.61	2.13	1.34
CD[2]	0.83**	2.3**	5.0**	2.7**	6.1**	6.3**	5.1**	6.7**	4.2**
Repeated measures analysis of variance(RMAV)									
	N[4]	*T*	*NT*	*TN*					
SE±	1.05	0.65	1.60	1.60					
CD	1.66**	1.81**	4.43	4.43					

1. Days after emergence (DAE)
2. C.D. at (0.05)

3&4. Refer Appendix 1.1

Appendix 1.8

Phosphorus and potassium uptake (kg ha^{-1}) of Sunflower 1996

Treatment[3]	P									K
	32[1]	39	44	53	60	67	79	89	92	92
N_1	0.13	0.16	0.38	0.44	1.88	2.18	2.50	2.03	1.96	0.79
N_2	0.24	0.51	1.32	1.60	2.88	3.65	3.98	3.75	3.55	1.64
N_3	0.26	0.55	1.53	1.67	3.06	3.94	4.10	4.73	4.79	2.20
N_4	0.38	0.56	1.54	2.25	3.85	4.19	4.51	4.81	4.48	1.83
N_5	0.55	1.10	2.07	3.01	6.24	6.97	8.63	7.85	6.85	2.42
N_6	0.32	1.79	1.57	2.49	6.69	7.12	7.47	7.04	6.76	1.97
Mean	0.31	0.61	1.40	1.91	4.10	4.67	5.20	5.40	4.73	1.81
SE±	0.04	0.09	0.17	0.18	0.53	0.38	0.46	0.33	0.32	0.17
CD[2]	0.12**	0.28**	0.54**	0.57**	1.68**	1.20**	1.46**	1.03**	0.99**	0.52**

Repeated measures analysis of variance(RMAV)

	N[4]	*T*	*NT*	*TN*
SE±	0.12	0.15	0.36	0.36
CD	0.38**	0.41**	1.00**	1.00

1. Days after emergence (DAE)
2. C.D. at (0.05)

3&4. Refer Appendix 1.1

Appendix 1.9

Leaf area index (LAI) of sole pigeonpea (S) and intercropped pigeonpea (IC), 1996.

Treatment[3]	Vegetative stage														
	32[1]			39			44			53			60		
	S	IC	Mean	S	IC	Mean	S	IC	Mean	S	IC	Mean	S	IC	Mean
N_1	0.07	0.07	0.07	0.10	0.09	0.10	0.13	0.10	0.12	0.42	0.34	0.38	0.46	0.38	0.42
N_2	0.07	0.07	0.07	0.11	0.11	0.11	0.16	0.13	0.15	0.40	0.36	0.38	0.53	0.40	0.47
N_3	0.09	0.09	0.09	0.11	0.11	0.11	0.19	0.14	0.16	0.43	0.36	0.40	0.56	0.44	0.50
N_4	0.09	0.08	0.09	0.12	0.11	0.11	0.21	0.18	0.20	0.45	0.42	0.44	0.60	0.57	0.58
N_5	0.11	0.08	0.10	0.16	0.13	0.14	0.21	0.19	0.20	0.50	0.45	0.48	0.75	0.68	0.71
N_6	0.09	0.08	0.08	0.15	0.13	0.14	0.20	0.17	0.18	0.49	0.42	0.46	0.67	0.62	0.65
Mean	0.09	0.08		0.12	0.11		0.18	0.15		0.45	0.39		0.60	0.52	
	SE±	*C.D*[2]		*SE±*	*C.D*		*SE±*	*C.D*		*SE±*	*C.D*		*SE±*	*C.D*	
N[4]	0.009	0.03 NS		0.003	0.009**		0.018	0.056 NS		0.023	0.072 NS		0.04	0.11**	
C	0.005	0.01 NS		0.002	0.007**		0.012	0.036 NS		0.017	0.051*		0.03	0.10 NS	
N at C	0.012	0.04 NS		0.005	0.017 NS		0.027	0.079 NS		0.037	0.107 NS		0.06	0.19 NS	
C at N	0.011	0.04		0.006	0.018		0.029	0.088 NS		0.040	0.124		0.08	0.23	

Treatment[3]	Vegetative stage												Flowering stage		
	67			79			87			96			103		
	S	IC	Mean	S	IC	Mean	S	IC	Mean	S	IC	Mean	S	IC	Mean
N_1	0.60	0.43	0.51	0.81	0.74	0.78	1.39	1.04	1.22	1.94	1.35	1.65	2.30	1.75	2.03
N_2	0.67	0.60	0.63	0.86	0.64	0.75	1.46	1.10	1.28	2.15	1.75	1.95	2.55	1.78	2.17
N_3	0.78	0.65	0.71	1.40	0.88	1.14	1.99	1.86	1.93	2.55	1.97	2.26	2.65	2.14	2.40
N_4	0.66	0.49	0.58	1.37	1.00	1.18	1.82	1.50	1.66	3.26	2.14	2.70	3.40	2.80	3.10
N_5	0.87	0.78	0.82	1.94	1.04	1.49	2.07	1.65	1.86	3.65	2.76	3.21	3.86	2.95	3.40
N_6	0.88	0.80	0.84	1.62	0.96	1.29	1.96	1.56	1.76	3.18	2.64	2.91	3.54	2.75	3.14
Mean	0.74	0.63		1.33	0.88		1.78	1.45		2.79	2.10		3.05	2.36	
	SE±	*C.D*		*SE±*	*C.D*		*SE±*	*C.D*		*SE±*	*C.D*		*SE±*	*C.D*	
N	0.05	0.16**		0.16	0.50*		0.09	0.28**		0.16	0.52**		0.16	0.50**	
C	0.05	0.14 NS		0.04	0.12**		0.08	0.25*		0.09	0.28*		0.18	0.55*	
N at C	0.09	0.28 NS		0.17	0.52**		0.17	0.49 NS		0.23	0.67 NS		0.35	1.03 NS	
C at N	0.11	0.34		0.09	0.28		0.20	0.62		0.22	0.69		0.44	1.34	

Contd....

Treatment[3]	Flowering stage						Pod development & maturity stage								
	122			137			150			164			189		
	S	IC	Mean	S	IC	Mean	S	IC	Mean	S	IC	Mean	S	IC	Mean
N_1	2.36	1.99	2.17	2.66	2.43	2.55	2.24	1.79	2.01	1.26	1.00	1.13	0.30	0.23	0.27
N_2	3.00	1.70	2.35	2.79	2.63	2.71	2.70	1.81	2.26	1.70	1.32	1.51	0.36	0.23	0.30
N_3	3.33	2.36	2.84	2.84	2.65	2.75	2.42	2.26	2.34	1.22	1.39	1.3	0.40	0.23	0.32
N_4	3.68	2.82	3.25	3.48	3.00	3.24	2.71	2.35	2.53	1.86	1.58	1.72	0.43	0.25	0.34
N_5	4.43	3.10	3.76	2.96	2.54	2.75	2.48	2.11	2.29	1.77	1.42	1.60	0.61	0.36	0.49
N_6	3.82	2.98	3.40	3.48	2.60	3.04	2.67	2.37	2.52	1.60	1.38	1.49	0.64	0.33	0.48
Mean	3.44	2.49		3.04	2.64		2.54	2.12		1.57	1.35		0.46	0.27	
	SE±	*C.D*		*SE±*	*C.D*		*SE±*	*C.D*		*SE±*	*C.D*		*SE±*	*C.D*	
N	0.36	1.15^{NS}		0.15	0.47^{NS}		0.21	0.65^{NS}		0.14	0.45^{NS}		0.07	0.22^{NS}	
C	0.15	0.45**		0.12	0.36*		0.12	0.37*		0.10	0.31^{NS}		0.05	0.14*	
N at C	0.44	1.31^{NS}		0.25	0.74^{NS}		0.29	0.86^{NS}		0.23	0.66^{NS}		0.10	0.30^{NS}	
C at N	0.35	1.09		0.29	0.89		0.29	0.90		0.25	0.77		0.11	0.34	

Repeated measures analysis of variance(RMAV)

	N	*C*	*T*	*NC*	*NT*	*CT*	*NCT*
SE±	0.05	0.02	0.06	0.06	0.15	0.08	0.21
C.D.	0.16**	0.06^{NS}	0.16**	0.19^{NS}	0.41**	0.23**	0.57^{NS}

1,2,3 & 4. Refer Appendix 1.1

Dry matter production (kg ha^{-1}) of sole pigeonpea (S) and intercropped pigeonpea (IC), 1996.

Treatment[3]	Vegetative stage														
	32[1]			39			44			53			60		
	S	IC	Mean	S	IC	Mean	S	IC	Mean	S	IC	Mean	S	IC	Mean
N_1	39	39	39	59	58	58	88	69	79	286	245	266	347	279	313
N_2	45	40	42	64	53	58	99	94	97	315	279	297	380	358	369
N_3	46	43	45	74	71	72	121	99	110	315	278	297	488	397	442
N_4	56	48	52	61	59	60	135	118	126	317	291	304	498	408	453
N_5	70	57	64	107	97	102	143	124	133	373	294	333	569	461	515
N_6	60	58	59	104	93	99	147	113	130	326	287	306	586	486	536
Mean	53	48		78	72		122	103		322	279		478	398	
	SE±	*C.D*[2]		*SE±*	*C.D*		*SE±*	*C.D*		*SE±*	*C.D*		*SE±*	*C.D*	
N[4]	5.09	16.1*		2.93	9.2**		8.84	27.9**		6.85	21.6**		28.6	90.0**	
C	2.35	7.23^{NS}		1.32	4.1**		7.25	22.3^{NS}		6.60	20.3**		14.1	43.5**	
N at C	6.52	19.2^{NS}		3.72	11.0^{NS}		15.35	45.2^{NS}		13.33	39.4^{NS}		37.6	110.7^{NS}	
C at N	5.74	17.7		3.23	10.0		17.75	54.7		16.16	49.8		34.6	106.6	

Treatment[3]	Vegetative stage												Flowering stage		
	67			79			87			96			103		
	S	IC	Mean	S	IC	Mean	S	IC	Mean	S	IC	Mean	S	IC	Mean
N_1	469	363	416	765	631	698	1508	1140	1324	1715	1408	1561	2266	1629	1948
N_2	630	492	561	868	688	778	1641	1290	1466	2162	1912	2037	2554	2271	2413
N_3	672	575	624	1261	848	1054	1919	1607	1763	2616	2184	2400	3149	2425	2787
N_4	633	500	567	1196	810	1003	1724	1598	1661	2651	2168	2410	3197	2810	3003
N_5	800	657	729	1660	946	1303	2211	1610	1910	3081	2588	2835	4263	3538	3901
N_6	726	643	685	1385	922	1153	1927	1609	1768	2890	2331	2610	3968	3586	3777
Mean	655	538		1189	808		1822	1476		2519	2099		3233	2710	
	SE±	*C.D*		*SE±*	*C.D*		*SE±*	*C.D*		*SE±*	*C.D*		*SE±*	*C.D*	
N	41.1	130.0**		73	231**		64	202**		108	339**		108	341**	
C	25.8	80.0**		26	80**		42	129**		67	205**		117	361**	
N at C	60.7	178^{NS}		86	256**		97	281^{NS}		158	463^{NS}		230	683^{NS}	
C at N	63.2	195		64	196		103	316		163	502		287	884	

Contd...

Treatment[3]	Flowering stage						Pod development & maturity stage								
	122[1]			137			150			164			189		
	S	IC	Mean	S	IC	Mean	S	IC	Mean	S	IC	Mean	S	IC	Mean
N_1	3640	2796	3218	5119	5050	5085	5863	5439	5651	6317	5831	6074	7325	6898	7112
N_2	4388	3522	3955	6214	5380	5797	6582	6081	6331	7561	7032	7297	8229	7843	8036
N_3	5399	4556	4977	3293	5444	5869	6905	6388	6647	7855	7133	7494	8816	7906	8361
N_4	5562	4088	4825	6436	5736	6086	7312	6640	6973	7976	7387	7681	9554	7975	8765
N_5	5825	4837	5331	7043	6098	6571	9152	7361	8256	9719	7593	8656	11167	9039	10103
N_6	5357	4773	5065	7300	5958	6629	7995	6791	7393	8203	7642	7922	9764	8923	9344
Mean	5028	4095		6401	5611		7301	6450		7938	7103		9142	8097	
	SE±	*C.D*[2]		*SE±*	*C.D*		*SE±*	*C.D*		*SE±*	*C.D*		*SE±*	*C.D*	
N	485	1528[NS]		300	945*		348	1095**		447	1408*		317	1000**	
C	156	480**		167	516**		135	415**		238	733*		176	543**	
N at C	555	1664[NS]		417	1224[NS]		419	1244[NS]		608	1785[NS]		440	1292[NS]	
C at N	382	1176		410	1263		330	1016		583	1795		431	1329	

Repeated measures analysis of variance(RMAV)

	N	*C*	*T*	*NC*	*NT*	*CT*	*NCT*
SE±	71	27	86	85	215	120	299
C.D.	224**	84[NS]	237**	263[NS]	595**	333**	829[NS]

1,2,3 & 4. Refer Appendix 1.1

Appendix 1.11

Nitrogen uptake (kg ha^{-1}) by sole pigeonpea (S) and intercropped pigeonpea (IC), 1996.

Treatment[3]	Vegetative stage														
	32[1]			39			44			53			60		
	S	IC	Mean	S	IC	Mean	S	IC	Mean	S	IC	Mean	S	IC	Mean
N_1	1.37	1.54	1.46	2.38	2.25	2.32	2.66	2.23	2.44	6.86	5.25	6.05	6.35	4.35	5.35
N_2	1.64	1.51	1.58	2.96	1.94	2.45	3.83	2.74	3.29	6.50	6.87	6.69	6.36	6.22	6.29
N_3	1.94	1.61	1.78	2.68	2.64	2.66	4.52	2.59	3.56	6.96	5.34	6.15	10.23	8.14	9.19
N_4	1.84	1.67	1.76	2.18	2.21	2.20	4.89	4.00	4.44	6.81	7.85	7.33	9.89	8.21	9.05
N_5	2.52	1.95	2.24	4.51	3.62	4.07	2.75	4.25	3.49	7.83	5.80	6.81	9.32	6.97	8.15
N_6	2.07	2.42	2.25	4.29	4.03	4.16	4.62	4.45	4.53	6.69	7.50	7.10	8.38	7.02	7.70
Mean	1.90	1.78		3.17	2.79		3.88	3.38		6.94	6.44		8.42	6.82	
	SE±	*C.D*[2]		*SE±*	*C.D*		*SE±*	*C.D*		*SE±*	*C.D*		*SE±*	*C.D*	
N	0.16	0.50*		0.20	0.62**		0.29	0.91**		0.28	0.87*		0.52	1.65**	
C	0.10	0.30^{NS}		0.07	0.20**		0.22	0.67^{NS}		0.27	0.84^{NS}		0.26	0.80**	
N at C	0.23	0.68^{NS}		0.23	0.68*		0.48	1.40^{NS}		0.55	1.62^{NS}		0.69	2.03^{NS}	
C at N	0.24	0.74		0.16	0.49		0.54	1.65		0.67	2.05		0.64	1.96	

Treatment[3]	Veetative stage												Flowering stage		
	67			79			87			96			103		
	S	IC	Mean	S	IC	Mean	S	IC	Mean	S	IC	Mean	S	IC	Mean
N_1	18.3	13.6	16.0	26.0	18.0	22.0	37.0	26.0	32.0	46.0	35.0	41.0	52.0	43.0	47.0
N_2	16.2	13.5	14.8	25.0	17.0	21.0	42.0	32.0	37.0	69.0	46.0	57.0	81.0	63.0	72.0
N_3	15.7	14.7	15.2	35.0	18.0	26.0	53.0	39.0	46.0	77.0	48.0	63.0	83.0	63.0	73.0
N_4	18.9	10.9	14.9	38.0	21.0	29.0	52.0	38.0	45.0	76.0	48.0	62.0	87.0	64.0	76.0
N_5	16.0	13.1	14.5	52.0	28.0	40.0	58.0	41.0	50.0	84.0	56.0	70.0	100.0	91.0	96.0
N_6	16.6	14.3	15.4	39.0	23.0	31.0	46.0	41.0	43.0	73.0	62.0	67.0	98.0	91.0	95.0
Mean	17.0	13.3		36.0	21.0		48.0	36.0		71.0	49.0		84.0	69.0	
	SE±	*C.D*		*SE±*	*C.D*		*SE±*	*C.D*		*SE±*	*C.D*		*SE±*	*C.D*	
N	1.17	3.70^{NS}		2.59	8.16**		1.66	5.22**		3.04	9.59**		2.44	7.7**	
C	1.00	3.07*		0.95	2.94**		1.78	5.49**		2.79	8.6**		2.63	8.1**	
N at C	2.09	6.14^{NS}		3.07	9.15*		3.50	10.4^{NS}		5.71	16.86^{NS}		5.17	15.35^{NS}	
C at N	2.44	7.51		2.33	7.19^{NS}		4.36	13.44		6.83	21.06		6.44	19.84	

Contd....

Treatment[3]	Flowering stage						Pod development & maturity stage								
	122			137			150			164			189		
	S	IC	Mean	S	IC	Mean	S	IC	Mean	S	IC	Mean	S	IC	Mean
N_1	99	80	89	135	112	123	108	88	98	115	96	106	139	91	115
N_2	114	91	102	180	151	166	111	89	100	119	110	114	142	130	136
N_3	152	91	122	202	155	178	145	108	127	157	118	138	198	132	165
N_4	146	97	121	169	153	161	93	92	92	133	129	131	176	151	164
N_5	146	124	135	217	176	196	175	101	138	187	117	152	236	169	203
N_6	147	119	133	218	141	179	149	120	134	165	131	148	214	166	190
Mean	134	100		187	148		130	100		146	117		184	168	
	SE±	*C.D*		*SE±*	*C.D*		*SE±*	*C.D*		*SE±*	*C.D*		*SE±*	*C.D*	
N	7.73	24.34*		7.01	22.09**		6.39	20.2**		8.01	25.3*		6.73	21.2**	
C	4.88	15.04**		8.94	27.55**		3.81	11.73**		5.59	17.2**		6.28	19.4**	
N at C	11.45	33.59^{NS}		17.0	50.8^{NS}		9.19	26.95*		12.56	36.9^{NS}		12.79	37.8^{NS}	
C at N	11.96	36.85		21.9	67.5		9.33	28.74		13.69	42.2		15.38	47.4	

Repeated measures analysis of variance(RMAV)

	N	*C*	*T*	*NC*	*NT*	*CT*	*NCT*
SE±	1.21	1.26	2.31	2.50	5.6	3.4	8.1
C.D.	3.82**	3.89^{NS}	6.41^{NS}	7.71**	15.52**	9.43**	22.53^{NS}

1,2,3 & 4. Refer Appendix 1.1

Appendix 1.12

Phosphorus uptake (kg ha^{-1}) of sole pigeonpea (S) and intercropped pigeonpea (IC), 1996.

Treatment[3]	Vegetative stage														
	32[1]			39			44			53			60		
	S	IC	Mean	S	IC	Mean	S	IC	Mean	S	IC	Mean	S	IC	Mean
N_1	0.14	0.14	0.14	0.19	0.18	0.18	0.26	0.27	0.27	0.65	0.58	0.61	0.69	0.50	0.60
N_2	0.16	0.14	0.15	0.21	0.17	0.19	0.33	0.30	0.32	0.68	0.62	0.65	0.40	0.68	0.54
N_3	0.16	0.14	0.15	0.20	0.21	0.21	0.39	0.30	0.34	0.68	0.55	0.62	1.08	0.80	0.94
N_4	0.20	0.16	0.18	0.19	0.19	0.19	0.46	0.34	0.40	0.69	0.58	0.64	0.98	0.78	0.88
N_5	0.23	0.17	0.20	0.35	0.36	0.35	0.38	0.42	0.40	0.81	0.62	0.71	0.99	0.67	0.83
N_6	0.20	0.21	0.20	0.31	0.31	0.31	0.50	0.35	0.42	0.76	0.62	0.69	1.07	1.20	1.13
Mean	0.18	0.16		0.24	0.24		0.39	0.33		0.71	0.59		0.87	0.77	
	SE±	*C.D*[2]		*SE±*	*C.D*		*SE±*	*C.D*		*SE±*	*C.D*		*SE±*	*C.D*	
N[4]	0.019	0.061^{NS}		0.017	0.06**		0.03	0.09*		0.03	0.09^{NS}		0.09	0.30*	
C	0.010	0.29^{NS}		0.010	0.03^{NS}		0.02	0.08^{NS}		0.02	0.07**		0.06	0.20^{NS}	
N at C	0.025	0.75^{NS}		0.025	0.07^{NS}		0.05	0.15^{NS}		0.05	0.14^{NS}		0.15	0.43^{NS}	
C at N	0.023	0.072		0.025	0.08		0.06	0.18		0.05	0.16		0.16	0.48	

Treatment[3]	Vegetative stage												Flowering stage		
	67			79			87			96			103		
	S	IC	Mean	S	IC	Mean	S	IC	Mean	S	IC	Mean	S	IC	Mean
N_1	1.16	0.73	0.95	2.24	1.53	1.88	3.33	2.31	2.82	4.01	2.69	3.35	4.97	3.27	
N_2	1.50	1.04	1.27	2.31	1.96	2.14	4.05	3.63	3.54	6.42	3.80	5.11	7.00	4.45	
N_3	1.48	1.23	1.36	3.32	1.70	2.51	5.29	3.35	4.32	6.32	3.50	4.91	6.86	4.43	5.65
N_4	1.68	0.95	1.32	3.20	2.21	2.70	4.88	3.79	4.33	6.45	4.44	5.44	7.78	5.07	6.42
N_5	1.93	1.49	1.71	4.86	2.48	3.52	5.52	5.83	5.68	6.38	4.59	5.49	8.00	7.18	7.59
N_6	1.78	1.48	1.63	3.84	2.03	2.93	5.62	3.92	4.77	6.30	4.87	5.48	7.23	7.61	
Mean	1.59	1.15		3.25	1.98		4.78	3.71		5.98	3.98		6.97	5.34	
	SE±	*C.D*		*SE±*	*C.D*		*SE±*	*C.D*		*SE±*	*C.D*		*SE±*	*C.D*	
N	0.15	0.46*		0.21	0.66**		0.57	1.78^{NS}		0.24	0.75**		0.40	1.25**	
C	0.08	0.23**		0.15	0.46**		0.30	0.92*		0.24	0.74**		0.36	1.12**	
N at C	0.20	0.57^{NS}		0.33	0.98^{NS}		0.76	2.25^{NS}		0.48	1.42^{NS}		0.74	2.20^{NS}	
C at N	0.18	0.56		0.37	1.14		0.73	2.24		0.59	1.82		0.89	2.74	

Contd...

Treatment[3]	Flowering stage						Pod development & maturity stage								
	122			137			150			164			189		
	S	IC	Mean	S	IC	Mean	S	IC	Mean	S	IC	Mean	S	IC	Mean
N_1	6.71	5.67	6.19	11.42	10.66	11.04	7.0	3.71	5.36	8.92	5.04	6.98	10.72	6.75	
N_2	8.41	7.18	7.80	15.30	12.51	13.90	6.58	5.00	5.79	8.48	7.25	7.87	11.17	8.98	
N_3	10.70	8.34	9.52	15.28	12.66	13.97	7.63	5.55	6.59	9.87	8.04	8.95	13.42	10.03	11.73
N_4	11.64	7.69	9.67	14.41	12.44	13.42	7.36	5.53	6.44	9.43	7.67	8.55	13.68	9.85	11.77
N_5	9.33	8.79	9.06	19.74	12.65	16.19	9.08	5.24	7.16	10.72	6.70	8.71	15.13	8.91	12.02
N_6	11.03	9.76	10.39	17.08	11.41	14.24	10.18	5.99	8.08	11.75	8.18	9.96	16.52	11.60	14.06
Mean	9.63	7.91		15.54	12.05		7.97	5.17		9.86	7.15		13.44	9.35	
	SE±	*C.D*		*SE±*	*C.D*		*SE±*	*C.D*		*SE±*	*C.D*		*SE±*	*C.D*	
N[4]	0.57	1.80**		0.56	1.78**		0.70	2.19^{NS}		0.91	2.88^{NS}		0.96	3.02*	
C	0.34	1.06**		0.82	2.52*		0.45	1.38**		0.62	1.91**		0.70	2.16**	
N at C	0.82	2.42^{NS}		1.53	4.58^{NS}		1.04	3.06^{NS}		1.41	4.13^{NS}		1.55	4.54^{NS}	
C at N	0.84	2.59		2.00	6.17		1.10	3.38		1.52	4.67		1.72	5.30	

Repeated measures analysis of variance(RMAV)

	N	*C*	*T*	*NC*	*NT*	*CT*	*NCT*
SE±	0.21	0.13	0.23	0.31	0.58	0.34	0.83
C.D.	0.66**	0.41^{NS}	0.64**	0.96^{NS}	1.62**	0.95**	2.30^{NS}

1,2,3 & 4. Refer Appendix 1.1

Appeldix 1.13

Leaf area index of sole pigeonpea (S) and sorghum/pigeonpea (IC) systems, 1996.

Treatment[3]	Vegetative Stage																	
	32[1]			39			44			53			60			67		
	S	IC	Mean	S	IC	Mean	S	IC	Mean	S	IC	Mean	S	IC	Mean	S	IC	Mean
N_1	0.07	0.13	0.10	0.10	0.35	0.22	0.13	0.43	0.28	0.42	0.85	0.63	0.46	0.99	0.73	0.60	1.21	0.91
N_2	0.07	0.14	0.11	0.11	0.37	0.24	0.16	0.63	0.39	0.40	0.90	0.65	0.53	1.05	0.79	0.67	1.50	1.09
N_3	0.09	0.17	0.13	0.11	0.43	0.27	0.19	0.71	0.45	0.43	1.18	0.81	0.56	1.35	0.95	0.78	1.99	1.38
N_4	0.09	0.16	0.13	0.12	0.40	0.26	0.21	0.71	0.46	0.45	1.17	0.81	0.60	1.32	0.98	0.66	1.77	1.22
N_5	0.11	0.18	0.15	0.16	0.51	0.33	0.21	0.95	0.58	0.50	1.63	1.07	0.75	1.95	1.35	0.87	2.54	1.70
N_6	0.09	0.16	0.13	0.15	0.46	0.31	0.20	0.87	0.53	0.49	1.57	1.03	0.67	1.77	1.22	0.88	2.36	1.62
Mean	0.09	0.16		0.12	0.42		0.18	0.71		0.45	1.22		0.60	1.41		0.74	1.90	
	SE±	*C.D*[2]		*SE±*	*C.D*		*SE±*	*C.D*		*SE±*	*C.D*		*SE±*	*C.D*		*SE±*	*C.D*	
N[4]	0.013	0.04[NS]		0.02	0.07*		0.03	0.10**		0.09	0.27*		0.06	0.19**		0.09	0.30**	
C	0.007	0.02**		0.01	0.03**		0.02	0.05**		0.04	0.14**		0.03	0.10**		0.07	0.21**	
N at C	0.017	0.05[NS]		0.03	0.08[NS]		0.04	0.12**		0.11	0.33**		0.08	0.24**		0.15	0.44[NS]	
C at N	0.016	0.05		0.03	0.08		0.04	0.12		0.11	0.33		0.08	0.25		0.16	0.50	

Treatment[3]	Vegetative stage									Flowering stage					
	79			87			96			103			122		
	S	IC	Mean	S	IC	Mean	S	IC	Mean	S	IC	Mean	S	IC	Mean
N_1	0.81	1.55	1.18	1.39	2.05	1.72	1.94	2.51	2.22	2.30	2.70	2.50	2.36	2.83	2.59
N_2	0.86	1.76	1.31	1.46	2.44	1.95	2.15	3.26	2.70	2.55	2.88	2.71	3.00	2.69	2.84
N_3	1.40	2.43	1.92	1.99	3.42	2.71	2.55	3.62	3.09	2.65	3.50	3.07	3.33	3.25	3.29
N_4	1.37	2.38	1.87	1.82	2.98	2.40	3.26	3.78	3.52	3.40	3.88	3.64	3.68	3.61	3.65
N_5	1.94	2.92	2.43	2.07	3.69	2.88	3.65	4.48	4.07	3.86	4.25	4.05	4.43	4.16	4.29
N_6	1.62	2.70	2.16	1.96	3.31	2.63	3.18	4.16	3.67	3.54	4.20	3.87	3.82	4.19	4.00
Mean	1.33	2.29		1.78	2.98		2.79	3.63		3.05	3.57		3.44	3.45	
	SE±	*C.D*		*SE±*	*C.D*		*SE±*	*C.D*		*SE±*	*C.D*		*SE±*	*C.D*	
N	0.24	0.76*		0.14	0.43**		0.15	0.48**		0.19	0.60**		0.35	1.12*	
C	0.05	0.14**		0.09	0.27**		0.09	0.27**		0.19	0.58[NS]		0.16	0.49[NS]	
N at C	0.25	0.78[NS]		0.21	0.60[NS]		0.22	0.64[NS]		0.38	1.11[NS]		0.45	1.32[NS]	
C at N	0.11	0.35		0.22	0.67		0.22	0.67		0.46	1.41		0.39	1.20	

1,2,3&4. Refer Appendix 1.1

Appendix 1.14

Dry matter production (kg ha-1) of Sorghum 1996

Treatment[3]	32[1]	39	44	53	60	67	79	87	96	103	122	130
N_1	33	126	211	391	528	823	1076	1207	2222	2615	3056	5387
N_2	36	131	229	432	594	922	1110	1722	2614	2954	3359	6492
N_3	44	152	287	710	866	1455	1793	2634	2792	3180	3744	8424
N_4	45	154	260	535	730	1057	1607	2094	2700	2975	3890	8882
N_5	68	176	347	898	1091	1827	2556	3172	3328	3491	4810	9360
N_6	47	154	283	806	1058	1571	2280	2740	3172	3488	4700	9166
Mean	46	149	270	629	811	1276	1737	2262	2805	3117	3927	7952
SE±	9.8	13.0	15.5	33	80	108	170	169	208	137	268	440
CD[2]	30.8^{NS}	41.1^{NS}	49**	105**	251**	340**	536**	534**	657*	432**	845**	1386**

Repeated measures analysis of variance(RMAV)

	N[4]	*T*	*NT*	*TN*
SE±	5.1	77	187	188
CD	159	212	518	520

Appendix 1.15 **Nitrogen uptake (kg ha^{-1}) of Sorghum, 1996.**

Treatment[3]	32[1]	39	44	53	60	67	79	87	96	103	122	130
N_1	1.2	4.2	5.1	5.6	5.8	8.7	10.7	13.0	16.1	33.1	37.7	41.7
N_2	1.2	4.5	5.7	6.1	6.7	11.8	12.1	15.1	22.9	38.1	43.5	59.0
N_3	1.7	6.0	7.7	8.2	8.3	16.3	18.1	23.7	29.2	35.9	39.7	64.3
N_4	1.5	4.7	7.4	7.9	8.5	11.8	15.5	16.0	22.3	32.3	38.9	73.7
N_5	2.7	7.3	13.4	12.8	13.4	20.0	23.0	29.0	36.0	44.1	55.3	83.8
N_6	1.8	5.9	7.0	10.1	12.6	17.8	19.3	24.8	26.8	33.9	54.9	85.7
Mean	1.7	5.4	7.7	8.5	9.2	14.4	16.5	20.3	25.6	36.2	45.0	68.1
SE±	0.37	0.39	0.48	0.51	1.15	1.44	2.06	1.49	3.47	2.15	3.10	6.5
CD[2]	1.16^{NS}	1.24**	1.51**	1.62**	3.62**	4.53**	6.50**	4.68**	10.0*	6.8*	9.8**	20.4*

Repeated measures analysis of variance(RMAV)

	N[4]	*T*	*NT*	*TN*
SE±	0.5	1.04	2.48	2.54
CD	1.58**	2.88**	6.88**	7.04

1. Days after emergence (DAE)
2. C.D. at (0.05)
3&4. Refer Appendix 1.1

Appendix1.16

Phosphorus & Potassium uptake (kg ha^{-1}) of Sorghum 1996

	Uptake of P												Uptake of K
Treatment[3]	32[1]	39	44	53	60	67	79	87	96	103	122	130	130
N_1	0.02	0.73	0.85	1.31	1.33	1.71	2.37	3.19	6.30	7.32	8.55	12.84	16.8
N_2	0.02	0.83	1.14	1.35	1.46	3.40	3.75	5.49	9.85	10.16	10.80	14.70	18.7
N_3	0.02	0.66	1.17	1.66	2.36	3.09	4.55	6.58	8.12	9.75	10.07	17.83	21.8
N_4	0.02	0.91	1.14	1.97	2.18	3.16	4.17	6.10	7.82	8.27	8.61	20.56	22.5
N_5	0.03	0.79	1.30	2.23	3.13	4.85	6.01	7.91	9.70	9.97	11.65	20.11	32.4
N_6	0.03	0.74	1.24	2.17	3.12	4.04	5.35	6.86	9.96	10.43	11.14	20.32	27.0
Mean	0.02	0.78	1.14	1.78	2.26	3.37	4.37	6.02	8.63	9.32	10.14	17.73	23.2
SE±	0.003	0.08	0.06	0.24	0.34	0.41	0.70	0.58	0.76	0.83	1.02	1.23	3.38
CD[2]	0.01^{NS}	0.24^{NS}	0.19**	0.75^{NS}	1.06*	1.29**	2.21^{NS}	1.81**	2.41*	2.61^{NS}	3.22^{NS}	3.86**	10.63^{NS}

Repeated measures analysis of variance(RMAV)

	N[4]	*T*	*NT*	*TN*
SE±	0.27	0.37	0.92	0.92
CD	0.60**	0.73**	1.80**	1.79

1. Days after emergence (DAE)
2. C.D. at (0.05)

3&4. Refer Appendix 1.1

Appendix 2.1

Leaf area index of sole soybean (S) and intercropped soybean (IC), 1997.

Treatment[3]	Vegetative stage						Flowering						Maturity stage		
	19[1]			28			45			61			75		
	S	IC	Mean	S	IC	Mean	S	IC	Mean	S	IC	Mean	S	IC	Mean
N_1	0.40	0.27	0.33	1.26	0.74	1.00	1.17	0.80	0.99	1.82	0.89	1.35	1.06	0.91	0.99
N_2	0.30	0.25	0.28	1.34	0.61	0.98	1.38	0.61	1.00	1.53	1.17	1.35	1.48	0.84	1.16
N_3	0.26	0.34	0.30	1.03	1.06	1.05	1.29	1.11	1.20	1.75	1.09	1.42	1.51	1.00	1.26
N_4	0.34	0.27	0.31	1.24	0.70	0.97	1.50	1.36	1.43	1.84	0.95	1.39	1.48	0.94	1.21
N_5	0.27	0.21	0.24	1.37	0.61	0.99	1.38	0.86	1.12	1.78	0.80	1.29	1.48	0.68	0.08
N_6	0.31	0.23	0.27	1.19	0.69	0.94	1.46	0.73	1.10	0.66	1.16	1.41	1.42	0.90	0.16
Mean	0.31	0.26		1.24	0.74		1.37	0.91		1.73	1.01		1.41	0.88	
	SE±	*C.D*[2]		*SE±*	*C.D*		*SE±*	*C.D*		*SE±*	*C.D*		*SE±*	*C.D*	
N[4]	0.02	0.06[NS]		0.05	0.17[NS]		0.17	0.54[NS]		0.20	0.63[NS]		0.07	0.22*	
C	0.02	0.06[NS]		0.06	0.19**		0.09	0.28**		0.09	0.28**		0.07	0.20*	
N at C	0.04	0.11[NS]		0.12	0.35[NS]		0.23	0.68[NS]		0.26	0.75[NS]		0.13	0.39[NS]	
C at N	0.05	0.14		0.15	0.46		0.22	0.68		0.22	0.69		0.16	0.49	

Repeated measures analysis of variance(RMAV)

	N	*C*	*T*	*NC*	*NT*	*CT*	*NCT*
SE±	0.07	0.03	0.05	0.08	0.13	0.07	0.18
C.D.	0.20[NS]	0.08[NS]	0.15**	0.24[NS]	0.36[NS]	0.20*	0.50[NS]

1,2,3 & 4. Refer Appendix 1.1

ppendix 2.2

ry matter production (kg ha^{-1}) of sole soybean (S) and intercropped soybean (IC), 1997.

Treatment[3]	Vegetative stage						Flowering stage						Maturity stage					
	19[1]			28			45			61			75			95		
	S	IC	Mean	S	IC	Mean	S	IC	Mean	S	IC	Mean	S	IC	Mean	S	IC	Mean
N_1	194	125	159	809	522	665	1374	788	1081	2275	1053	1664	3115	1619	2367	2980	1518	2249
N_2	156	130	143	808	389	599	1450	785	1118	2330	1679	2005	3382	1631	2507	2575	1379	1977
N_3	130	173	152	687	624	655	1314	956	1135	2530	1469	2000	3799	1943	3021	2566	1301	1934
N_4	158	128	143	815	436	625	1447	843	1145	2955	1003	1979	3472	1681	2576	2923	1469	2196
N_5	142	124	133	934	410	672	1496	858	1177	2473	1311	1892	3537	1598	2567	2579	1476	2028
N_6	144	119	131	630	547	588	1191	640	916	2155	1273	1714	2974	1603	2138	3239	1467	2353
Mean	154	133		780	488		1379	812		2453	1298		3380	1679		2810	1435	
	SE±	*C.D*[2]		*SE±*	*C.D*		*SE±*	*C.D*		*SE±*	*C.D*		*SE±*	*C.D*		*SE±*	*C.D*	
N[4]	8	25^{NS}		39	124^{NS}		98	309^{NS}		139	438^{NS}		190	599^{NS}		183	577^{NS}	
C	6	18*		36	110**		33	103**		66	203**		75	232**		70	217**	
N at C	13	38^{NS}		73	216^{NS}		114	341^{NS}		180	530^{NS}		230	683^{NS}		220	654^{NS}	
C at N	15	45		88	270		82	252		161	497		184	567		172	531	

epeated measures analysis of variance (RMAV)

	N	*C*	*T*	*NC*	*NT*	*CT*	*NCT*
SE±	68	18	43	74	119	59	156
C.D.	214^{NS}	54*	121**	229^{NS}	329*	163**	433^{NS}

,2,3 & 4. Refer Appendix 1.1

Appendix 2.3

Nitrogen, phosphorus and potassiun uptake (kg ha^{-1}) of Soybean 1997

	N														
	28[1]			45			61			75			95		
Treatment[3]	S	IC	Mean	S	IC	Mean	S	IC	Mean	S	IC	Mean	S	IC	Mean
N_1	30	19	25	55	28	42	87	36	61	129	62	95	116	63	89
N_2	31	15	23	56	20	38	84	60	72	141	64	102	102	60	81
N_3	27	24	25	41	35	38	86	51	68	163	75	119	105	51	78
N_4	27	18	22	54	29	41	99	36	67	146	69	107	107	60	83
N_5	34	17	26	58	28	43	92	42	67	136	62	99	100	59	80
N_6	22	20	21	38	21	29	72	48	61	97	64	81	125	56	90
Mean	29	19		50	27		87	45		135	66		109	58	
	SE±	*C.D*[2]		*SE±*	*C.D*		*SE±*	*C.D*		*SE±*	*C.D*		*SE±*	*C.D*	
N[4]	1.9	6.1^{NS}		4.2	13.4^{NS}		7.0	22.2^{NS}		8.9	28.1^{NS}		6.0	18.9^{NS}	
C	1.5	4.6**		2.2	6.7**		3.8	11.6**		4.7	14.4**		2.8	8.8**	
N at C	3.2	9.5^{NS}		5.7	16.7^{NS}		9.6	28.2^{NS}		12.1	35.4^{NS}		7.7	22.8^{NS}	
C at N	3.7	4.3		5.3	16.4		9.2	28.4		11.5	35.3		7.0	21.4	
Repeated measures analysis (RMAV)															
	N[4]	*C*	*T*	*NC*	*NT*	*CT*	*NCT*								
SE±	3.3	1.3	2.3	4.1	6.0	3.2	8.1								
C.D.	10.5^{NS}	2.9*	4.5**	8.9^{NS}	16.7^{NS}	8.8**	22.6^{NS}								

	P			K		
	95			95		
Treatment	S	IC	Mean	S	IC	Mean
N_1	8.7	5.5	7.1	54.1	28.9	41.5
N_2	9.7	5.6	7.6	50.0	28.3	39.1
N_3	8.4	4.6	6.5	48.3	25.2	36.8
N_4	10.9	5.7	8.3	54.2	29.0	41.6
N_5	8.6	5.2	6.9	47.8	28.5	38.1
N_6	11.0	5.6	8.3	67.4	29.3	45.9
Mean	9.6	5.4		52.8	28.2	
	SE±	*C.D*		*SE±*	*C.D*	
N	0.45	1.4^{NS}		3.6	11.1^{NS}	
C	0.26	0.8**		1.3	3.8**	
N at C	0.64	1.9^{NS}		4.1	12.3^{NS}	
C at N	0.63	2.0		3.1	9.4	

1. Days after emergence (DAE)
2. C.D. at (0.05)

3&4. Refer Appendix 1.1

Appendix 2.4

Leaf area index of sole soybean (S) and soybean/sunflower (IC) systems, 1997.

Treatment[3]	Vegetative stage						Flowering stage						Maturity stage		
	19[1]			28			45			61			75		
	S	IC	Mean	S	IC	Mean	S	IC	Mean	S	IC	Mean	S	IC	Mean
N_1	0.40	0.39	0.40	1.26	1.24	1.25	1.17	1.53	1.35	1.82	1.63	1.72	1.06	1.18	1.22
N_2	0.30	0.38	0.34	1.34	1.28	1.31	1.38	1.31	1.35	1.53	1.92	1.73	1.48	1.48	1.53
N_3	0.26	0.44	0.35	1.03	1.62	1.33	1.29	2.08	0.69	1.75	1.80	1.77	1.51	1.61	1.66
N_4	0.34	0.43	0.38	1.24	1.31	1.28	1.50	2.20	1.85	1.84	1.71	1.78	1.48	1.30	1.39
N_5	0.27	0.33	0.30	1.37	1.31	1.34	1.38	1.58	1.48	1.78	1.33	1.56	1.48	1.34	1.31
N_6	0.31	0.33	0.32	1.19	1.24	1.22	1.46	1.58	1.52	1.66	1.85	1.61	1.42	1.36	1.24
Mean	0.31	0.38		1.24	1.34		1.37	1.71		1.73	1.71		1.41	1.38	
	SE±	*C.D*		*SE±*	*C.D*		*SE±*	*C.D*		*SE±*	*C.D*		*SE±*	*C.D*	
N[4]	0.02	0.07^{NS}		0.07	0.21^{NS}		0.15	0.48^{NS}		0.20	0.64^{NS}		0.08	0.25*	
C	0.02	0.07*		0.06	0.20^{NS}		0.09	0.28*		0.09	0.29^{NS}		0.07	0.21^{NS}	
N at C	0.04	0.12^{NS}		0.13	0.38^{NS}		0.22	0.64^{NS}		0.26	0.77^{NS}		0.14	0.42^{NS}	
C at N	0.05	0.16		0.16	0.48		0.22	0.69		0.23	0.71		0.17	0.52	

Repeated measures analysis of variance (RMAV)

	N	C	T	NC	NT	CT	NCT
SE±	0.07	0.03	0.05	0.08	0.13	0.07	0.18
C.D.	0.22^{NS}	0.08^{NS}	0.15^{NS}	0.25^{NS}	0.37^{NS}	0.20*	0.51^{NS}

1,2,3 & 4. Refer Appendix 1.1

Appendix 2.5

Dry matter production (kg ha^{-1}), nitrogen, phosphorus & potassium uptake (kg ha^{-1}) of Sunflower 1997

Treatment[3]	Dry matter production						N					P	K
	19[1]	28	45	61	75	85	28	45	64	75	85	85	85
N_1	69	468	1137	2098	1947	1862	17	32	67	59	29	3.6	4.9
N_2	58	554	1119	1852	2312	2217	19	30	62	55	35	5.6	6.5
N_3	51	439	1166	1863	1829	1716	17	34	69	55	25	4.7	4.7
N_4	68	502	1358	1757	1867	1805	17	33	56	60	30	5.2	5.2
N_5	61	449	1412	1620	1863	1761	18	40	51	51	31	3.8	4.7
N_6	63	432	1309	1713	2069	1912	17	35	53	62	42	5.8	5.3
Mean	61	474	1250	1817	1981	1865	17.5	34	60	57	32	4.8	5.2
SE±	6.8	42	135	210	187	176	1.5	4.1	80.0	3.7	3.7	0.38	0.7
CD[4]	22^{NS}	132^{NS}	425^{NS}	663^{NS}	588^{NS}	556^{NS}	4.8^{NS}	13.1^{NS}	25.1^{NS}	11.8^{NS}	11.7^{NS}	1.21**	2.2^{NS}

Repeated measures analysis (RMAV)

	N[2]	*T*	*NT*	*TN*				*N*	*T*	*NT*	*TN*		
SE±	71	52	134	127				2.7	1.83	4.8	4.7		
CD	222^{NS}	144**	371^{NS}	353				7.8^{NS}	5.8**	13.4^{NS}	13.2		

1. Days after emergence (DAE)
2. C.D. at (0.05)

3&4. Refer Appendix 1.1

Appendix 2.6

Leaf area index of sole pigeonpea (S) and intercropped pigeonpea (IC), 1997.

Treatment[3]	Vegetative Stage														
	19[1]			28			45			61			75		
	S	IC	Mean	S	IC	Mean	S	IC	Mean	S	IC	Mean	S	IC	Mean
N_1	0.03	0.02	0.03	0.09	0.05	0.07	0.22	0.08	0.15	0.91	0.16	0.53	1.64	0.22	0.93
N_2	0.02	0.02	0.02	0.07	0.07	0.07	0.08	0.13	0.11	1.04	0.26	0.65	1.84	0.35	1.09
N_3	0.02	0.02	0.02	0.12	0.07	0.10	0.26	0.06	0.16	0.66	0.16	0.41	1.37	0.25	0.81
N_4	0.03	0.02	0.02	0.08	0.06	0.07	0.26	0.07	0.17	0.41	0.19	0.30	1.29	0.44	0.86
N_5	0.03	0.02	0.02	1.10	0.10	0.10	0.32	0.13	0.23	0.87	0.22	0.55	1.38	0.33	0.86
N_6	0.03	0.03	0.03	0.11	0.07	0.09	0.27	0.10	0.19	1.07	0.37	0.72	1.44	0.33	0.89
Mean	0.03	0.02		0.10	0.07		0.24	0.10		0.83	0.22		1.49	0.32	
	SE±	*C.D*[2]		*SE±*	*C.D*		*SE±*	*C.D*		*SE±*	*C.D*		*SE±*	*C.D*	
N[4]	0.003	0.011^{NS}		0.01	0.03^{NS}		0.03	0.09^{NS}		0.04	0.21*		0.09	0.29^{NS}	
C	0.002	0.006^{NS}		0.01	0.02**		0.02	0.05**		0.10	0.13**		0.06	0.17**	
N at C	0.005	0.014^{NS}		0.01	0.04^{NS}		0.04	0.12^{NS}		0.07	0.29^{NS}		0.13	0.39^{NS}	
C at N	0.005	0.015^{NS}		0.01	0.04		0.04	0.12		0.10	0.32		0.14	0.42	

Treatment[3]	Flowering stage						Pod development & maturity stage								
	113			137			154			178			193		
	S	IC	Mean	S	IC	Mean	S	IC	Mean	S	IC	Mean	S	IC	Mean
N_1	3.23	0.73	1.98	2.44	2.05	2.25	1.45	1.0	1.22	0.57	0.46	0.52	0.08	0.12	0.10
N_2	3.67	1.28	2.48	3.05	1.47	2.26	1.20	0.75	0.97	0.43	0.56	0.50	0.07	0.11	0.09
N_3	3.45	1.72	2.59	2.79	1.31	2.05	1.34	0.82	1.08	0.37	0.44	0.41	0.04	0.03	0.03
N_4	4.43	1.24	2.84	2.76	1.36	2.06	1.20	1.29	1.25	0.63	0.52	0.58	0.06	0.18	0.12
N_5	5.51	1.11	3.31	2.19	1.4	1.80	1.68	2.43	2.06	0.61	0.30	0.45	0.06	0.17	0.11
N_6	4.21	1.05	2.63	4.08	1.79	2.94	3.10	1.63	2.37	0.36	0.44	0.40	0.07	0.13	0.10
Mean	4.08	1.19		2.88	1.56		1.66	1.32		0.50	0.45		0.06	0.12	
	SE±	*C.D*		*SE±*	*C.D*		*SE±*	*C.D*		*SE±*	*C.D*		*SE±*	*C.D*	
N	0.26	0.81*		0.22	0.69^{NS}		0.40	1.25^{NS}		0.05	0.16^{NS}		0.03	0.08^{NS}	
C	0.16	0.49**		0.08	0.26**		0.23	0.72^{NS}		0.03	0.09^{NS}		0.02	0.06*	
N at C	0.38	1.09^{NS}		0.26	0.78**		0.57	1.66^{NS}		0.07	0.22^{NS}		0.04	0.12^{NS}	
C at N	0.39	1.19		0.21	0.64		0.57	1.76^{NS}		0.07	0.23^{NS}		0.04	0.14	

Repeated measures analysis of variance(RMAV)

	N	*C*	*T*	*NC*	*NT*	*CT*	*NCT*
SE±	0.05	0.03	0.07	0.07	0.17	0.10	0.47
C.D.	0.11*	0.06*	0.14**	0.15^{NS}	0.33**	0.19**	0.93**

1,2,3 & 4. Refer Appendix 1.1

Appendix 2.7

Dry matter production (kg ha^{-1}) of sole pigeonpea (S) and intercropped pigeonpea (IC), 1997.

Treatment[3]	Vegetative stage														
	19[1]			28			45			61			75		
	S	IC	Mean	S	IC	Mean	S	IC	Mean	S	IC	Mean	S	IC	Mean
N_1	15	13	14	74	34	54	184	81	133	671	178	425	1440	172	806
N_2	15	17	16	49	48	48	200	89	145	677	118	398	1516	217	866
N_3	13	14	14	81	43	62	200	50	125	658	151	405	1770	259	1014
N_4	15	13	14	57	38	47	213	75	144	746	126	436	1220	355	787
N_5	16	14	15	55	54	54	267	122	195	807	155	481	853	321	587
N_6	14	14	14	59	48	53	303	125	214	1056	336	696	1280	359	820
Mean	15	14		62	44		228	90		769	177		1346	280	
	SE±	*C.D*[2]		*SE±*	*C.D*		*SE±*	*C.D*		*SE±*	*C.D*		*SE±*	*C.D*	
N[4]	0.96	3.01^{NS}		3.21	10.12^{NS}		17.0	53.6**		45.5	143.3**		83.1	261.8^{NS}	
C	0.63	1.93^{NS}		2.08	6.40**		8.1	24.9**		25.4	78.1**		42.1	130.0**	
N at C	1.45	4.24^{NS}		4.83	14.2**		22.0	65.0**		63.2	186.0**		110.5	325.1**	
C at N	1.53	4.76		5.09	15.7		19.8	61.1		62.1	191.4		103.1	317.7	

Treatment[3]	Flowering stage						Pod development & maturity stage								
	113			137			154			178			193		
	S	IC	Mean	S	IC	Mean	S	IC	Mean	S	IC	Mean	S	IC	Mean
N_1	4798	1765	3281	5317	2097	3707	7719	2231	4975	7410	3645	5528	6894	3459	5177
N_2	4443	1321	2882	5342	3290	4316	7248	3115	5182	6535	4156	5346	6315	3543	4929
N_3	5226	842	3034	5803	3032	4418	7784	3382	5583	7574	3673	5623	6624	3005	4814
N_4	5603	1203	3403	5907	2582	4245	7862	3148	5505	9348	4050	6699	6410	4107	5259
N_5	6585	1190	3888	7508	3179	5344	9456	3512	6484	7027	4827	5927	6600	4761	5665
N_6	5559	1186	3373	6148	3129	4639	9210	4270	6740	8270	5100	6685	7656	4762	6209
Mean	5369	1251		6004	2885		8213	3276		7694	4242		6750	3935	
	SE±	*C.D*		*SE±*	*C.D*		*SE±*	*C.D*		*SE±*	*C.D*		*SE±*	*C.D*	
N	396.0	1248^{NS}		312	983*		434	1367*		335	1056^{NS}		454	1432^{NS}	
C	207.8	640**		180	553**		254	783**		231	713**		176	542**	
N at C	535.1	1573^{NS}		441	1293*		618	1813^{NS}		522	1533^{NS}		547	1625^{NS}	
C at N	509.0	1568		440	1355		623	1918		567	1947		431	1328	

Repeated measures analysis of variance(RMAV)

	N	*C*	*T*	*NC*	*NT*	*CT*	*NCT*
SE±	82	63	109	136	266	159	382
C.D.	257*	194*	301**	420^{NS}	736**	440**	1060^{NS}

1,2,3 & 4. Refer Appendix 1.1

Nitrogen uptake (Kg ha^{-1}) by sole pigeonpea (S) and intercropped pigeonpea (IC) 1997.

Treatment[3]	Vegetative stage												Flowering stage		
	28[1]			45			61			75			113		
	S	IC	Mean	S	IC	Mean	S	IC	Mean	S	IC	Mean	S	IC	Mean
N_1	2.63	1.21	1.92	9.1	2.5	5.8	27.9	5.2	11.0	48.6	5.8	27.2	149	50	100
N_2	1.96	1.76	1.86	3.5	4.3	3.9	29.6	4.5	17.1	55.1	6.3	30.7	137	38	88
N_3	2.79	1.56	2.18	7.5	1.8	4.6	30.2	6.5	18.4	52.2	7.8	30.0	166	22	94
N_4	2.03	1.24	1.64	8.1	2.0	5.0	29.8	6.2	18.0	36.8	11.2	24.0	172	41	106
N_5	2.09	2.04	2.07	7.2	3.8	5.5	29.8	5.4	17.6	29.2	10.6	19.9	166	30	98
N_6	2.26	1.58	1.92	9.2	4.8	7.0	26.9	6.9	16.9	41.9	13.0	27.4	157	42	100
Mean	2.30	1.56		7.4	3.2		29.0	5.8		44.0	9.1		158	37	
	SE±	*C.D*[2]		*SE±*	*C.D*		*SE±*	*C.D*		*SE±*	*C.D*		*SE±*	*C.D*	
N[4]	0.16	0.49^{NS}		0.69	2.18^{NS}		2.12	6.69^{NS}		3.55	11.2^{NS}		10.8	34.2^{NS}	
C	0.10	0.29**		0.35	1.07**		1.19	3.65**		2.01	6.2**		6.6	20.5**	
N at C	0.23	0.67^{NS}		0.92	2.70**		3.0	8.67**		4.97	14.6^{NS}		15.8	46.3^{NS}	
C at N	0.23	0.72		0.85	2.62		2.90	8.95		4.92	15.2		16.3	50.1	

Treatment[3]	Flowering stage			Pod development & maturity stage								
	137			154			178			193		
	S	IC	Mean	S	IC	Mean	S	IC	Mean	S	IC	Mean
N_1	154	87	136	181	54	118	94	56	75	91	48	70
N_2	220	68	144	200	65	133	100	45	73	100	58	79
N_3	240	83	161	223	84	154	126	70	98	104	65	85
N_4	184	45	109	192	100	146	119	46	83	103	65	84
N_5	181	98	139	232	128	180	96	79	88	104	72	88
N_6	181	94	127	266	121	194	128	88	108	115	78	97
Mean	193	79		216	92		111	64		103	64	
	SE±	*C.D*		*SE±*	*C.D*		*SE±*	*C.D*		*SE±*	*C.D*	
N	9.9	31.3^{NS}		18.7	59.0^{NS}		7.4	23.4*		6.38	20.1*	
C	8.3	25.5**		9.4	28.9**		4.2	12.9**		2.38	7.3**	
N at C	17.4	51.3^{NS}		24.8	72.9^{NS}		10.4	30.5^{NS}		7.59	22.6^{NS}	
C at N	20.3	62.4		22.9	70.7		10.3	31.7		5.82	17.9	

Repeated measures analysis of variance(RMAV)

	N	*C*	*T*	*NC*	*NT*	*CT*	*NCT*
SE±	2.6	1.7	3.6	3.9	8.7	5.1	12.4
C.D.	8.1*	5.1*	10.0**	11.9^{NS}	24.2**	14.1**	34.4^{NS}

1,2,3 & 4. Refer Appendix 1.1

Appendix 2.9

Phosphorus and potassium uptake (kg ha^{-1}) of Soybean & pigeonpea at harvest 1996 & 1997

	Pigeonpea 1997						Pigeonpea 1996		
	P			K			K		
Treatment[3]	S[1]	IC	Mean	S	IC	Mean	S	IC	Mean
N_1	7.6	3.6	5.6	48.7	18.0	38.3	65.9	51.3	58.6
N_2	8.7	4.9	6.8	51.2	23.8	41.5	65.0	55.4	60.2
N_3	8.5	4.9	6.7	56.5	25.2	40.8	78.6	64.0	71.3
N_4	8.4	4.5	6.5	59.6	29.4	44.5	84.5	63.9	74.2
N_5	8.8	5.7	7.8	60.4	23.2	41.8	90.6	59.6	75.1
N_6	9.5	4.4	7.0	54.6	30.8	42.7	88.4	66.0	77.2
Mean	8.6	4.7		56.5	25.1		78.8	60.0	
	SE±	*C.D*[2]		*SE±*	*C.D*		*SE±*	*C.D*	
N[4]	0.43	1.37**		2.50	7.87**		3.2	10.0*	
C	0.34	1.06**		1.98	6.09**		2.4	7.5**	
N at C	0.74	2.16**		4.24	12.5^{NS}		5.3	15.6^{NS}	
C at N	0.84	2.59		4.84	14.9		6.0	18.5	

1. S= sole crop; IC= intercrop
2. C.D. at (0.05)
3&4. Refer Appendix 1.1

Appendix 2.10

Leaf area index (LAI) of sole pigeonpea (S) and sorghum/pigeonpea (IC) systems, 1997.

Treatment[3]	Vegetative stage														
	19[1]			28			45			61			75		
	S	IC	Mean	S	IC	Mean	S	IC	Mean	S	IC	Mean	S	IC	Mean
N_1	0.03	0.21	0.12	0.09	1.43	0.76	0.22	2.23	1.22	0.91	2.36	1.64	1.64	2.57	2.10
N_2	0.02	0.25	0.14	0.07	1.51	0.79	0.08	2.45	1.27	1.04	3.30	2.17	1.84	2.54	2.19
N_3	0.02	0.25	0.13	0.12	0.98	0.55	0.26	2.40	1.33	0.66	3.24	1.95	1.37	2.81	2.09
N_4	0.03	0.30	0.16	0.08	1.95	1.01	0.26	2.06	1.16	0.41	2.75	1.58	1.29	2.82	2.06
N_5	0.03	0.26	0.14	0.1	1.28	0.70	0.32	1.58	0.95	0.87	3.06	.197	1.38	2.57	1.98
N_6	0.03	0.25	0.14	0.11	1.74	0.93	0.27	3.14	1.7	1.07	3.57	2.32	1.44	3.54	2.49
Mean	0.03	0.25		0.10	1.49		0.24	2.31		0.83	3.05		1.49	2.81	
	SE±	*C.D*[2]		*SE±*	*C.D*		*SE±*	*C.D*		*SE±*	*C.D*		*SE±*	*C.D*	
N[4]	0.0.14	0.044^{NS}		0.12	0.40^{NS}		0.23	0.71^{NS}		0.17	0.54^{NS}		0.19	0.60^{NS}	
C	0.008	0.024*		0.07	0.21**		0.14	0.44**		0.07	0.22**		0.07	0.23**	
N at C	0.019	0.057		0.17	0.51^{NS}		0.33	0.98^{NS}		0.21	0.62		0.23	0.68	
C at N	0.019	0.058		0.17	0.52		0.35	1.07		0.17	0.53		0.18	0.55	

Treatment[3]	Flowering stage						Pod development & maturity stage								
	113			137			154			178			193		
	S	IC	Mean	S	IC	Mean	S	IC	Mean	S	IC	Mean	S	IC	Mean
N_1	3.23	2.59	2.91	2.44	2.05	2.25	1.45	1.00	1.23	0.57	0.46	0.52	0.08	0.12	0.10
N_2	3.67	2.50	3.09	3.05	1.57	2.31	1.20	0.75	0.98	0.43	0.56	0.50	0.07	0.11	0.09
N_3	3.45	2.63	3.04	2.79	1.31	2.05	1.34	0.82	1.08	0.37	0.44	0.41	0.04	0.03	0.03
N_4	4.43	2.94	3.69	2.76	0.96	1.86	1.20	0.89	1.05	0.63	0.52	0.58	0.06	0.18	0.12
N_5	5.51	3.67	4.59	2.19	1.70	1.94	1.68	1.43	1.56	0.61	0.30	0.45	0.06	0.17	0.11
N_6	4.21	3.51	3.86	4.08	1.79	2.94	3.10	1.63	2.37	0.36	0.44	0.40	0.07	0.13	0.10
Mean	4.08	2.97		2.88	1.56		1.66	1.09		0.50	0.45		0.06	0.12	
	SE±	*C.D*		*SE±*	*C.D*		*SE±*	*C.D*		*SE±*	*C.D*		*SE±*	*C.D*	
N	0.32	1.02*		0.22	0.69^{NS}		0.40	1.25^{NS}		0.05	0.16^{NS}		0.03	0.08^{NS}	
C	0.16	0.49**		0.08	0.26**		0.23	0.72^{NS}		0.03	0.09^{NS}		0.02	0.06*	
N at C	0.43	1.25		0.26	0.78**		0.57	1.66^{NS}		0.07	0.22^{NS}		0.04	0.12^{NS}	
C at N	0.39	1.21		0.21	0.63		0.57	1.75		0.07	0.23		0.04	0.14	

Repeated measures analysis of variance(RMAV)

	N	*C*	*T*	*NC*	*NT*	*CT*	*NCT*
SE±	0.07	0.03	0.08	0.09	0.21	0.12	0.29
C.D.	0.23*	0.10^{NS}	0.23**	0.28^{NS}	0.57**	0.32**	0.80*

1,2,3 & 4 Refer Appendix 1.1

Appendix 2.11

Dry matter production of Sorghum 1997

Treatment[3]	19[1]	28	45	61	75	95
N_1	113	783	2830	5611	8071	11395
N_2	132	849	2986	7302	9273	12016
N_3	113	875	5178	5523	7999	13033
N_4	150	983	2336	6185	8429	12114
N_5	123	827	2193	6319	9917	13276
N_6	127	914	3148	7940	9904	14219
Mean	126	872	2612	6480	8932	12676
SE±	9.8	109	251	564	730	747
CD[2]	30.8^{NS}	343*	792^{NS}	1776^{NS}	2299*	2355^{NS}

Repeated measures analysis of variance(RMAV)

	N[4]	*T*	*NT*	*TN*
SE±	210	225	546	552
CD	661*	624**	1512^{NS}	1528

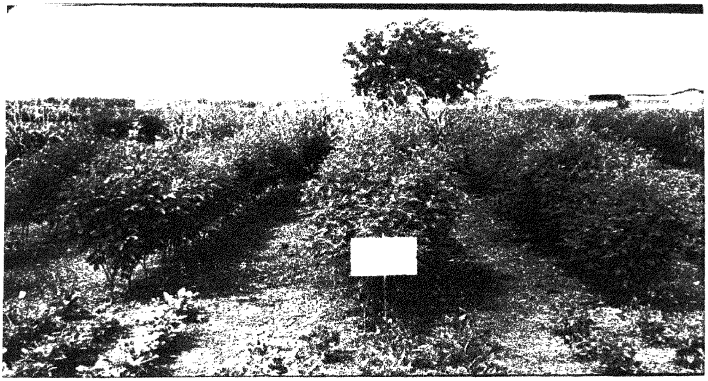
2.12b. Nutrient uptake (kg ha-1) of Sorghum 1996.

	N					P	K
Treatment[3]	28[1]	45	61	75	95	95	95
N_1	23	89	129	113	90	15	37
N_2	25	84	154	99	116	13	43
N_3	28	58	77	71	133	14	36
N_4	28	58	112	120	139	14	41
N_5	24	52	108	143	158	13	39
N_6	30	79	129	169	153	19	44
Mean	26	70	118	121	131	14	40
SE±	2.9	98	17.1	14.6	13.8	1.6	3.0
CD[2]	9.0^{NS}	30.7^{NS}	54.0^{NS}	46.5*	43.5*	5.1^{NS}	9.3^{NS}

Repeated measures analysis of variance(RMAV)

	N[4]	*T*	*NT*	*TN*
SE±	4.3	5.1	12.0	13
CD	13.5*	14.5**	34.0**	36

1. Days after emergence (DAE)
2. C.D. at (0.05)
3&4. Refer Appendix 1.1




20 - N
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