EVALUATION OF LAND MANAGEMENT PRACTICES FOR NUTRIENT BUDGETING AND DYNAMICS IN SOYBEAN-BASED CROPPING SYSTEMS IN VERTIC INCEPTISOLS

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Miss K.P.NAGAVALLEMMA has satisfactorily prosecuted the course of research and that the thesis entitled **EVALUATION OF LAND MANAGEMENT PRACTICES FOR NUTRIENT BUDGETING AND DYNAMICS IN SOYBEAN-BASED CROPPING SYSTEMS IN VERTIC INCEPTISOLS** submitted is the result of original research work and is of sufficiently high standard to warrant its presentation to the examination. I also certify that the thesis or part thereof has not been previously submitted by her for a degree of any University.

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CERTIFICATE

This is to certify that the thesis entitled ***"EVALUATION OF LAND MANAGEMENT PRACTICES FOR NUTRIENT BUDGETING AND DYNAMICS IN SOYBEAN-BASED CROPPING SYSTEMS IN VERTIC INCEPTISOLS" SUBMITTED*** *in partial fulfillment of the requirements for the degree of* ***Doctor of Philosophy (Agriculture)*** *in* ***SOIL SCIENCE AND AGRICULTURAL CHEMISTRY*** *of the* ***Acharya N.G. Ranga Agricultural University,*** *Hyderabad is a record of the bonafied research work carried out by* ***Miss. K.P.NAGAVALLEMMA*** *under my guidance and supervision. Students Advisory Committee has approved the subject of the thesis.*

No part of the thesis has been submitted for any other degree or diploma. The published part has been fully acknowledged. The author of the thesis has duly acknowledged all assistance and help received during the course of the investigations.

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(K.P. NAGAVALLEMMA)

DECLARATION

I, Ms. K.P. Nagavallemma hereby declare that this thesis entitled " **EVALUATION OF LAND MANAGEMENT PRACTICES FOR NUTRIENT BUDGETING AND DYNAMICS IN SOYBEAN BASED CROPPING SYSTEMS IN VERTIC INCEPTISOLS** " is a bonafide record of work done by me during the period of research at ICRISAT, Patancheru. This thesis has not formed in whole or in part, the basis for the award of any degree or diploma.

Vallily

(K.P.Nagavallemma)

Date: 17-10-2000

LIST OF ABBREVIATIONS

C : carbon

CD : Critical difference

cm : centimeter

°C : celcius in degrees.

d : day

dSm^{-1} : deci Siemen per metre

et al. : et alibi (and others)

EC : Electrical conductivity

Fig. : Figure

FYM : Farmyard manure

G : gram

Ha : hectare

h : hour

Kg : kilogram

K : Potassium

L : Litre

M : metre

M ha : million hectares

M t million tonnes

N : nitrogen

OC : organic carbon

Ppm : parts per million

P : phosphorus

q ha^{-1} : quintal per hectare

S.Ed : standard error deviation

Sq. m : square metre

$>$: greater than

$<$: less than

% : percentage

µg : micrograms

µmol : micromoles

wk : week

@ : at the rate of

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ABSTRACT

Vertic Inceptisols cover over 60 million ha of landscape in central-peninsular India. These soils are highly prone to land degradation due to their mineralogical-textural composition, position on toposequences, and the prevalence of the practice of summer (rainy cropping season) fallowing Of late, however, soybean cultivation has been adopted on a wide-scale on these soils, but the yield of the crop are low. Productivity of the soybean-based land use systems on these soils need to be improved and sustained at higher levels by a better management of natural resources in particular soil, nutrients and water. Soil erosion also needs to be reduced by the introduction of improved land management practices. Experiments were, therefore, conducted during the rainy and post-rainy seasons in 1997 and 1998, on an operational watershed scale, on a Vertic Inceptisol watershed [Black soil watershed BW7] at the ICRISAT center, Patancheru, near Hyderabad, India to study: (1) The effect of two landform treatments, namely flat and broadbed and furrow (BBF) systems and two soil depths namely shallow (<50 cm) and medium-deep (>50 cm) on nutrient (N, P and K) budgets of soybean-based cropping systems (soybean/pigeonpea and soybean+chickpea); (2) Soil nitrogen and carbon dynamics, systems productivity and Vesicular arbuscular mycorrhizal colonization in crops roots; (3) and Laboratory experiments were conducted [in a Vertic Inceptisol] to study the patterns of C and N release from pigeonpea [*Cajanus cajan* (L.)] and *Glyricidia sepium* residues.

It was observed that soil properties viz., soil available N, soil respiration, microbial biomass C and microbial biomass N were significantly influenced by the landform and soil depth treatments under sole and intercropped soybean, pigeonpea and sequentially cropped chickpea systems during both years of the investigation. Flat landform showed a higher available soil N content than the BBF at both the presowing and the vegetative stages in

soybean during 1997 but soil under BBF landform had more available N content than the flat at the vegetative stage of soybean crop during 1998. The medium-deep soil showed a significantly higher available N content compared to the shallow soil under soybean during the rainy season in 1997, but had no significant effect in the year 1998. Landform, soil depth treatments and their interaction had no significant effect on available soil N content under pigeonpea (except at the harvest stage in 1997) and under chickpea during post-rainy seasons of both the experimental years. Mean net N mineralization during the two years was not influenced significantly by landform treatments (except at the presowing stage in soybean in 1998) or by soil depths (except at the harvest stage in pigeonpea in 1997) under soybean, pigeonpea and chickpea crops.

Nodulation of crops grown in the sole and intercropped soybean, pigeonpea and chickpea cropping systems was significantly influenced by landform and soil depth treatments. However, landform treatments had no significant effect on nitrogenase activity of sole and intercropped soybean, pigeonpea and chickpea crops during the two years of investigations. Sole soybean showed a maximum nitrogenase activity (195 μmol C_2H_4 m^{-2} h^{-1}) compared to that of the intercropped soybean (84 μmol C_2H_4 m^{-2} h^{-1}) at the pod development stage during 1997.

Nitrogen fixed by soybean and chickpea crops as estimated by N-difference and ^{15}N isotope dilution methods, was not affected significantly by landform configuration during both the years of investigation. However, the effect of landform system on nitrogen fixed by pigeonpea as estimated with N-difference and ^{15}N isotope dilution methods were significant during 1998. Pigeonpea grown on BBF landform fixed a significantly higher amount of N compared the N fixed by pigeonpea crop grown on flat-bed system. The soybean crop grown in the medium-deep soil fixed a significantly more amount of N compared to the crop grown in the shallow soil during 1998. In the chickpea crop, this increase was 1.4 and 1.5 times more during 1997 and 1998. Sole soybean crop fixed a significantly higher nitrogen compared to the intercropped soybean as estimated with N-difference and ^{15}N isotope dilution methods.

The uptake of N and P by soybean, pigeonpea and chickpea crops showed a linear increase with the crop growth and development upto the pod development stage and it then decreased at the harvest stage of the crops. The landform and soil depth treatments significantly influenced N and P uptake by the sole and intercropped soybean, pigeonpea and chickpea crops at some of the stages of crop growth and development.

The amount of runoff of rain water observed on flat landform treatment during the rainy cropping season (1998) was higher (287 mm, 33% of seasonal rainfall) compared to the BBF landform treatment (225 mm, 26% seasonal rainfall). The amount of NO_3^- N lost in runoff water was larger in the flat (13 kg N ha^{-1}) compared to the BBF landform (10 kg N ha^{-1}).

In soybean crop grown on the two landforms, it was observed that the total drymatter yield varied significantly but the seed yield remained more or less the same during rainy season in 1997. The higher total drymatter (2650 kg ha^{-1}) and seed yield (910 kg ha^{-1})

of soybean was observed on the BBF landform on the Vertic Inceptisols. In soybean and pigeonpea crops, soil depth did not show any significant effect on drymatter and seed yield in both the years of investigation. However, in chickpea, soil depth effect was significant on total drymatter and seed yield. The total system productivity (seed yield) of soybean + chickpea was significantly higher (1.6 and 1.2 times more) than that of soybean / pigeonpea cropping during1997 and 1998 respectively.

The ^{15}N isotope dilution method showed a less negative nitrogen balance (-6 kg ha^{-1}) under the BBF landform compared the flat bed system (-77 kg ha^{-1}). Further, N-difference method results showed that the BBF system influenced the nitrogen balance positively (+55 kg ha^{-1}) but flat bed treatment had a negative N balance (-19 kg ha^{-1}). The BBF landform resulted in a better positive P balance (+18 kg ha^{-1}) compared with the flat landform (+12 kg ha^{-1}). The depletion of K was more (-48 kg ha^{-1}) in case of flat landform than the BBF system (-42 kg ha^{-1}).

In soybean and pigeonpea crops it was noted that root colonization by VAM varied significantly under the two landform treatments. Shallow soil recorded a higher root colonization in pigeonpea (17%) and in chickpea (25%) during 1997.

Laboratory experiment was conducted to study N mineralization showed that the cumulative mineral N (NH_4^+ + NO_3^-) content increased significantly from 3.2 mg N kg^{-1} at 5 days after incubation to 105 mg N kg^{-1} soil at 150 days after incubation. A higher mineralization of soil nitrogen (121 mg N kg^{-1}) was observed when *Glyricidia* leaves were applied at the soil surface compared to all other treatments at 150 days after incubation.

N mineralization studies showed that the time required to mineralize 25 mg N kg^{-1} soil varied from 18 to 34 weeks using the exponential model. The first order rate constant of N mineralization (K) varied from 0.0015 to 0.0104 d^{-1}, and it was highest when *Glyricidia* leaves were applied at surface to the soil. Another laboratory experiment was also conducted to study C mineralization showed that the amount of cumulative CO_2 respired from the incubated soil samples varied significantly with organic residues application during 24 weeks of incubation; it ranged from 307 to 1466 µg C g^{-1} soil. The first order rate constant of C mineralization (K) varied from 0.114 to 0.159 wk^{-1}. Time required to mineralize 50% of potential mineralizable carbon (C_o) varied from 4 to 6 weeks as estimated by the exponential model.

Introduction

CHAPTER I

INTRODUCTION

Two-thirds of the cultivated area (142 M ha) in India is under rainfed farming. These areas are inhabited by poor farmers and are relatively less endowed with natural resources for productive agriculture. Rainfed agriculture has been one of the priority areas of development of the Government of India (GOI) since independence. However, the efforts became more focused during the last three 5-years plans of the GOI. Development of rainfed areas is now being taken up on watershed basis involving the participation of beneficiaries. It involves a central focus on water conservation because inadequacy of rainfall results in partial or total failure of agricultural crops in dryland farming areas. Watershed management involves a holistic approach to rainfed agriculture. Of the several components of watershed development, the adoption of appropriate farming systems, soil conservation measures and water storage structure have received the highest priority. When appropriately applied these methods of improved rainfed farming have substantially improved the income of farmers and productivity of lands, an example is the Tejpura watershed in Jhansi, Uttar Pradesh (Umarani, 1999).

Soybean (*Glycine max L.)* has become a miracle crop of the twentieth century and is often designated as 'golden bean'. It is a triple beneficiary crop which contains about 20% of oil and 38-42% high quality protein, possessing high level of essential amino acids, and it fixes atmospheric nitrogen (N) in the soil at the rate of 65-100 kg ha^{-1} in symbiotic partnership with *Rhizobium*. Soyabean yields more usable proteins per unit area than any cultivated crop, at least three times more than rice (*Oryza* *sativa L.)*, wheat (*Triticum aestivum L.*), or maize (*Zea mays L.*). Due to its multifaceted advantages, soybean has progressed fast as an oilseed crop after World War (Magar and Deshmukh, 1999). Soybean ranks top among the oilseed crops and contributes one third of the total supply of the world's vegetable oil pool (Quayum *et al.*, 1985). The present area under soybean in India is estimated to be about 6 million ha with a production of 5 million tonnes. With an increase in soybean area of 0.5 million ha every year, it is estimated that by 2001, the crop will stabilize at 8 million ha with production of 12 million tonnes (NRCS, 1998). The average yield of soybean in India (900 kg ha^{-1}) is only about 50% of the world average (1900 kg ha^{-1}) and 70% of Asian average (1300 kg ha^{-1}). With the adoption of improved technology for soybean cultivation, Indian farmers can also obtain yield levels higher than the world average of about 2 t ha^{-1} (Magar and Deshmukh, 1999).

Farmers are expanding soybean-based agriculture on Vertisols and associated black soils. Vertic Inceptisols, which occur in association with Vertisols in the toposequences, occupy about 60 M ha out of 72 M ha Vertisols in India (Sehgal and Lal, 1988). These soils have similar physical and chemical properties as the Vertisols, except that these are of shallow to medium depth (25-60 cm depth of black soil material) and somewhat lighter in texture. These occur on slopes not exceeding 5% and are prone to soil erosion. These soils have low to medium available water holding capacity (100-200 mm plant extractable water) which varies with soil depth. The productivity of the cropping systems in these soils is threatened because of low water holding capacity, low organic matter status, poor biological nitrogen fixation (BNF), loss of nutrients and beneficial organisms resulting in degradation of soil. In order to sustain the productivity of these soils, there is an urgent need to identify suitable cropping systems and land management practices. In India, soybean area is increasing rapidly @ 3-5% annually predominantly in Vertic Inceptisols. A study reported by the International Soil Resource Information Center (ISRIC) has shown that the soybean-growing areas in India are highly degraded due to physical, chemical and biological degradation. Soil erosion is particularly high in Vertisols and associated soils that are prone to sheet and gully erosion under tropical monsoonal ecologies.

Soybean-based systems are some of the most promising cropping systems that sustain the productivity and improve the economic status of farmers in rainfed areas. The deep penetrating root system of soybean enables the plants to utilize the limited available soil moisture more efficiently than other crops under moisture stress conditions, and also contributes more substantially to loosening up the soil. The crop enriches the soil fertility and improves the physical characteristics of the soil by its ability to fix atmospheric nitrogen in symbiotic association with *Rhizobium* and by increasing organic matter through leaf fall. Soybean is tolerant to excessive soil moisture conditions than other pulse and oilseed crops (Panjab Singh, 1999). Since soybean is a legume with high nitrogen fixing capacity, it not only meets its own N requirement, but it leaves behind about 30-40 kg N ha^{-1} for the succeeding crop. It exhibits minimum interference with the associated crop and withstands shade, low water availability, and nutrient stress when grown with other crops (Bhatnagar, 1991). Soybean is a good cover crop which helps in reducing topsoil erosion and runoff. Due to its broad leaves, it intercepts the raindrops and thus reduces the erosivity of rains. However, to obtain high crop yield, provision of adequate drainage during the growing season is important particularly in Vertisols (Singh *et al.*, 1999).

Annual rainfall in Central India and in Andhra Pradesh where the Vertisols occur, varies from 750 to 1500 mm and almost 80% of this rainfall is received from June until September. Total rainfall received during these four months often exceeds the water requirement of crops grown during the rainy season. This necessitates the need to develop technologies that use the excess water for sustaining agricultural productivity. Various land surface management practices (e.g., tillage, ridges and furrows, broadbed and furrows etc) for Vertisols have to be investigated in India to control the flow of excess rainwater, thereby minimizing soil erosion and increasing infiltration (Pathak *et al.*, 1985; Gupta and Sharma, 1994). In view of this, the present study was undertaken with the following objectives:

1. To study the nutrient (N,P and K) budgeting at watershed level in different land management practices and soil depths by quantifying the contribution from biological nitrogen fixation, nutrient uptake and nitrogen loss through runoff and deep drainage in Vertic Inceptisols under soybean-based cropping system.
2. To study the nitrogen (mineral N, biomass N and net mineralization) and organic matter dynamics (organic carbon and biomass C) in different land management practices and soil depths in Vertic Inceptisols under soybean-based cropping systems

3. To study the nitrogen release in soil and uptake by the crop from *Glyricidia* loppings added to Vertic Inceptisols in different land management practices and soil depths under soybean-based cropping systems and *in vitro* studies.
4. To study the mycorrhizal colonization in different land management practices and soil depths in Vertic Inceptisols under soybean-based cropping systems.

CHAPTER II

REVIEW OF LITERATURE

The literature related to the landform management systems, soil chemical and biological properties, nutritional budgeting (BNF, nutrient uptake and runoff), crop yields, soybean-based cropping system, Vesicular arbuscular-mycorrhizal fungi (VAMF) and *in vitro* studies viz , Nitrogen mineralization potential (N_o) and carbon mineralization potential (C_o)was collected The literature was collected on broad view basis of my work because limited literature is available

2.1 Importance of Land Management Systems

Ryan and Sarin (1981) studied on the Economics of technology options for Vertisols in the relatively dependable rainfall regions of the Indian semi-arid tropics Since 1976 research has been conducted at ICRISAT Center, Patancheru, on operational scale Vertisol watersheds and sub watersheds of from 1 to 5 ha Joint research of the farming systems and economics program from 1976 to 1981 has shown that such an improved watershed-based technology based on maize inter-cropped with pigeonpea can increase profits by about 600% compared with a traditional system based on rainy season fallow followed by postrainy season sorghum and chickpea This improved system utilizing graded broad beds and furrows (BBF) has generated profits averaging Rs 3650 ha^{1} yr^{-1} over 5 years than traditional system (Rs 500^{-1} ha yr^{-1}) on the Vertisols at ICRSIAT center The graded broad beds and furrows increase profits by about 30% compared with a flat cultivation system using a maize / pigeonpea intercrop With the maize-chickpea sequential system the graded broad beds and furrows have a 20% profit advantage

In 1982-83, the on-farm test was repeated at Tadanpally and extended further to other Vertisol areas with problems different from those at ICRISAT Center (ICRISAT, 1984) At two locations (Farhatabad (Karnataka) and Begumgunj (Madhya Pradesh),) ICRISAT scientists directly supervised the tests, but at other locations, they were conducted by the respective state departments of agriculture with advice from ICRISAT as required Farhatabad has an annual rainfall of 730 mm and Begumgunj 1100 mm, early-season rains are much more assured at Begumgunj than at Farhatabad The relative profitability of the improved technology (weighted over all the watershed cropping systems) was low at Begumgunj, compared with other locations Yet the trial gave encouraging results, with the majority of farmers recognizing the potential of the system Moreover, some cropping systems involving soybean such as soybean/pigeonpea, emerged as the most promising (gross profit Rs 3535 ha^{1}) The marginal rate of return calculated on the basis of these cropping systems was 175% At Farhatabad, where the average rainfall is lower than at ICRISAT center and less dependable, sole pigeonpea produced gross returns of Rs 4186 ha^{1}, followed by mungbean-sorghum and pigeonpea, which gave only 2186 ha^{1} At Tadanpally, where rainfall is similar to that at ICRISAT center, the sorghum, pigeonpea inter-crop produced the highest gross profits (Rs 4589^{1}) In 1983-84, the on-farm verification trials were continued at Farhatabad and Begumgunj under the direct supervision of ICRISAT At Farhatabad, rains started one month later than normally expected, resulting in the loss of viability in the dry seeded crops and poor plant stand However, water logging caused by subsequent continuous rains showed the importance of BBF in draining excess water The cropping system that gave the highest gross profits was sesame / pigeonpea (Rs 7916 ha ^{1}) followed by sole pigeonpea (RS 5228 ha ^{1}) The groundnut / pigeonpea inter-crop (Rs 3524 ha ^{1}) gave higher returns than blackgram / pigeonpea (Rs 2092 ha ^{1})

El-swaify *et al* (1985) found the installing a land configuration within the field which provides adequate (in situ) control of runoff and erosion, improves, subsurface drainage for a favorable aeration status and workability of soil in the seed or root environment, and defines the traffic and cropping zones within the field is the second step of ICRISAT's improved technology for SAT Vertisols A broadbed and furrow (BBF) system involving graded wide beds separated by furrows which drain into grassed waterways appears to fulfill these requirements satisfactorily BBF was successfully tested by ICRISAT both in research and operational scale studies at farmers fields than flat bed system When this system is maintained in place on a long-term basis, a progressive improvement in soil tilth occurs in the bedzone For instance the penetration resistance in this zone was significantly lower than its counterpart in flat systems This facilitates land preparation during the summer season and dry sowing of the rainy season crop, both are required steps in the improved technology It also allows deep seed placement for adequate germination under receding moisture conditions when post rainy season planting must be performed Furthermore, air filled porosity in the upper 15cm layer was found to be significantly higher for BBF than for the flat system during wet spells This confirms the effectiveness of the BBF in improving drainage in the seed and root environment of Vertisols

2.2 Soil Chemical and Biological properties

Wani *et al* (1991a) observed that rotations including fababeans as green manure, forages and barley had higher mineral N in soil during the plant growth stages and these treatments had higher proportion (0 43 to 0 50%) of mineral N than total soil N rotations containing oats, barley and forages but not fertilized since 1930 and crop residues were removed Highest mineral N content was observed at 22 days after emergence than compared to 50, 74 and 102 DAE Microbial N content was increased during different stages of barley growth, highest at 102 DAE in all treatments The mean microbial biomass C declined significantly with increasing plant age upto 50 days after emergence, and then increased for the duration of the growth period The carbon respired over 10 days in agro-ecological plot 1[following faba-beans in an 8-year agro-ecological rotation (209 μg g ^{1} soil)] was significantly higher than that in the fertilized Breton treatment Mean mineral N decreased from 35 mg kg ^{1} 22 days after emergence to 4 mg kg ^{1} soil 74 days after emergence with a small increase to 7 mg kg ^{1} soil by 102 days after emergence With increase of plant age, microbial N also increased significantly 22<50 and 74 < 102 days after emergence

Alagarswamy *et al* (1996) evaluated the effect of land surface management practices on the biological and chemical properties of soil in Vertic Inceptisols in BW7 watershed at ICRISAT during rainy season 1995 Surface (0-30 cm) soil samples were collected five times (presowing, 35, 72, 95 and 128 DAS) during the soybean growth period in the rainy season to study biological and chemical properties Mean mineral N content in soil samples from both the landform treatments (BBF and Flat) was similar

(7 6 to8 1 µg N g^{1} soil) Mineral N content increased significantly from 3 0 µg N g^{1} soil for presowing samples to 9 75 µg N g^{1} soil for samples collected 35 DAS Between 35 DAS and 72 DAS, it increased further and then at 95 DAS, it decreased It again increased at the harvesting stage The net N mineralization in soil samples was also similar for both the landform treatments The amount of Net-N mineralized at 35 DAS was 4 5 times more than the amount of N mineralized from samples collected prior to sowing of soybean During 72 DAS net N mineralization decreased significantly as compared to 35 DAS and later increased till the harvesting of soybean The soil respiration (87 to 91 µg C g^{1} soil 10 d^{1}) biomass C (295-297 µg C g^{1} soil) and biomass N (10 to 10 3 µg N g^{1} soil) in surface soil samples were not influenced due to landform treatment Sampling time influenced soil respiration significantly with the highest amount of soil respiration (114 µg C g^{1} soil 10 d^{1}) observed at 95 DAS and it was followed by harvesting stage and presowing stage ≥72 DAS and ≥35 DAS Microbial biomass C in soil remained similar (290 to 292 µg C g^{1} soil) for samples collected prior to sowing and upto 35 DAS and then it decreased to 243 µg C g^{1} soil at 72 DAS It increased to 346 µg C g^{1} soil at 95 DAS and again decreased to 310 µg C g^{1} soil at harvesting stage Microbial biomass N content was maximum (12 4 µg N g^{1} soil) for presowing samples, decreased to 8 4 µg N g^{1} soil at 35 DAS, then increased till 95 DAS and harvesting stage

Deshmukh *et al* (1996) conducted an experiment in Vertic Inceptisol of Akola and studied the biological and chemical properties of soil samples in cotton / mungbean intercropping trial during rainy season 1995 Surface soil samples up to 30 cm depth were collected four times prior to sowing, 56, 69 and155 DAS and analyzed for biological and chemical properties Mean soil respiration increased significantly (P≤0 05) with the increasing crop age up to the harvesting of the mungbean crop Mean microbial biomass C decreased significantly (P≤0 05) at 53 DAS (193 μg C g^{1} soil) as compared to the biomass C prior to sowing of the crop and then increased at the time of mungbean harvesting Mean microbial biomass N decreased from 10 8 μg N g^{1} soil for samples collected prior to sowing to 7 9 μg N g^{1} soil at 53 DAS and then marginally increased at mungbean harvesting stage Mean mineral N content in soil increased upto mungbean harvesting stage (6 7 μg N g^{1} soil) as compared to the mineral N content in soil samples collected prior to sowing of the crop (5 2 μg g^{1} soil) Net N mineralization was similar at all the sampling times (2 9 to 3 2 μg N g^{1} soil 10d^{1}) Patil *et al* (1996) observed mineral N content, net N mineralization and soil respiration in soil samples to a depth of 30 cm were collected three times, i e , presowing, 52 and 66 DAS during rainy season cropping in Vertisols of Solapur Mineral N content in soil across the sampling times was 1 45 times higher in case of soybean +sorghum system than the fallow + sorghum system (9 7 vs 6 6 μg N g^{1} soil) Mean mineral N content decreased to 3 2 μg N g^{1} soil at 52 DAS from 9 4 μg N g^{1} soil at sowing time and again increased to 10 1 μg N g^{1} soil at 66 DAS (at harvest) Decrease in mineral N content at 52 DAS even in the case of fallow plots, which indicated the loss of mineral N most likely by leaching Net N mineralization in surface soil samples was similar in all the cropping systems Mean soil respiration was significantly (P≤0 01) more in case of systems (blackgram + sorghum, soybean + sorghum, and cowpea + sorghum) which had crop during the rainy season than the fallow plots (59 5 to 61 5 vs 48 8 μg C g^{1} soil 10d$^{1)}$

Saran *et al* (1996 b) conducted an experiment during rainy season of 1992 and studied the nutrient budgeting of soybean – safflower system Surface soil samples to a depth of 30 cm were collected three times (prior to sowing, 39 and 98 DAS) and analyzed for biological and chemical properties of soil Mean mineral N content in soil samples decreased significantly ($P \leq 0$ 01) with increasing plant age Highest mineral-N content of 31 mg kg^{-1} soil was observed prior to sowing and it decreased to 8 mg N kg^{-1} soil at 98 DAS Mean soil respiration decreased from 72 µg C g^{-1} soil 10 d^{-1} for presowing samples to 43 µg C g^{-1} soil $10d^{-1}$ for the samples collected at 39 DAS and then increased to 114 µg C g^{-1} soil $10d^{-1}$ at 98 DAS Microbial biomass C in soil was highest (582 µg C g^{-1} soil) prior to sowing of the crop and then it decreased with the plant age till the harvest of the soybean crop (199 µg C g^{-1} soil) Similar trend was observed for microbial biomass N

Saran *et al* (1996a) studied the effect of landform treatments on biological and chemical properties of Vertisol under soybean, rainy season 1995, Indore They found the mineral N content in soil at 28 DAS was highest (10 5 µg N g^{-1} soil) in case of flat treatment followed by ≥ BBF (8 7 µg N g^{1} soil), raised-bed (8 3 µg N g^{-1} soil) and sunken pit of RSB (7 0 µg N g^{-1} soil) The amount of net N mineralized in soil samples was similar in all the landform treatments Soil respiration was highest (65 µg C g^{-1} soil 10 d^{-1}) in the case of sunken pit followed by ≥ raised-bed of RSB (40 µg C g^{-1} soil 10 d^{-1}) and ≥ BBF (25 µg C g^{-1} soil $10d^{-1}$) and flat landform treatment (20 µg C g^{-1} soil 10 d^{-1}). Microbial biomass C was highest (207 µg C g^{-1} soil 10 d^{-1}) in case of flat treatment followed by ≥ BBF (133 µg C g^{-1} soil), ≥ sunken-bed and sunken pit of RSB. Similar trends for microbial N were also observed However, statistically all landforms had similar biomass N content

Wani *et al* (1996) observed the nitrogen behavior during crop growth from a long-term field experiment with eight cropping systems at ICRISAT Asia Center (IAC), India Mineral-N content in surface soil samples collected after the harvest of the ninth season of cropping in the long term crop rotation experiment, showed generally a higher amount of Mineral-N in the soil from legume-based cropping systems than that in nonlegume-based cropping systems Mean mineral N (NO_3^-+NH_4^+) in soil decreased from 8 5 to 5 9 μg g^{-1} soil at 30 days after emergence (DAE), and further decreased to 3 7 μg g^{-1} soil at 58 DAE At harvest at 106 DAE, mean mineral-N content in soil was 3 3 μg g^{-1} soil Mean net N-mineralization in soil was similar to that in samples collected prior to sowing and at 30 DAE, and decreased significantly at 58 DAE and then marginally increased upto harvest The mean net N mineralization across the sampling times in pigeonpea-based systems was 9 to 13 8 times higher (2 10 μg g^{-1} soil $10d^{-1}$) than that in the S-SF-S-SF system (two years, sorghum in the rainy season followed by safflower during postrainy season) Mean microbial-N increased significantly at 58 DAE and either remained unchanged thereafter or increased marginally at harvest stage

Jenson *et al* (1997) examined the temporal variation of soil microbial biomass C and N mineral N, and soil-surface CO_2 flux *in-situ* in two arable soils periodically for a full year after field incorporation of 0, 4 or 8 t biomass ha^{-1} of oil seed rape straw in late summer Both unlabelled and ^{15}N - labelled straw were applied Soil surface CO_2 flux, used as an index of soil respiration, was up to 2 fold higher in the straw-amended treatments than in the unamended treatment at both sites during the first 6-8 weeks, but the general temproal pattern was mainly controlled by soil temperature and soil water content Microbial biomass C and N increased very rapidly after the straw amendments Temporal variations in soil microbial biomass C and N were only within +13-22% of the mean at both sites and in all straw treatments over the one year period Microbial biomass C to N ratios were not significantly different between straw treatments and were relatively constant over time

Wani et al (1997) reported that in the tropics, during dry periods, upward movement of NO_3 takes place due to capillary movement of water, resulting in increased mineral N concentrations in the top soil layer before the sowing of the rainy season crop (Nye and Greenland 1960, Wetselaar 1961 a and b) Frequent drying and wetting of soil is a common feature in the tropics, and results in a flush of mineral N in soil due to accelerated mineralization of labile organic matter fraction (Birch, 1960)

Dinesh *et al* (1998) studied the soil microbial biomass and enzyme activities as influenced by organic manure incorporation into soils of a rice-rice system and found that soils freshly amended and soils previously amended with organic manures registered significantly greater microbial biomass and enzyme activity than the unamended control The microbial biomass and enzyme activity, however, varied with the type of organic manure incorporated in to the soil Except for acid phosphatase, which showed slight inhibition, all the other enzymes were activated to different degrees by organic manure incorporation

Murphy *et al* (1998) reported that pattern of distribution of the microbial biomass and the rate of N transformations were similar for soils collected from (i) a permanent 8 year subterranean clover-based pasture plot located at the east Beverley research annex 21 km east of Beverley, and (ii) from a field previously cropped to wheat for 2 years at the Agriculture WA research Station at Avondale, 8 km west of Beverley, Western Australia There was a rapid decline in microbial biomass C and N and gross N mineralization with soil depth Approximately 55% of the microbial biomass, 70-88% of gross N mineralization, and 46-70% of NH_4^+ consumption was in the surface 0-10 cm in both soils

Ahad and Debnath (1998) studied the effect of some crops namely, rice, maize, soybean and jute on the transformation of nitrogen to available form in the rhizosphere at different stages of growth under field conditions in the District Seed Farm of Bidhan Chandra Krishi Viswavidyalaya, West Bengal, India The rhizosphere soil of all the crop species maintained higher level of NH_4^+, NO_3^-N and total mineralized N ($NH_4^+ + NO_3^-$) than the non-rhizospere soil The interaction between growth stages and species indicated that the sequence of species differences with respect to forms of N did not follow the same trend throughout the entire growth period The mineralization effect of soybean was at par with that of capsularis jute Mineralization was lowest in lowland rice and the effect of olitorius jute, maize and upland rice were at par On an average, the highest amount of mineralized N was maintained at 75 days > at 105 days Growth stage and species interaction was significant At 45 days of growth stage the amount of mineralized N was highest in capsularis jute and lowest in maize, but at 75 days of growth stage the value was highest in soybean and lowest in lowland rice

2.3 Nutrient budgeting (BNF, nutrient uptake , runoff and nutrient balance)

2.3.1 Biological nitrogen fixation

Gibson *et al* (1982) reported the nitrogen-fixation rates by some tropical legumes Nitrogen fixed by *Glycine max* in Senegal was 165 kg ha^{1} and in India 102 kg ha^{1}

Kumar Rao and Dart (1987) studied on comparing nodulation and nitrogen fixation of 11 pigeonpea cultivars of different maturity groups grown on an Alfisol, it was reported that soil moisture deficit might be one of the reasons for the cessation of nitrogenase activity by 100 DAS even though the plants were not apparently drought stressed

Sekhon *et al* (1987) observed that in chickpea 30 kg N ha^{1} applied at post-flowering stage (113 DAS) decreased N_2ase activity but increased nitrate reductase activity and nitrogen content, due to its ability to take up nitrate efficiently during the post flowering stage in Ludhiana

Nambiar *et al* (1988) reported that the environmental factors affecting the nitrogen fixation in legumes Nitrogen fixation follows a diurnal pattern, with nitrogenase activity building up during the dark period Other major factors which influence nitrogen fixation in legumes are soil pH, soil nutrients, soil moisture, soil temperature and light intensity, excess or insufficient soil moisture reduced nitrogen fixation Moisture plays an important role in ensuring migration of rhizobia applied to the seed coat, to the root zone, where they are required to infect the roots and form nodules Nitrogen fixation peaked during the piddling stage and declined at maturity (Nambiar and Dart, 1983)

Peoples and Herridge (1990) reported the percent nitrogen derived from atmosphere (% Ndfa) by some grain legume grown in SAT In sole crops ranged from 17 to 85 for chickpea, 10 to 88 for pigeonpea and 0-95 for soybean The % Ndfa in intercropped pigeonpea ranged from 65 to 96 Schroder (1992) estimated the biological nitrogen fixation in grain legumes (the nitrogen fixation estimates represent averages of several experiments conducted around the world) The nitrogen fixation in *Cajanus cajan* (L) is 224 kg N ha^{1}, in *Cicer-arietinum* (L) is 104 kg N ha^{1} and in *Glycine max* (L) is 88 kg N ha^{1}

Nodulation in mung beans, pigeonpea and soybean grown on broad bed and furrows (BBF) on Vertisols was better than when grown on a flat surface However, improved nitrogenase activity in BBF was found with mung bean and pigeonpea only (Wani *et al*, 1995a) However, in Vertisols, chickpea sown on flatbeds nodulated better than those sown on ridges with the same sowing density (Rupela and Saxena, 1987)

Alagarswamy *et al* (1996) evaluated the effect of land surface management practices on the quantification of biological nitrogen fixation (BNF) in soybean during rainy season 1995 in Vertic Inceptisol (BW7 watershed) at ICRISAT Soybean plants were sampled at 35, 70 and 91 DAS for nodulation and nitrogenase activity The nodule number and mass of nodules in soybean increased with the plant age upto 70 DAS (i e , early podding stage) and then declined marginally towards pod maturity Soybean nodulation was better in BBF than in flat landform treatment The N_2ase activity of soybean showed a trend similar to that of nodulation However, the effects of land configuration on N_2ase were not significant At harvest, BNF in soybean was estimated by N difference method using sorghum as a non-fixing control Soybean fixed 179 kg N ha^{1} (76 5% of total plant N uptake) through BNF Soybean grown on BBF fixed a marginally higher (185 kg ha^{-1}, 79 5%) amount of N than the N fixed on flat land (172 kg

ha^{-1}, 73.5%). Soybean grown on medium depth soil fixed from a higher amount (188 kg ha^{-1}) and the proportion of total plant N (80.4%) through BNF than the amount (169 kg ha^{-1}) and the proportion (72.6%) of N from BNF on shallow depth.

Patil *et al.* (1996) observed highest number of nodules, maximum nodule mass and nitrogenase activity in soybean, it was followed by cowpea and blackgram in Vertisols of Solapur. Among the three crops, soybean recorded maximum nitrogenase activity (48.9 μmol $C_2H_4m^{-2}$ h^{-1}) followed by copwpea (41.7 μmol $C_2H_4m^{-2}$ h^{-1}) and blackgram (25.4 μmol $C_2H_4m^{-2}$ h^{-1}) at 52 days after sowing.

Saran *et al.* (1996 b) reported that the applications of mineral N along with FYM and crop residues decreased nodulation and N_2ase activity than FYM or crop residues alone. Saran *et al.* (1996 a) showed that nodulation and N_2ase activity in soybean were influenced by land form treatment in Vertisols of Indore. The nodule number of soybean at 28 DAS was higher in the BBF landform system (2608 no. sq m^{-1}) than the flat landform system (2000 no. sq m^{-1}). The nitrogenase activity of soybean at 28 DAS was highest in BBF landform system (5.47 μmol $C_2H_4m^{-2}$ $plant^{-1}$ h^{-1}) compared to the flat landform system (4.51 μmol $C_2H_4m^{-2}$ $plant^{-1}$ h^{-1}). Van Lieu *et al.* (1996) reported that the nodulation in soybean and mungbean at pod formation stage was good.

Kundu *et al.* (1997) studied that the time course of N_2 fixation in commercially popular variety (Punjab-1) of soybean grown on typic Haplusterts of Madhya Pradesh and concluded that the N_2 derived from atmosphere (% Ndfa) in soybean on the 45th day after sowing was 38 percent and thereafter % Ndfa value increased steadily and attained a maximum of 63% at the 75 DAS. From the BNF point-of-view, the period between the

55 and 75 DAS was found very important as during this period 61 percent of the total biologically fixed N was accumulated

2.4 Nutrient uptake

Shinde *et al* (1982) studied the effect of applied on NPK uptake in the vegetative and reproductive parts at different growth stages of soybean in Vertisols associated soils of Madhya Pradesh and found that the cumulative uptake of N, P, and K was highest at harvest stage

Veerabadran (1989) reported that crops grown in BBF system recorded higher nutrient uptake (N, P and K) due to high moisture regime coupled with drymatter production than in flat bed system in Vertisols Selvraju (1994) reported that BBF system imposed during rabi season favoured nutrient uptake of sorghum, pearl millet and pigeonpea This might be due to the increased moisture storage which in turn facilitated for more root proliferation The flat bed system recorded least nutrient uptake (N, P and K) than BBF Alagarswamy *et al* (1996) evaluated the effect of land surface management practices on the N and P uptake of soybean during rainy season 1995 in Vertic Inceptisols in BW7 watershed at ICRISAT and found the time course of N and P uptake by soybean showed a linear increase upto 70 DAS of crop growth At harvest, soybean for estimating N, P and K content The total N, P and K uptake by soybean were not influenced significantly by the landform treatment (BBF and Flat) Similarly, soil depth [shallow (<50 cm) and medium-deep (<90cm)] also had no effect on the nutrient uptake A mean uptake of 229 6 kg ha^{-1} N, 20 4 kg ha^{-1} P and 101 3 kg ha^{-1} K was observed P and K uptake by soybean were marginally higher in shallow soils as compared to the medium depth Although soil depth and landform treatments had no effect on nutrient uptake by soybean, nutrient uptake from BBF was higher on shallow soil than that of flat landform. However, in medium depth soil, nutrient uptake was higher in case of flat landform treatment than in the case of BBF.

2.5 Runoff, soil erosion and nutrient loss

Pathak *et al.* (1985) investigated the improved management (BBF at 0.6% slope cropped) has been much more effective than traditional management (Flat, rainy cropping season in fallow) in reducing resource losses by runoff and soil erosion. On experimental watersheds in ICRISAT during the period 1975-80 (annual rainfall of 818 mm), total runoff averaged 220 mm, soil loss 7 t ha^{-1} and storm peak runoff rate 0.16 m^3/s/ha for traditional farming as compared to 91 mm, 1 t ha^{-1} and 0.07 m^3/s/ha for improved BBF at 0.4% slope. This trend was consistently confirmed every year in similar comparisons during the same period.

Srivastava and Jangwad (1988) studied the water balance and erosion rates of Vertisol watersheds under different land management practices and noted that broad bed and furrow (BBF) system lost only 14% rainfall and 1.5 t ha^{-1} yr^{-1} soil as compared to 24% runoff and 6.4 t ha^{-1} yr^{-1} soil by the flat system in Vertisols at Patancheru, India. Kale *et al.* (1992) studied the effect of various cropping (Inter/strip cropping) systems of sunflower and pigeonpea crops land treatments in reducing runoff, soil loses in different micro-watersheds at Solapur during 1984-85 to 1989-90 on shallow soil and reported that the contour bunding + strip cropping system (CB+SC) was found most efficient in reducing runoff by 38% and soil loss 58% over broad bed furrow + intercropping system (BBF+IC). However BC+SC system reduced runoff, soil loss by 51.5 percent and 71.1

percent over contour bunding + intercropping (CB+IC) system respectively Further CB+SC system and BBF+IC system are equally rewarding in terms of crop production and monetary returns as compared to CB+IC system

Gupta and Sharma (1994) studied four consecutive years (1988-91) for evaluation of the impact of different land configurations, namely, flat beds (FB), broad-bed and furrow (BBF), narrow-bed and furrow (NBF) and raised sunken bed (RSB) on field water balance, in situ conservation of rain water, drainage and soil and nutrient losses from a Vertisol in Indore The mean runoff values of four seasons for FB, BBF, NBF and RSB were 10, 7, 12, and 4 per cent of seasonal rainfall respectively The corresponding deep percolation of rain water across 1 m deep soil profile for these systems was 138, 117, 97 and 192 mm respectively Thus, the RSB system recorded 39, 64 and 98 per cent more deep percolation in comparison to that of Flat, BBF and NBF systems, respectively The seasonal soil loss recorded from RSB system was only 192 kg ha^{1} which was 44, 30 and 42 percent less as compared with that from NBF, BBF and FB, respectively The loss of available N from RSB system was only 1 60 kg ha^{1} as against 14 to 18 kg ha^{1} from other systems The results of this study conclusively suggest that RSB system can be recommended as an effective means of circumventing the problems of both excess as well as deficit rainfall as it facilitated in-situ conservation of rain water, soil and plant nutrients thereby enhancing productivity of drylands of the region on a sustainable basis

Alagarswamy *et al* (1996) evaluated the effect of land surface management practices on runoff in Vertic Inceptisols in black watershed 7 (BW7) at ICRISAT during rainy season 1995 and they found the total seasonal runoff from BBF treatments was slightly lower (168mm) than the flat treatment (196mm) The highest peak runoff rate of

0 098 m^{3} sec^{-1} ha^{-1} was recorded in flat treatment compared to 0 068 m^{3} sec^{-1} ha^{-1} in BBF A field study was conducted on Vertic Inceptisol during 1995-97 seasons at the ICRISAT Center, Patancheru, India to study the effect of two landforms (BBF and Flat)and two soil depths on runoff soil loss and nutrient loss (Piara Singh *et al*, 1999) Total runoff was higher on flat (28% of seasonal rainfall) than on BBF (21% of seasonal rainfall) This concomitantly increased profile water content (10 to 30 mm) of both soils in BBF compared to flat landform during 1995-96 BBF landform on both soil types had relatively more extractable water in the soil compared to the flat landform

Sharma and Parmar (1997) evaluated that the performance of different land configurations with respect to their impact on runoff, soil and nutrient loss, and productivity of rainfed crops and concluded that the performance of soybean crop was very good on raised sunken beds followed by BBF and broadbed tied furrow (BBTF) and the seasonal runoff from flat beds was 249 mm, BBF (229 mm), BBTF (223 mm) and raised sunken beds (RSB) systems (195mm) which 47%, 44%,43% and 37% of the rainfall respectively Soil erosion from Flat lands was highest (2 2 t ha^{1}) followed by BBF (1 2 t ha^{1}), BBTF (1 5 t ha^{-1}) and RSB (0 7 t ha^{-1}) The seasonal loss of nitrogen from flat bed, BBF, BBTF and RSB was 20, 19, 18 and 16 kg N ha in Vertisols of Indore

2.6 Nutrient balance (N, P and K)

Wani *et al* (1995b) calculated net N balances for different cultivars of pigeonpea and chickpea grown in India and showed that all the varieties depleted soil nitrogen when all above ground material was taken away Different maturity groups of pigeonpea cultivars fixed 4-53 kg N ha^{1} season^{-1} and removed 20-49 kg N ha^{-1} from the soil In chickpea, different cultivars fixed 23-40 kg N ha ^{1} season ^{1} and removed 63-77 kg N ha ^{1} season ^{1} from the soil In soybean 128-312 kg N ha ^{1} season fixed and removed 28-104 kg N ha ^{1} season ^{1} from soil

Kundu *et al* (1996) conducted an experiment in Vertisols of Malwa region of Madhya Pradesh and studied the effect of farmyard manure on nitrogen fixation in soybean [*Glycine max (L) Merr*] and its net potential contribution to N balance as measured by ^{15}N – tracer methodology during rainy season 1993 The potential contribution of N2 fixation to the N balance in soil was found negative, being 55 9 – 90 5 kg N ha ^{1} Calculations showed that such negative balance could be reduced by 11 6 – 36 4 kg N ha ^{1} on returning the whole soybean trash to the soil It was concluded that cultivation of soybean apparently left a negative N balance in the soil and the magnitude of such negative balance could be still higher if the soybean trash is not returned to the soil

Dubey (1999) studied the soil available nutrient balance as influenced by phosphate solubilizing agents and phosphate application in soybean on Vertisols in Madhya Pradesh Available soil N showed a deficit balance in all the treatments by –2 1 to –23 1 kg N ha ^{1} season ^{1} except treatments viz , super phosphate @ 13 2 kg P ha ^{1} + phosphate solubilizing bacteria and superphosphate @ 26 4 kg P ha ^{1} Phosphorus balance varied in the treatments The available net K showed negative balance in all the treatments

2.7 Yield

Increased crop growth and yields due to broadbed furrows in Vertisols were reported by several workers (CRIDA, 1982, UAS, 1983, Thiagarajan and Ramaiah, 1984, Bhatawadekar, 1985, CRIDA, 1990) Selvaraju (1994) reported decreased intercropped cowpea yields due to the low light intensity through shading of base crop (pearl millet) in Vertisols

Abebe et al (1994) conducted field experiments on Vertisols at 5 sites in Ethiopia in 1988-91, chickpeas were grown in BBF or flat bed and lentils were grown in BBF or ridge and furrows (RF) At all sites grain / seed yields were highest in BBF followed by the traditional ridge and furrows The advantages of the BBF technology in improving drainage and increasing crop yield are discussed Deshmukh *et al* (1994 a) reported that increased soybean yields 6% in case of broad bed and furrow over flat bed, 4 5% due to combination of inorganic and organic sources of nitrogen (20N + 4t FYM) over inorganic source of nitrogen alone (40N) and 12%) due to 30 cm row spacing over 45 cm at Indore Field trails were carried out by Mamo *et al* (1994) at 3 locations during 1989-1991 to study the effects of P fertilization at 0, 10, 20, 30 or 40 kg ha^{-1} and of land preparation methods (flat or the BBFS) on chickpea var mariye The combined results of seasons and locations showed that the BBFS gave significantly higher grain (54%) and straw (41%) yields than sowing on flat seedbeds Alagarswamy *et al* (1996) evaluated the effect of land surface management practices on the total drymatter production and pod yield of soybean during rainy season 1995 and found that in the shallow soils the total dry matter yield was 4 2 t ha^{-1} on the flat and 3 9 t ha^{-1} on BBF The grain yield was not significantly influenced by landform treatments However, the yield was marginally higher in flat (1700 kg ha^{-1}), when compared to BBF (1600 kg ha^{-1}). Soil depth [shallow

(<50cm) and medium (<90cm)] differences did not influence yield in BBF, while it influenced significantly ($P \leq 0\ 01$) in flat landform treatment

Klaij *et al* (1996) observed the influence of land management on wheat yield in Vertisols of Ethiopia The highest grain and straw yields of wheat (3009 kg ha^{-1} and 8095 kg ha^{-1}) were observed under BBF landform system The lowest grain and straw yields (1528 kg ha^{-1} and 3102 kg ha^{-1}) were observed under flat landform system

Saran *et al* (1996 a) reported the seed and straw yields of soybean as influenced by different land configurations on Vertisols, rainy season 1995, Indore The higher seed yield of 1970 kg ha^{-1} was obtained in flat-beds compared to the seed yield of 1400 kg ha^{-1} was obtained in BBF landform system The higher straw yield of 1600 kg ha^{-1} was obtained in flat landform system compared to the straw yield of 1200 kg ha^{-1} in BBF landform system The total plant drymatter (shoot + root + nodules) was higher in BBF system than flat landform system Results obtained this year are quite different to the ones which were generally observed in the earlier years For example, in 1994 the soybean seed yields were highest in BBF landform systems (1330 kg ha^{-1}) when compared to flat landform system, which had the lowest yield (260 kg ha^{-1}) The difference in the soybean yields between treatments are extremely high During 1994, waterlogging was a serious problem which resulted in a very poor yield in the flat-bed system Singh *et al* (1996) conducted an experiment on a Vertisol at the Zaloke Research Station The main treatments were i) flat landform and ii) BBF Seed yield of mungbean in BBF landform ranged from 258 to 340 kg ha^{-1} with an average yield of 312 kg ha^{-1} In the flat landform the mungbean yields ranged from 284 to 397 kg ha^{-1} with an average yield of 368 kg ha^{-1} indicating that the crop on BBF produced less seed yield than on flat Similarly, sesamum yielded less in BBF (37 kg ha^{-1}) than in flat (44 kg ha^{-1}) Low yields in BBF than on flat landform are attributed to the less number of rows per plot and therefore, less plant population in the BBF when compared to the flat

Bejiga *et al* (1997) studied the effects of soil surface drainage and sowing dates on the yield of chickpea (*Cicer arietinum* (L)) Three seedbed types (broadbed and furrow (BBF), ridge and furrow (RF), and flat) and three sowing sowing dates were used The trial was grown at Debre Zeit and Akaki, Ethiopia in 1987, 1988 and 1989 cropping seasons There was no significant difference among the mean seed yields of different seed bed types Ingle *et al* (1999) conducted a field trail at Nagpur, Maharashtra, India, in kharif 1997, soybeans cv Js 80-21 gave mean seed yields of 1 58, 1 70 and 1 84 t ha^{1} when sown on flat beds, broadbeds and furrows and ridges and furrows respectively A field study was conducted on a Vertic Inceptisol during 1995-97 seasons at the ICRISAT Center, Patancheru, India to study the effect of two land forms (broadbed and furrow (BBF) and flat and two soil depths (shallow and medium-deep) on crop yields of soybean-chickpea rotation (Piara Singh *et al*, 1999) Long term simulation of soybean showed that at least a yield of 1 t ha^{-1} can be obtained on Vertic Inceptisols in all years at Patancheru In most years, soil depth and land form did not influence yield However, during years which had relatively low rainfall corresponding to soybean yields less than 2 5 t ha^{-1}, yields were slightly higher on medium-deep soil compared to the shallow soil In contrast to soybean, chickpea yields were higher for the medium-deep soil than for the shallow soil

2.8 Soybean- based Cropping Systems productivity

Tomar *et al* (1987) studied the suitability of different planting patterns in pigeonpea and soybean intercropping system under rainfed conditions on black clay soil during 1981-83 at the college of Agriculture, Indore (MP) and found that pigeonpea + soybean in 1 2 row ratio (2 rows of soybean at 30 cm in between 2 rows of pigeonpea spaced 90 cm apart) was most productive with land equivalent ratio of 1 43 and benefit / cost ratio of 3 The yield of pigoenpea and soybean obtained in this system of intercropping were 80% and 67% of respective sole crop yields

Bhaskar *et al* (1992) evaluated fitness of soybean crop in rotation with other crops, 16 improved varieties of soybean were grown on the black cotton soils (Vertisols) of the Vidarbha region of Maharashtra The results of a 3 year study showed that PK 472 was superior in productivity in the Vertisols, yielding 2 t ha^{1} followed by 'JS 79-277' and 'JS 75-46' 1 9 t ha^{1} The promising and economic sequence was soybean-pigeonpea and soybean-chickpea The gross returns were Rs 24,210 and Rs 24,090 respectively

Deshmukh *et al* (1994 b) at Indore determined the productivity and economic viability of soybean-blackgram based cropping sequences for Vertisols of *malwa region* and showed that the maximum net profit (Rs 31,818 ha^{1}) and benefit-cost ratio (4 0) was realized in soybean-safflower while it was Rs 20,044 ha^{1} with a B C of 3 in blackgram-safflower sequence Jadhao *et al* (1994) studied that the groundnut and soybean-based 9 crop sequences for high productivity in Vertic Inceptisols in Akola and revealed that the during the rainy season soybean and during the post-rainy cropping season chickpea and safflower gave the highest yield compared with the other crops The soybean-safflower (3 t ha^{1}) and soybean-chickpea (3 t ha^{1}) crop sequences recorded significantly higher grain production than all the other crop sequences

Bhatnagar *et al* (1996) found that soybean offers good potential to be introduced into sequential cropping or intercropping systems It is a short duration (85-130 days) leguminous energy rich crop It is relatively tolerant to drought and excessive moisture It is a remunerative cash crop too The other desirable features are that its cultivation does not cause any allelopathic effect on companion/succeeding crops, leaves 45 to 60 kg residual N na^{1} to the succeeding crop and created salutary physico-chemical environment in the soil for crop growth It was also instrumental in sustaining soil organic matter status through substantial recycling of foliage/rhizosphere root mass Experimental evidence has established that soybean could fit aptly in any of the traditional cropping systems in all the five agroclimatic zones of India specified for soybean Hence, the inclusion of soybean in any of the existing cropping systems generates much more dividends than any other cropping sequence Joshi *et al* (1997) studied the planting pattern in pigeonpea (*Cajanus cajan* (L)) and soybean (*Glycine **max*** (L)) intercropping under rainfed conditions during rainy season of 1991-94 at Parbhani and found that soybean 'PK 472' with 2 rows was found most suitable for intercropping in pigeonpea spaced at 135 cm apart This intercropping system gave the highest soybean-grain equivalent (3,211 kg ha^{1}), gross (Rs 26,627 ha^{1}) and net (Rs 22,771 ha^{1}) monetary returns, land equivalent ratio (1 5) and yield recovery (160%)

Bobde *et al* 1998 conducted a long-term experiment during 1991-92 to 1995-96 to study nutrition management of soybean (*Glycine max* (L) Merr) and soybean-based cropping system in Nagpur on Vertic Inceptisols Application of 7 5 tonnes FYM ha^{1} along with reduced dose of fertilizer to 50% gave significantly more grain yield of soybean as well as more monetary returns than the absolute control and recommended dose of fertilizer only Succeeding crops viz , Indian mustard (*Brassica juncea* (L) czernj & cosson), wheat (*Triticum aestivum* L emend Fiori & paol) and (*Cicer arietinum*

(L) taken after soybean gave 140, 132 and 107 extra monetary returns respectively over no post-rainy season crop grown after soybean (fallow treatment) A field experiment was conducted during the rainy cropping season and post-rainy seasons (1992-93 and 1993-94) on a deep clay-loam soil to evaluate the most remunerative double cropping systems under rainfed conditions (Dwivedi *et al* 1998) Sorghum (*Sorghum bicolor* (L) Moench) yielded higher than soybean (*Glycine max* (L) Merr) but the net returns were higher from soybean Higher yield of wheat (*Triticum aestivum* L emend Fiori & Paol), Chickpea (*Cicer arietinum* L) and linseed (*Linum usitatissimum* L) was obtained when grown after blackgram (*Phaseolus mungo* L) compared with that grown after soybean, sorghum and rice (*Oryza sativa* L) However, the maximum net returns (Rs 20,637 ha ^{1}) were obtained with soybean-chickpea sequence, followed by best sequence soybean-linseed (Rs 17,086 ha ^{1}), soybean-wheat (Rs 14,018) and blackgram-chickpea (Rs 14,181 ha ^{1})

Joshi *et al* (1998) reported that intercropping of soybean with cotton in 1 1 or 1 2 rows and with pigeonpea in 1 2 rows was promising and had tremendous potential for efficient use of Vertisols in Maharashtra Considering the area of post-rainy crops, the extra-early soybean varieties have great promise over short duration, traditional pulses to maximize double cropping in rainfed Vertisol region

Magar and Deshmukh (1999) reported an experiment conducted at the Maharashtra Association for cultivation of Science (MACS), Pune during kharif and rabi seasons of 1997-98 to identify the most remunerative rabi rainfed crop suitable for planting after kharif soybean (CV MACS 124) (MACS, 1998) During rabi season, wheat, chickpea (*Cicer arietinum* (L)), and mustard (*Brassica* sp) were sown The data revealed that soybean yields ranged from 2263 kg ha^{-1} to 2827 kg ha^{-1} with an average yield of 2593 kg ha^{-1} Among the three rabi crops tested, chickpea gave the highest yield of 2031 kg ha^{-1} followed by wheat (1582 kg ha^{-1}) Soybean-chickpea and soybean-wheat were the most remunerative crop sequences in Maharashtra than the traditional sequence of groundnut (*Arachis hypogaea L)* - wheat, considering net returns, productivity, returns per unit volume of water, water-use efficiency (WUE), and grain equivalent

2.9 Vesicular Arbuscular Mycorrhizal fungi (VAMF)

The symbiotic association between plant roots and fungal mycelia is termed as mycorrhiza (fungus root, plural mycorrhizae) These fungi are found associated with majority of agricultural crops VAM occur over a broad ecological range from aquatic to desert environments (Mosse *et al* 1981) They are ubiquitous in geographic distribution occurring with plants growing in arctic, temperate and tropical regions alike These fungi belonging to the general *Endogone, Glomus, Entrophosphora, Gigaspora, Acaulospora, Scutellispora,* are obligate symbionts and have not been cultured on nutrient media

VAM fungi infect and spread inside the root They possess special structures, globose or oval terminal swellings known as vesicles and arbuscules The arbuscules help in the transfer of nutrients from the fungus to the root system and the vesicles, which are 'saclike' structures and store P as phospholipids There is little host specificity for VAM but the competitive ability of a given species with native strains may influence the dominance of a certain endomycorrhizal fungus in a root system VAM have been associated with increased plant growth and with enhanced accumulation of plant nutrients, particularly P, Zn, Cu, and S mainly through greater soil exploration by mycorrhizal hyphae (Abbot and Robson 1984, Wani *et al*, 1991 b)

Bolan (1991) reported that the beneficial effects of mycorrhizae on plant growth have often been related to the increase in the uptake of immobile nutrients, especially P and the mechanisms for the increase in the uptake of P by mycorrhizae and the sources of soil P for mycorrhizal and non-mycorrhizal plants are examined Various mechanisms have been suggested for the increase in the uptake of P by mycorrhizal plants These include exploration of larger soil volume, faster movement of P into mycorrhizal hypae, and solubilization of soil phosphorus Exploration of larger soil volume by mycorrhizal plants is achieved by decreasing the distance that P ions must diffuse to plant roots and by increasing the surface area for absorption Faster movement of P into mycorrhizal hyphae is achieved by increasing the affinity for P ions and by decreasing the threshold concentration required for absorption of P Solubilization of soil P is achieved by the release of organic acids and phosphatase enzymes Mycorrhizal plants have been shown to increase the uptake of poorly soluble P sources, such as Fe and Al-bound and rock phosphates However, studies in which the soil P has been labeled with radioactive 32p indicated that both mycorrhizal and non-mycorrhizal plants utilized the similarly labeled P sources in soil Ellis *et al* (1992) studied the effect of soybean (*Glycine max L*) and grain sorghum (*sorghum bicolor L)* rotation and fertilization on plant response and VAMF (Vesicular-arbuscular mycorrhizal fungi) root colonization and diversity, and relate effects to soil environment Root colonization by VAMF ranged from 93% at 15 cm to 15% at the 120 cm soil depth Root density and VAMF colonization were least when soybean was grown the previous year and manure was applied

The results of field trials conducted in India reviewed by Wani and Lee (1992) indicated that VAM inoculations increased yields significantly in around 50 percent trials and the response varied with soil type, soil fertility and VAM cultures This scenario is similar to that for *Rhizobium* or *Azospirillum* In such a situation, until suitable methods are evolved to multiply VAM on a large scale for field inoculation of crops directly sown in the field, the best strategy to utilize VA mycorrhizal fungi for crop production is to concentrate on crops normally grown in nursery beds where they can be easily inoculated with selected strains and then transplanted Wani and Lee (1995) examined the effect of such management practices as fallowing, tillage, cropping pattern, fertilizers, and pesticides on mycorrhizal association with crop plants after identifying management practices to exploit mycorrhizal associations thereby increase crop production, under different cropping systems during 1991-93 in ICRISAT The mean number of VAM spores in soil samples collected at the flowering stage during 1991-93 showed a marginal increase from 13 spores g^{1} soil in the zero tillage-no amendment treatment to 16 spores g^{1} soil in the deep tillage (2-cm) - no amendment treatment The deep tillage - no amendment treatment significantly increased mycorrhizal colonization of roots (58%) during 1991-1993 as compared to 44% in the zero tillage no amendment Similar effects in terms of increased mycorrhizal colonization due to deep tillage were also observed in the plots mulched with poddy straw

Dubey and Gupta (1996) reported that the soil inoculation with VAM fungi increased the mean yields of soybean by 7% and pigeonpea by 5% under rainfed conditions but soil inoculation with VAM + *Rhizobium* led to the yield increase of 20 1 soybean and 31 0% in pigeonpea in Vertisols region of M P Patil *et al* (1996) observed root colonization by Vesicular arbuscular mycorrhizal (VAM) fungi A maximum VAM root colonization was observed in case of cowpea (27%) followed by blackgram (19%) and soybean (17%) Saran *et al* (1996 a) observed the Vesicular arbuscular mycorrhizal (VAM) colonization in soybean roots Mean mycorrhizal colonization of soybean roots at 39 DAS stage was 26% and increased to 34% by harvest time

Saran *et al* (1996 b) found the mycorrhizal colonization by VAM fungi in soybean roots was lowest (5%) in case of plants grown in sunken pits as compared to mycorrhizal colonization of 12, 13 and 14% in case of plants grown in flat bed, BBF landform and raised-bed respectively

IN VITRO STUDIES

2.10 N Mineralization Potential (N_0)

The synchronization of nutrient release from plant residues and uptake by plants has become a central paradigm in applied soil biology research (Myers *et al*, 1994) The efficiency with which N in plant residues is used depends on the rate at which they are mineralized and thus on the time when they are made available relative to crop requirements This is of great importance in the field if N mineralized is lost by leaching from the rooting zone before it can be taken up by the crop Leaching problems are therefore more severe when crops are shallow-rooted and when mineral N is present in the nitrate form (Van Noordwijk *et al*, 1992)

Most studies of soil N mineralization within the past 20 years have been short-term and motivated primarily by the need for rapid and reliable methods of assessing soil N availability In such studies, therefore, incubation time usually was limited to a practicable minimum (7 to 14 days) Although only a small proportion of the potentially mineralable N is released during short-term incubations, results often appeared to reflect relative N-supplying capabilities of soils (Bremner,1965) Few critical comparisons of short and long-term mineralization have been made, however, because of difficulties inherent in obtaining reliable measurements with extended periods of incubation In early studies of long-term N mineralization capabilities of soils, samples usually were incubated continuously in bottles or flasks The N mineralization-time curves thus obtained seldom provided a rational or consistent basis for estimating long-term N-supplying capacities of soils

Sonawane *et al* (1995) revealed that mineralization from urea was more rapid and higher, 92% of N added was minerlaized within 8 days With progress of time mineralized N gradually decreased due to voltalization losses In case of *Glyricidia* 28 and in *Leucaena* 32 percent of added N was mineralized within 9 days There was slow release of N up to 45 days and thereafter it was rather stable probably because of equal rate of mineralization and immobilization Mineralization in case of crop residue follow the trend as observed in control treatment Beneficial effects of use of crop residue coupled with *Leucaena* loppings or urea in soil for release of mineral nitrogen were noticed

Smith and Sharpley (1990) studied the effects of crop residue placement and type on soil N availability for a range of soils under aerobic laboratory conditions at 35°C. Representative field rates of alfalfa, corn, oat, peanut, sorghum, soybean and wheat crop residues were applied to eight Oklahoma surface soils. The N availability was measured on the basis of indigenous and fertilizer-derived soil N mineralized during short (14d) and long (84d) term incubation and found that short-term, an initial depression (more than 80% with corn) in net mineralization occurred with non legume residue additions. The depression was enhanced when the residues were incorporated rather than left on the soil surface. N mineralization was enhanced more than 50% with the alfalfa addition. Effects of crop residue type on N mineralization showed ranges up to three-fold or more and generally proceeded in the order alfalfa > peanut > soybean > oat ≥ sorghum > wheat > corn. Long-term, N mineralization for all systems was more comparable to that without residue additions.

Christenson Donald and Butt Mohammad (1997) compared the relative effects of several cropping systems on mineralized N, No and the rate constant of mineralization of a Histeguay silty clay soil. N_0 was estimated from a long-term incubation study (40 weeks) using exponential and hyperbolic models and found that the N_0 ranges from 70 to 109 mg kg^{-1} for the exponential model and 86 to 144 mg kg^{-1} for the hyper bolic model. Values of No are closely related to the estimated amount of crop residue returned. It requires 0.33 t ha^{-1} of crop residue returned to increase No 1 mg kg^{-1}. Estimated No values are consistently greater for the hyperbolic than for the exponential model. However, there is a close relationship between the instantaneous rates of reaction of the two models suggesting both models can be used in laboratory incubation studies to estimate No using a nonlinear least-squares fitting technique.

Christenson Donald and Butt Mohammad (1998) evaluated the mineralization potential (No) of the predominate soil series in the Saginaw Valley and Thumb region of Michigan with the goal of utilizing this information to formulate N fertilizer recommendations. Air-dried samples representing 17 sites were incubated (40 weeks) and

NO_3^- and NH_4^+ produced were measured periodically. These data were used to determine N-mineralization potential (No) utilizing exponential and hyperbolic models. The initial hypothesis for this study was the existence of a unique No value for each soil series. If this were the case, then this measurement could be used to formulate soil series specific N recommendations. Results show there is as much variability in No values within soil series as between soil series. Consequently, utilizing a single No value for a soil series in formulating N recommendations is not practical.

Three methods; litterbags, incubation of materials in pots and incubation in leaching-tubes were compared to determine the effects of N, lignin and polyphenols of legume tree prunings on their decomposition and N release rates in a red-yellow podzolic soil (Ultisol) at Lampung, Indonesia (Handayanto *et al.,* 1994). Decomposition and N release rates of the prunings were in the order *Glyricidia* > *Leucaena* > *Calliandra* > *Peltophorum* in all three incubation methods, however, the patterns of N release varied between incubation methods and species. The amounts of N mineralized in soil amended with the prunings over 56 days incubation period ranged from 10% (*Peltophorum*) to 32% (*Glyricidia*) of the N initially added as prunings estimated by leaching-tube method.

Islam *et al.* (1998) assessed the effect of added organic residues on the net potentially mineralizable N pool and first-order rate constants of some wet-land rice soils under simulated flooded conditions in the laboratory and found that soil treated with rice straw had a higher N mineralization rate than soils treated with Peavine, which was due to a lower C:N ratio for rice straw. The potential mineralizable N pool (N_O) in soils amended with rice straw and pea vine under flooded conditions, estimate using a 1st order exponential equation, were 7 to 15 times, and 3 to 9 times greater for rice straw N_O

values and pea vine respectively than the control The K_N values for unamended soils ranged from 0 35 to 0 52 mg N kg^{1} wk^{1} and rice straw and pea vine treated soils were from 0 75 to 1 22 and 0 46 to 0 58 mg N kg^{1} wk^{1} The lower N_o and K_N values in pea vine treatments suggested there was greater immobilization of N than in rice straw treatments

Wani *et al* (1995 b) studied the quantity and patterns of net mineralization of soil N in Vertisols under eight cropping systems in the semi-arid tropical areas After the harvest of the ninth year crops, soil samples were collected from 20 cm depth and incubated for 20 weeks Cumulative mineral N accumulation during incubations of 20 weeks varied significantly ($P<0$ 05) with the cropping history of the soil The rate of net N mineralization from all the soils was initially high and declined during later stages of incubation but remained greater than zero in all the soils throughout the incubation period Mineral N accumulation curves for six out of eight soils were more accurately described by the exponential model than the linear model Time required to mineralize 25 mg N kg^{1} soil varied from 1 5 to 19 6 wk using the exponential model For both models, cropping systems which contained pigeonpea required less time to mineralize a fixed quantity of N than did chickpea based systems For the COP/PP-S+SF treatment (cowpea intercropped with pigeonpea in the first year followed by sorghum in the next rainy season and safflower in the post-rainy season) the instantaneous rate of N mineralization was far higher than the other treatments upto the eighth week but decreased drastically at weeks 16 and 20 The zero order rate of N mineralization using the linear model for soil samples varied from 1 33 to 5 95 mg kg^{1} soil wk^{1}

Dinesh and Dubey (1998) investigated the N-mineralization rates in soils freshly amended with green manures like *Sesbania, Glyricidia, Leucaena,* and *Azolla* and the relationship between various N-mineralization parameters and chemical composition of the green manures incorporated in the soil in incubation studies and found that the N mineralization rates were greatest during the first week and decreased with time in all soils The green manure amended soils leached 247 mg kg^{-1} more $NO_3^- + NO_2^-$-N than the unamended control In general, the total N mineralized (mean 61%) was almost twice that of net N mineralized (mean 30%) in the amended soils The percent of total N mineralized, however, varied with the nature of green manure incorporated into the soil It was greatest in the soil amended with *Sesbania* and lowest in the soil amended with *Azolla* The kinetic parameters derived using the double exponential model indicated that green manure amended soils possessed significantly higher N-mineralization potentials and rate constants compared to the unamended control The kinetic parameters also varied with the nature of green manure incorporated into the soil Among the various parameters lignin content, lignin to N ratio and lignin + polyphenol to N ratio of the green manures were the key factors governing the rate of decomposition and subsequent N mineralization from the amended soils

2.11 Decomposition of Organic Matter Studies (CO_2 evolution)

Organic matter represents a most reliable index of soil fertility and contributes to soil productivity in a number of ways (Levi-Minzi *et al*, 1990) Investigation on decomposition of organic materials added to soil is an important aspect of analysis of the organic matter balance in soil and is essential to an understanding of the relative value of different materials for improving soil fertility (Saviozzi *et al*,1993) the decomposition process, called mineralization, is characterized by a decrease in organic matter content and an increase of available minerals previously immobilized in organic form Quantitative information on the decomposition rates and patterns of organic residues is fundamental for a better understanding of organic matter dynamics and nutrient element cycling in soils Carbon makes up approximately 40% of the total dry plant biomass For this reason, C mineralization is often used as a general indicator of the persistence or decomposability of organic materials (Janzen and Kucey, 1988)

All heterotrophic microorganisms are capable of decomposing organic matter and this decomposition process has been used to indicate the biological state of soil (Nannipieri *et al* 1990) Several techniques have been developed for measuring the degree of organic matter decomposition O_2 consumption, CO_2 emission, decrease in organic matter and the disappearance of specific constituents such as cellulose and lignin Although CO_2 emission is widely considered to accurately reflect the degree of mineralization of a soil's organic matter content (Saviozzi *et al* 1993), it must be borne in mind that short-term experiments often used are severely limited when it comes to extrapolation of the organic matter turnover in natural soil as opposed to one in laboratory conditions (Hsieh *et al* 1981) Another approach to understanding the degree of mineralization of organic materials in a soil is to study the decomposition kinetics by fitting the CO_2 emission values to mathematical equations

Sarmah and Bordoloi (1994) studied in an aerobic incubation with different organic matter it was found that, the rate of CO_2 evolution was highest during the first week of incubation Of the various sources of organic matter, the highest CO_2 evolution was recorded *S rostrata* (2 39 g kg^{1}) followed by rice straw (2 26 kg^{1}) and farmyard manure (0 56 g kg^{-1}) Nitrogen mineralization was very fast from *S rostrata* (86 mg kg^{-1}) followed by farmyard manure (51 mg kg ^{1}) in Janji location soils of Assam

Jothimani *et al* (1997) reported that *Glyricidia* evolved more amount of CO_2 than the Coirpith treatments throughout the period (180 days) of incubation in laboratory condition Both cumulative (2 243 g kg^{-1} soil) and rate of CO_2 evolution (0 068 g kg^{-1} d^{-1}) was higher in the case of *Glyricidia* than the Coirpith treatments (1 188 and 0 040 respectively)

Curtin *et al* (1998) conducted an experiment to determine the contribution of decomposing wheat (*Triticum aestivum* L) straw to CO_2 emissions from a Swinton Silt loam (Fine-silty, mixed, mesic Typic Haploboroll) under controlled conditions (constant 20°C) and Two types of straw (i e , fresh straw collected shortly after harvest and standing stubble that had "weathered" in the field for a year) were either incorporated into or placed on the soil surface at a rate equivalent to 2800 kg ha ^{1}, one set of soils was watered every 2 or 3d to 90% field capacity and a second set was allowed to dry (from 90% field capacity) to below the permanent wilting point before watering Emissions of CO_2 were measured every 2 or 3d with a vented chamber connected to a portable CO_2 analyzer Within 2d, incorporation of straw increased CO_2 flux from 0 3 to ≈1 5μmol CO_2 m^{-2}s ^{1} Surface straw had significantly increased fluxes, but the effect was small compared with incorporated straw Straw type had little effect on emissions Total CO_2-C emitted in 77 d from continuously moist soil was 25 g m^{-2} with no added straw, 41 g m^{-2} with surface straw, and 73 g m^{-2} with incorporated straw (values are averages for two straw types) In all, 38% of incorporated-straw C and 13% of surface straw C was emitted as CO_2 Soil subjected to moist-dry cycles emitted from 36 to 62% less CO_2 than continuously moist soil

An incubation study was conducted (Kaboneka *et al*, 1997) for 30 days in Taloka (fine, mixed, thermic mollic Albaqualf) and Leadvale (fine, silty, siliceous, thermic typic Fragiudult) silt loam soils to evaluate carbon (C) and nitrogen (N) mineralization from soybean, corn and wheat residues Corn and soybean residues were collected at the tasseling and vegetative stages, respectively Wheat straw was collected after harvest Carbon dioxide (CO_2) evolution and inorganic N accumulation were measured and they found that decomposition ranged from 39% for wheat to 67% for soybean Carbon dioxide evolution peaked on the third day, and 30 to 50% of residue C was decomposed during the first six days of incubation Decomposition and N mineralization were higher in the Taloka compared to the Leadvale soil, and generally followed the sequence soybean > corn > wheat residues as did percent rapid fraction, and rapid and slow fraction rate constants Nitrogen mineralization, as estimated by ammonium (NH_4^+) and nitrate (NO_3^-) formation occurred only with the soybean residue, whereas the corn and wheat residues were characterized by N immobilization Throughout the study on the basis of percent total added residue N, 34 and 5% of soybean N were mineralized in the Taloka and the Leadvale soils respectively Similar values were –39 and –42% for corn and –68 and –82% for wheat N

Pascual *et al* (1998) investigated the kinetics of carbon (C) mineralization when different doses of organic materials with varying degrees of stability were added to an arid soil Respiration assays showed that the incorporation of wastes led to a greater emission of carbon in the form of CO_2 and greater degree of microbial activity than those occurring in the control soil. Soils treated with fresh waste (municipal solid waste and sewage sludge) gave off more CO_2 than that treated with compost, with higher values being obtained at high than at low doses. Carbon dioxide emission was reduced with the length of time the organic materials remained in the soil. The data of cumulative CO_2 were filled to the equation $C = C_0 (1-e^{-kt}) + C_1$. The parameters derived from this model were used as indices of organic matter decomposition, because the product of C_0 and K was more precise than either value separately. In all cases, an initial rapid phase of mineralization was clearly differentiated from a second slower phase.

Catherine *et al.* (1990) studied on kinetic of carbon dioxide evolution in relation to microbial biomass and temperature and found the intensification of agricultural practices on calcareous soils leads to drastic changes in biochemical processes due to modifications of CO_2 partial pressure in soil pores. For this reason, CO_2 evolution was measured *in vitro* from Typic Rendoll soils of the Champagne Crayeuse at four temperatures. Microbial biomass was also estimated by a plate-count technique that had been calibrated by two independent methods: chloroform fumigation and bioluminescence. Carbon dioxide evolution curves fit an equation consisting of a zero- and first-order reaction. The three parameters of this equation were interpreted as: (i) the amount of easily decomposable organic matter generated by the disturbance, and (ii) the sustained respiration of the native microflora. This model implies that the rate of CO_2 evolution is maximum at the short of the incubation, while the observed maximum in bacterial biomass occurred about 5d later. Comparison of the results presented herewith data from the literature shows that there is an almost continuous spectrum of values for the amounts of easily decomposable organic matter generated by any disturbance, and that the time constant for its mineralization is of the order of a very few days. Therefore, the use of the double exponential model is superfluous unless the duration of the incubation experiments exceeds 100d.

The review of literature presented in the foregoing pages indicates that the implication of landform systems and legumes influenced the status of soil mineral N, net N mineralization, microbial biomass of Carbon and nitrogen, nodulation and BNF of the legumes. *In vitro* studies organic matter residues influenced the nitrogen mineralization potential (N_0) and carbon mineralization potential (C_0).

Materials and Methods

CHAPTER III

MATERIALS AND METHODS

Experiments were carried out in the research scale watershed at ICRISAT, Patancheru during rainy and post-rainy seasons of 1997 and 1998, with a view to find out the impact of land management systems on productivity of soybean/pigeonpea intercropping and soybean + chickpea sequencial cropping systems, nutrient budgeting, and dynamics in Vertic Inceptisol. The details of the procedures and techniques adopted for field study and the analytical techniques followed during the present investigation are described 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, (17^0 32' N latitude, 78^0 16' E longitude and 540 meters elevation) Andhra Pradesh, India. 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 when 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 (June-October), post-rainy dry season (October-February) and a summer (March-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 South Asia get rainfall under the influence of monsoon circulation which usually sets in around early June and extends till mid-October. During those four and half months more than 80% of the annual rainfall is received at Hyderabad. The pattern of rainfall is slightly bimodal with one peak occurring during the south west (in July) rainy season and the second peak in the intervening period of South West and North East monsoons in September (Virmani, 1995). The mean annual rainfall recorded for a period of 30 years i.e., 1940-70 was 704 mm and the annual PET was 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*) starts in October and continues until January. 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 February 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 rains sets-in during mid-June and recede in early October. 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 1997-98

Total seasonal rainfall was 523 mm during the rainy season (June to October) Table 1. The amount of rainfall and rainy days were 19mm and 6 respectively during June, indicating delayed onset and consequently crop sowing. A total of 54 rainy days during rainy season and maximum number of rainy days (26) during August and September were recorded. Between March and May, it rained 127 mm which was utilized for the tillage operations. During post-rainy season (November to March) a total of 111 mm rainfall with 13 rainy days during the post- rainy days were recorded (Table 1).

Table 1. Mean monthly weather data of the year 1997-98.

Month	Daily mean solar radiation (MJm^{-2}d^{-1})	Evaporation (mm) monthly total	Mean temperature (°C)			Monthly rainfall total (mm)	Rainy days (No.)
			Daily Max.	Daily Min.	Daily Avg.		
January	16.0	134	27.2	14.0	20.6	11	2
February	20.4	176	31.6	13.7	22.7	0	0
March	21.3	249	35.2	18.4	26.8	57	3
April	23.0	254	34.9	20.9	27.9	38	5
May	24.3	329	38.3	24.0	31.2	32	3
Rainy Season							
June	21.4	307	36.2	23.9	30.1	19	6
July	15.8	203	31.8	23.3	27.6	157	17
August	15.8	174	30.6	22.5	26.7	140	13
September	17.4	132	30.3	21.9	26.1	133	13
October	18.2	141	30.6	19.5	25.1	74	5
Post-rainy season							
November	15.3	116	29.3	19.6	24.5	50	7
December	14.2	107	28.1	18.0	23.1	31	5
January	16.9	139	29.6	15.4	22.5	0	0
February	19.7	172	31.8	16.5	24.2	0	0
March	21.4	261	35.3	20.0	27.7	30	1
	-	-	-	-	-	-	-

3.2.2 WEATHER DURING 1998-99

During the rainy season a total of 1053 mm rainfall was received (Table 2). The rains arrived in the month of Jun with a 102 mm shower on-time. Seventy nine rainy days recorded during the period June to October. The rainy season crops established very well and the crop growth in the watersheds was good to excellent. The amount of rainfall and rainy days were 20 mm and 7 respectively during the post-rainy season.

Table 2 Mean monthly weather data of the year 1998-99

Month	Daily Mean solar radiation ($MJm^{-2}d^{-1}$)	Evaporation (mm) monthly total	Mean temperature (°C)			Monthly rainfall total (mm)	Rainy days (No.)
			Daily Max.	Daily Min.	Daily Avg.		
January	16.9	139	29.6	15.4	22.5	0	0
February	19.7	172	31.8	16.5	24.2	0	0
March	21.4	261	35.3	20.0	27.7	30	1
April	22.8	319	38.7	23.0	30.9	49	2
May	22.4	332	39.4	24.7	32.1	35	3
Rainy Season							
June	19.6	286	35.7	23.1	29.4	102	7
July	16.4	182	31.9	21.4	26.7	287	15
August	14.3	116	29.6	20.7	25.2	300	22
September	14.9	106	29.3	20.5	24.9	199	20
October	16.8	121	29.6	18.6	24.1	165	15
Post-rainy season							
November	15.9	117	28.7	15.1	21.9	15	5
December	16.8	132	27.5	9.2	18.4	0	0
January	16.2	128	27.9	11.4	19.7	0	0
February	19.4	185	31.2	16.1	23.7	3	1
March	20.9	254	35.6	18.1	26.9	2	1
	-	-	-	-	-	-	-

3.3. FIELD EXPERIMENTA DETAILS

3.3.1. Soil characteristics

The experiment was conducted during the 1997 and 1998 rainy and postrainy seasons (*kharif and rabi*) on a Vertic Inceptisol (The soil is a member of the fine, montmorillonitic, isohyperthermic family of paralithic Vertic Ustropepts) watershed. The montmorillonitic, isohyperthermic family of paralithic Vertic Ustropepts) watershed. The physical and chemical properties of the soil are given in Table 3. The Vertic Inceptisol used in the experiment belonged to the Kasireddipalli soil series as classified by Murthy and Swindale (1993).

Table 3. Soil properties of experimental site (BW7), ICRISAT Center, Patancheru, India.

Depth (cm)	PH	EC ($dS\ m^{-1}$)	Organic carbon (%)	Available N ($kg\ ha^{-1}$)	Available P ($kg\ ha^{-1}$)
0-15	8.09	0.24	0.80	5.85	-
15-30	8.28	0.18	0.67	5.66	3.59
30-60	8.48	0.17	0.48	3.12	1.86
60-90	7.90	0.18	0.40	3.51	1.67

Electrical conductivity (Keeney and Nelson, 1982)

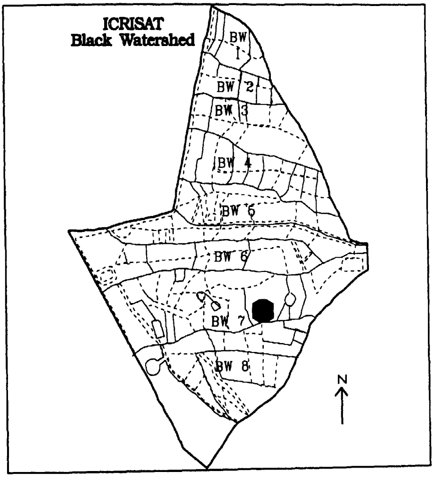
Organic C (Nelson and Sommer, 1982)

Available P (Olsen and Sommer, 1982)

Available N (Dalal *et al.*, 1984)

3.3.2. Design and treatments

A series of eight Vertisol watersheds have been established at ICRISAT Center, Patancheru, A.P., India.. These vary in size from 2-25 ha and cover a total of 80 ha. These are acronymed black soils watershed # 1 (BW_1) to black soils watershed # 8 (BW_8). The research presented here relates to black soils watershed # 7 (BW_7) (Fig. 1). The experiment was started



igure 1. Location of BW7 watershed in ICRISAT, Patancheru, Andhra Pradesh, India.

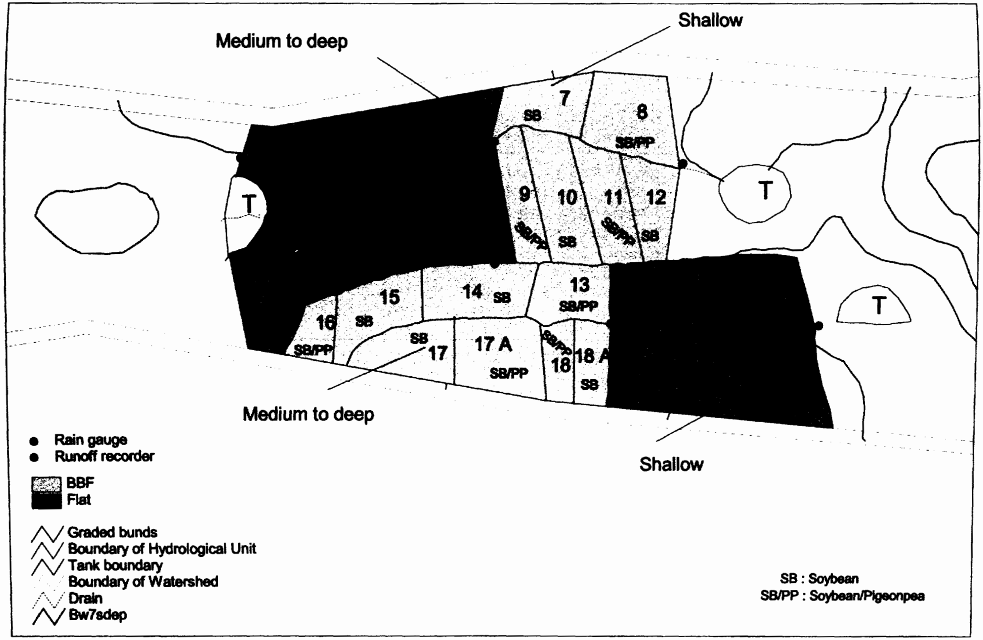


Fig 2. Layout of field experiment (BW-7 watershed)

during rainy season 1995. Our research work was carried out during rainy and post-rainy seasons 1997 and 1998. On the basis of a detailed topographical survey, two small watersheds of 2.2 and 2.5 ha were designed and developed at black soils watershed # 7 [BW_7 (Fig. 2)]. The general slope of the land was less than 2%. The watershed had two main drainage ways to discharge approximately 0.18 $m^3 s^{-1} ha^{-1}$ of peak runoff rate. The soil was a Vertic Inceptisol, which is classified as the member of the fine, montmorillonitic, isohyperthermic family of paralithic Vertic Ustropepts. The soil profile in the watershed varied in depth from 30 to 90 cm, underlaid by a relatively coarse weathered material locally known as 'murrum'. This coarse material holds water and can be penetrated by roots for water uptake. Because of the natural variability in soil depth (the depth of the black soil material), the whole watershed area was divided into shallow ($<$50 cm soil depth) and medium-deep ($\geq$ 50 cm soil depth) blocks. Each block was further divided into two parts to which two landform treatments were assigned. The landform treatments were broadbed and furrow (BBF) and flat systems. The width of the bed in the BBF landform was 1.0 m with 0.5 m wide furrows on either side of the bed. The whole watershed thus consisted of four hydrological units arising from the factorial combinations of two soil depths and two landforms, which were : 1) flat shallow, 2) BBF shallow, 3) flat-medium-deep, and 4) BBF medium-deep (Fig. 2). The size of each hydrological unit was different ranging from 0.75 to 1.27 ha. Because of physical restrictions besides their natural occurrence, these hydrological units were not replicated. These hydrological units were further partitioned into 6-8 subplots, ranging in size from 0.07 to 0.20 ha, and treated as replications (Fig. 2). Two cropping systems (soybean / pigeonpea, soybean + chickpea) assigned were grown to these subplots. Sowing of crops in the BBF system was done on a 0.8% grade, while in the flat system it was done along the contour lines. Detailed observations on various aspects of crop growth and resource use were recorded on these sub plots in each hydrological unit.

Treatments (2x2x2=8):

1) Landform treatments : 2
    - i) Flat
    - ii) Broadbed and furrow (BBF)
2) Soil depths : 2
    - i) Shallow soil (< 50cm)
    - **ii)** Medium-deep soil (≥ 50 cm)

3) Cropping systems : 2
    - i) Soybean + pigeonpea (intercrop)
    - ii) Soybean + chickpea (sequential)

No. of blocks (replications) are not common for all the treatments.

1) Flat-shallow	– 4
2) Flat-medium-deep	– 4
3) BBF-medium-deep	– 4
4) BBF – shallow	– 3

Net plot size : 225 sq. m

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 1.0 m breadth and a furrow of 0.5 m width. The field was levelled to erase any micro-relief. Seedbed preparation was completed during the dry season, well ahead of the sowing time, with minimal tillage and soil compaction.

Rainy Season: A basal dose of 250 kg ha^{-1} of single superphosphate (16% P_20_5) was incorporated before sowing of soybean and pigeonpea. *Glyricidia* loppings and FYM were broadcaste in the field 7 and 10-13 days before sowing of soybean and pigeonpea, respectively. The soybean and pigeonpea seeds were treated with *Rhizobium japonicum* and IC3195 respectively @ 70 g 25 kg^{-1} seed and dried in the shade. No chemical N was applied. *Glyricidia* leaves were used as source of nitrogen. Microplots were demarked with iron pegs in subplots. The details of crops and varieties used in the experiment are given in Table 4. Sowing was done with a bullock operated seed drill at recommended plant spacings (Table 4). Soybean and pigeonpea were sown on 7 Jul 1997 (on the onset of the monsoon). In 1998 soybean and pigeonpea were sown on 16 June 1998. The sowing pattern in case of soybean / pigeonpea crop was as 4 rows of soybean + one row of pigeonpea on the bed and in case of the sole crop 4 rows of soybean. To control weeds pre-emergence herbicide (Fluchloralin @ 2.25 a.i ha^{-1}) was sprayed for the control of narrow leaf weeds and grasses. Gap filling was done 7-10 days for soybean and pigeonpea during 1997 and 1998. Thinning was done 16-23 days after sowing (DAS) during 1997 and 40-45 DAS during 1998 for soybean and pigeonpea. One hand weeding was given at 16-30 DAS for soybean during 1997 and 1998. Two hand weedings were given at 16-30 DAS and 120

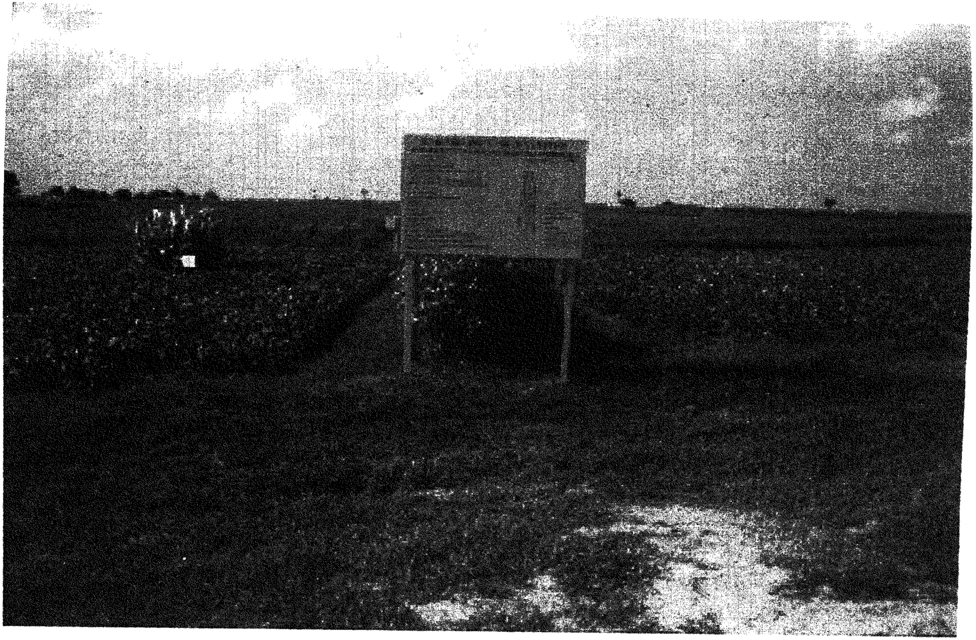


Plate 1. Experimental site of BW7 Watershed

DAS for pigeonpea during 1997 and 1998. Post emergence herbicide (Paraquat 40 EC @ 4.0 L ha^{-1}) was applied for the control of grasses.

Full plant protection was provided to control pests and diseases. Various pesticides used included Dimethoate (30 EC @ 1 L ha^{-1}) against leaf minor in soybean, Endosulfan (35 EC @ 2 L ha^{-1}) against jassids and caterpillers in soybean; Endosulfon (35 EC @ 2 L ha^{-1}); Quinolphos (30 EC @ 3 L ha^{-1}), Methomyl (12.5 EC @ 4 L ha^{-1}) against *Helicoverpa* in pigeonpea. *Helicoverpa sp.* is a polyphagous pest, but it is effectively controlled by Methomyl (12.5 EC @ 4 L ha^{-1}). During 1997, pigeonpea crop was fully affected due to heavy infestation of *Helicoverpa* sp., so more chemicals were used for control of this larvae. During 1998, for control of this larvae Methomyl (12.5 EC @ 4 L ha^{-1}) was used and also the *Helicoverpa* larvae were effectively controlled by shaking of pigeonpea plants and larvae were collected in bags and destroyed.

Post-rainy season During this season, no land preparation and fertilizers were applied. The chickpea seed was treated with IC 59 @ 70 g per 25 kg seed and dried in the shade. Sowing was done with a bullock operated seed drill at recommended plant spacings (Table 4). Chickpea was sown on 9 October 1997 immediately after harvesting of the sole soybean crop. In 1998, chickpea was sown on 21 October 1998. The sowing pattern in case of chickpea was as 4 rows of chickpea. Gap filling was done 8-10 DAS for chickpea during both 1997 and 1998. Three hand weedings (21, 40 and 65 DAS) during 1997 and two hand weedings (30 and 70 DAS) during 1998 were given for chickpea. Post emergence herbicide (Paraquat 40 EC @ 4.0 L ha^{-1}) was applied for the control of grasses. Methomyl (12.5 EC @ 4 L ha^{-1}) pesticide was used against *Helicoverpa* sp in chickpea. Birds resting stands were installed in the field for pest control in chickpea.

Plate 2. Aerial view of the BW-7 watershed experiment.

Table 4. Crops and varieties.

Crop	Variety	Duration	Spacing	Seed rate
Soybean	PK 472	90-100 days	30 cm x 10 cm	50-60 kg/ha
Pigeonpea	ICPL 87119	180 days	150 cm x 30 cm	8-10 kg/ha
Chickpea	ICCC 37	100 days	30 cm x 10 cm	50-60 kg/ha

The crops were harvested at maturity. Harvest was carried out from an area of 225 sq. m which included 5 locations of each plot, at each location 3 broad beds (10 m length and 4.5 m width) were included

Microplot

For quantifying the biological nitrogen fixation (BNF) by soybean, pigeonpea and chickpea, microplots (2x1.2 m^2) were selected in the mainplot. For the estimation of BNF by ^{15}N isotope dilution technique 10 atom% ^{15}N excess was applied to 10 kg N ha^{-1} in the form of $(NH4)_2SO_4$ only during the prior to sowing of the soybean and pigeonpea crops. In 2x1.2 m^2 microplot of sole soybean, in one m length non-fixing sorghum CSH9 (short duration) plants were grown along with sole soybean plants in remaining one meter length (in one m length 4 rows soybean besides in one m length 4 rows sorghum CSH9). In case of soybean/pigeonpea plots, in place of four soybean rows, four rows were planted with CSH9 and in place of pigeonpea row, one row of long duration sorghum variety IS 17820 was planted. For sorghum plants the spacing at 10 cm was maintained. In case of chickpea microplots, in one m length non-nodulating chickpea (Va 4918M) plants were grown along with nodulating chickpea plot. All other agronomic practices were similar for microplots as mentioned for the main field. At harvest, BNF in soybean, pigeonpea, chickpea was

Plate 3. Aerial view of the BW-7 watershed experiment

estimated by N difference method and ^{1}N isotope dilution method was used. Sorghum and non-nodulation chickpea are non-biological crops grown in the microplots as a N fixing control.

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 and post rainy seasons of 1997-98 and 1998-99 are presented in Tables 1 and 2. The rainfall received in the two years of study was substantially different. The amount of rainfall recorded during rainy and post-rainy seasons was 523 mm and 111 mm, 1053 mm and 20 mm during 1997-98 and 1998-99 respectively.

3.5.2 SOIL CHEMICAL AND BIOLOGICAL PROPERTIES

3.5.2.1 Sampling details

Soil samples from 0 to 30 cm depth were collected in polythene bags and stored at low temperature (4-5 C) in a cold room till they were analyzed. The soil samples were collected at pre sowing, vegetative, pod formation and at harvest were processed and sieved through 2 mm sieve.

3.5.2.2 Mineral N (NH_4^++NO_3)

Materials and reagents

2M KCl, dried MgO, Devarda's alloy, 0 005 N H_2SO_4, wide mouth screw cap bottles, 4% boric acid, autotitrater and distillation unit

Method

Mineral N (NH_4 + NO_3) content in the soil was estimated by extracting soil (20 g dry weight basis 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 was analysed for NH_4+ NO_3 (t_0) by distilling the aliquot in a microkjeldahl apparatus using 0 2g MgO and 0 2 g Devarda's alloy It was titrated with 0 005 N H_2SO_4 (Jackson, 1973), 1 mL of 0 005N H_2SO_4 equals 70 µg of N content N content was calculated as under

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

Where

A = Normality of H_2SO_4 (0 005 N) x 70

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

3.5.2.3 Net N mineralization

Materials and reagents :

2M KCl, dried MgO, Devarda's alloy, 0 005 N H_2SO_4, wide mouth screw cap bottles, boric acid and indicator solution

Method

Net N mineralization is the difference between actual N mineralized and microbial immobilization of N. An increase in mineral N levels with time indicates net mineralization. It is calculated as :

Net N mineralization = $(NH_4^{+}N + NO^{-}_{3}N)_{t10} - (NH^{+}_{4\,0}N + NO^{-}_{3\,0}N)_{t0}$

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 $\mu g\ g^{-1}$ soil (t_{10}) - mineral N $\mu g\ g^{-1}$ soil (t_0)

(μg N g^{-1} soil 10 d^{-1})

3.5.2.4 Soil respiration

It was estimated according to the method of Anderson (1982). A 20 g dry weight basis 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. Twenty mL of standard IN NaOH solution was pippeted into another small 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 0.5N HCl.

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 and

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

3.5.2.5 Microbial biomass

Reagents

Alcohol free chloroform ($CHCl_3$), IN NaOH, 0.05 NHCl, 3N $BaCl_2$, 2M KCl, MgO, boric acid indicator and Devarda's alloy, 0.005 H_2SO_4

Method

Microbial biomass was estimated by ninhydrin-reactive nitrogen extracted from soil fumigated for 5 days according to the method of Amato and Ladd (1988). A 20 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 alcohol-free $CHCl_3$ (chloroform) and the other set was left unfumigated. For fumigating the soil samples, glass beakers were kept in a large vacuum 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 vacuum pump till the chloroform started boiling. $CHCl_3$ was allowed to boil for 1-2 minutes and then the desiccator was sealed and incubated. The soil samples were placed 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 desiccator after 5 days fumigation and incubation was removed using vacuum pump repeatedly allowed air to enter and evacuating air posses to remove the chloroform vapours completely from the desiccator. Slowly desiccator was opened and soil sample beakers were removed. The vacuum was then slowly released in the desiccator 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 ninhydrin-reactive N. Five mL aliquots of the extract was passed through a millipore prefilter (AP20 01300). Ninhydrin-reactive N was estimated by reacting 0.5 mL aliquots and 3.5 mL of filtered 2 M KCl extracts with a ninhydrin reagent (2 mL) (Aldrich Chemicals) pipetted to tubes and shake on test tube shaker. The solution in test tubes were arranged in aluminum cage and immersed in boiling water (100°C). The sample test tubes were kept for boiling upto 15 minutes and cooled in ice water, collected test tubes were added with 5 mL 58% alcohol and test tubes were shaked and sealed with paraffin and the absorbances were read at 570nm. Non-fumigated 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

3.5.3 Quantification of BNF

3.5.3.1. Nodulation and Acetylene reduction assay (ARA)

This was done twice. Plants were cut at ground level, and the roots and nodules were dugout and collected. Soil was dug carefully to collect most of the roots and nodules readily apparent in the soil matrix. Roots and nodules were placed into a 800 mL glass bottle. The bottle was closed with a lid and sealed to make it air tight. 80 mL of air was evacuated from bottle and then 80 mL of acetylene was injected into it. After an incubation of 30 min. 5 ml gas sample was collected in pre-evacuated venoject tube 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 0.6 cm O.D., packed with porapack N. 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}. Acetylene reduction assay (ARA) was calculated as follows:

$X = ((C_2H_4 / SE) \times (BA / C_2H_2)) - BE / SE$

$Y = (110 \times V.C \times GV) / 22.4 \times 0.5$

$\mu m\ C_2H_4\ h^{-1} = X \times Y \times 0.06$

where $\mu m\ C_2H_4\ h^{-1}$ = Micro moles of ethylene produced per hour.

C_2H_4 = Sample ethylene

C_2H_2 = Sample acetylene

BA = Blank acetylene

BE = Blank ethylene

V C = Vacutainer Correction Factor (total volume of vacutainer/amount of gas sample injected

GV = Gas Volume

SE = Standard ethylene

0 5 = Time of incubation (h)

22 4 = Gas constant

0 06 = Correction factor for converting micro moles to nano moles

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)

3.5.3.2. N-Difference method

The simplest field estimates of N fixation are obtained by measuring total amount of N in the legume crop Kjeldahl analysis for N content of plant dry matter can be used to estimate total N yield of legumes This technique is based on the assumption that the test legume and reference plant remove identical amounts of N from the soil Some seasonal variations of the N-difference method do exist Generally the quantity of legume and N derived from N_2 fixation (Q) is calculated as

Q = N yield (legume – N yield (reference)

3.5.3.3 ^{15}N isotopoe dilution method

In this method ^{15}N labelled fertilizer or organic materials were added to the growing soil medium in amounts insufficient to significantly affect N_2-fixation, in an attempt to label the inorganic nitrogen pool from which the plants obtain their nitrogen The method assumes that roots of the test crops or varieties utilize the same volume of soil for their nitrogen requirement

Both fixing and a nonfixing reference plants are grown in the presence of a ^{15}N labelled source in as near-identical conditions as is practical If both the plants contain identical concentrations of ^{1} N, no N_2 fixation has occurred Any ^{14}N incorporated by the presumed fixer from the atmosphere will lead to a lower ^{15}N concentration i e , isotope dilution occurs From the comparisons of the ^{15}N contents of the two plants it is possible to calculate the amount of N fixed

$$\% \text{ N fixed} = 1 - \frac{\text{atom\% N excess(fixing plant)}}{\text{atom\% N excess(non-fixing plant)}} \times 100$$

Actual N fixed = % N fixed x total N uptake by the plant

3.5.4 Estimation of nitrate N loss through runoff water

The nitrate N loss through runoff water was estimated by collecting and analysing runoff water samples for each runoff events from the experimental watershed Runoff from each hydrological unit was measured by installing 1 5' H-flumes with mechanical stage level recorders which provides the detailed information on runoff such as (a) number of runoff events, (b) runoff volume (c) peak runoff rates, and (d) flow duration and time to peak rate The runoff water samples were collected by automatic pumping

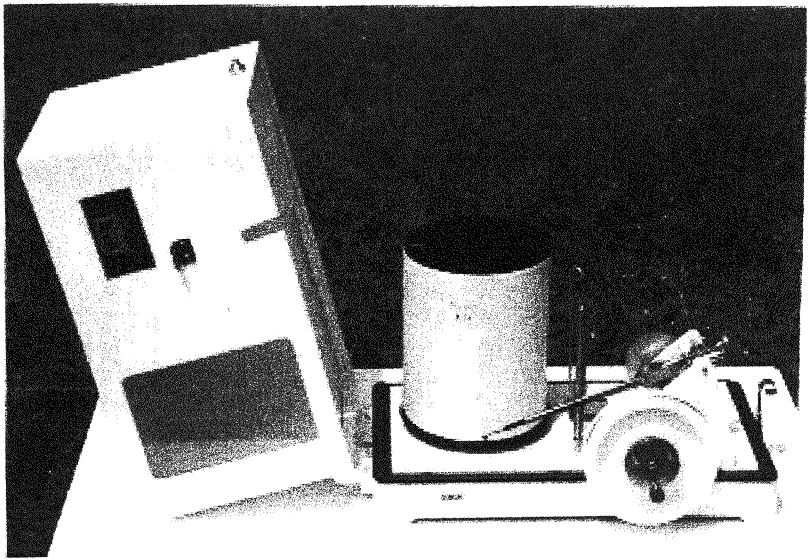


Plate 4 A drum-type recorder for the continuous recording of runoff

sediment sampler The runoff gauging site in the experimental watershed is equipped with H-flume stage-level recorder and automatic pumping sediment sampler The working of the runoff measuring devices and automatic pumping sediment samplers are described in the following paragraph

Runoff measurements :

Various methods are available for measuring runoff depending upon the specific needs of the location Any method selected should measure runoff accurately for low, medium and high discharge rates Precalibrated devices such as flumes and wiers along with automatic stage level recorders for measuring runoff are most commonly used at research stations because of their high accuracy (USDA,1979)

Accurate determination of runoff volume, peak runoff rate, and other related information from small areas invariably requires the continuous recording of the water level during runoff event Stage-level recorders are commonly used for this purpose A stage-level recorder produces a graphic record of the stage of flow over a control with respect to time and it is accepted as very reliable (Laryea *et al*, 1997) The mechanical stage-level recorder (5-I W-1) mechanically converts the vertical movement of a counter-weighted float resting on the surface of a liquid into a curvilinear, inked record of the height of the surface of the liquid relative to a datum plane and with respect to time The time element consists of a weekly winding spring-driven clock supported on a vertical shaft to which the chart drum is firmly secured vertically The gauge element consists of a float and counterweight-graduated float pulley The movement of the float is transmitted to a cam and, with the help of a set of gears it moves the pen on the chart in a vertical

Plate 5 H-flume attached to a stilling well and connected to a drum type recorder for measuring runoff

direction. Some recorders have a reversing mechanism and can therefore record an unlimited range of flow depth.

The runoff chart thus obtained from a stage-level recorder gives a continuous record of depth of flow with respect to a reference level, and as a function of time. This stage graph is subsequently processed to obtain the runoff rates and volumes that are later used for analysis (Pathak *et al.*, 1981).

Pumping sediment sampler for runoff sample collection :

Automatic pumping sediment sampler monitors rapidly fluctuating flow nature to account for the temporal variation in the suspended sediment and nutrient concentration during the runoff event (Pathak, 1991). The sampler consists of mechanical circular structure fitted with windscreen wiper motor (DC shunt motors) and pump motor with about 50 bottles and controllable by an electronic module specially designed for this purpose.

The microcontroller control unit, which when initialized by the water level sensors, operates the system, first by purging the pipe to clean off the old sample water, positions the nozzle on sample hole and then pumping the sample water into a bottle and positions the nozzle on to the next purge hole. This way, one sample bottle is filled as per the set time (i.e., 5,10,15 or 20 minutes interval) during a runoff event. The pump is kept at the center of the channel, completely immersed in the flowing water. About 750 ml of runoff water is pumped into each bottle. A total of 50 bottles per runoff event can be collected. The system stops automatically with the help of a micro-switch after pumping 50 bottles.

Runoff water samples thus collected are analyzed in the laboratory for NO_3^- N concentration The nitrate loss was calculated as follows:

$$\text{Nitrate N loss (kg ha}^{-1}\text{)} = \frac{\text{Runoff (m}^{3}\text{)} \times \text{N concentration (g L}^{-1}\text{)}}{10 \times \text{Area (ha)}}$$

3.5.5 Vesicular arbuscular mycorrhizal fungi (VAMF):

The quantification of Vesicular arbuscular mycorrhizal fungi (VAMF) colonization in plant roots was carried out by the Phillips and Hayman (1970) procedure for clearing and staining roots for rapid assay of mycorrhizal colonization. It represents a major break through in VAM research

Procedure for assessing mycorrhizal colonization in the host plant roots.

Root sample collection:

The primary site for VAM to develop is in the cortical region of the terminal feeder roots which is the most active site for nutrient uptake. As roots mature, the cortex ruptures and is sloughed off and, thus mycorrhizae are seldom observed in older roots. The roots were excavated carefully and collected the subsample of terminal feeder roots. The reprehensive subsample of the entire root system was collected from four or five different portions. The root samples were washed gently with tap water carefully to remove any adhering soil particles and placed in autoclavable vials or screw cap tubes.

The roots were preserved in FAA (formalin: acetone: alcohol = 5:5:90 v/v) till cleared for staining. Clearing and staining procedure for roots:

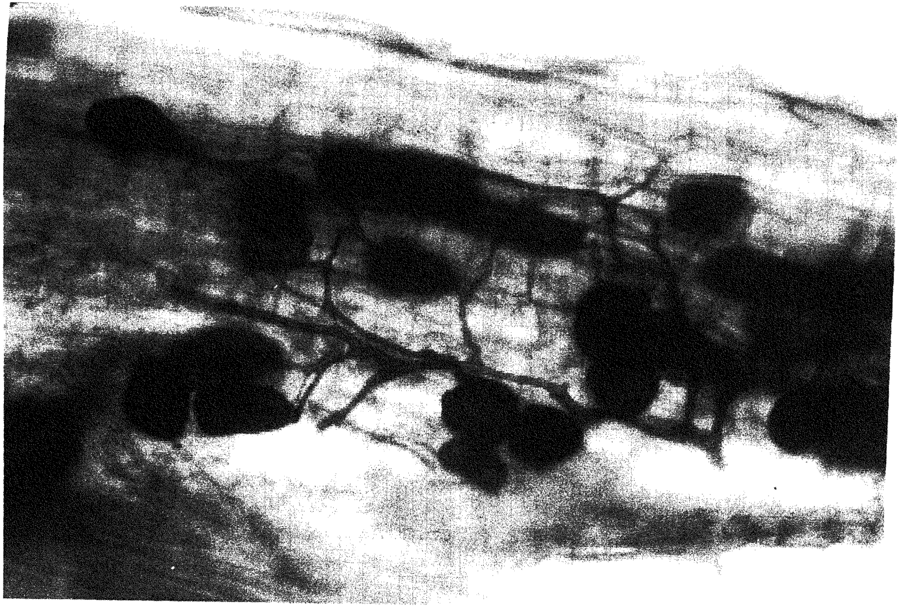


Plate 6. Mycelia + vesicles of mycorrhiza in pigeonpea at 133 DAS during kharif 1998

1 The roots were cut into 3 cm segments and placed in the vials Potassium hydroxide solution (8%) was added so that the roots were completely immersed in the solution

2 The roots were digested at 96°C for 5 min in an autoclave Duration of digestion in the autoclave should be standardized based on the crop, age of the plant and growth conditions

3 KOH solution was decanted out carefully after autoclaving, and 1% HCl was added and allowed to stand for 10 min to neutralise excessive KOH and decanted later

4 Trypan blue solution (0 08% trypan blue in lactic acid-glycerol) was added and allowed to stand for 24 hours

5 The stain was decanted and lactic acid glycerol solution (without trypan blue) was added and preserved till the roots were observed for mycorrhizal colonization

6 Roots were arranged on glass slide and observed for the presence of vesicles and arbuscules

7 Relative content of mycorrhizal colonization was calculated as follows

$$\text{Present mycorrhizal colonization} = \frac{\text{No of root segments with mycorrhizal colonization}}{\text{Total no of root segments observed}}$$

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

Because of the large subplot size, five samples of both rainy and post rainy season crops were taken from each subplot to determine their yields at harvest Each year the total area harvested per sub plot was 225 m sq The harvested material was dried in a large hot-air oven at 60^{0}C for a week and then weighed The harvested material was threshed to separate the seed from the stalk and weighed to determine seed yield

Plate 7 . Mycelia + vesicles of mycorrhiza in pigeonpea at 133 DAS during kharif 1998

3.7. Plant Chemical Analysis.

Plant samples collected at vegetative, pod formation and at harvest stages of each crop were oven dried. The dried samples were powdered and analysed for the contents of N, P and K in soybean, pigeonpea and chickpea as per the procedures given in Table 5. The uptake of nutrients by crop was calculated as follows:

$$\text{Nutrient uptake (kg ha}^{-1}\text{)} = \text{Drymatter (kg ha}^{-1}\text{)} \times \frac{\text{nutrient concentration (\%)}}{100}$$

Table: 5. Plant Analysis.

Properties	Method of analysis
Nitrogen (%)	Macro kjeldahl's method (Jackson, 1973)
Phosphorus (%)	Triacid digestion method (HNO_3, H_2SO_4 and $HClO_4$ in the ratio of 10:4:1) and by using Klett summerson photoelectric colorimeter (Jackson, 1973)
Potassium (%)	Triacid digestion method (HNO_3 and $HClO_4$ in the ratio of 10:4:1) and by using flame photometer (Jackson, 1973)

4. STATISTICAL ANALYSIS FOR FIELD EXPERIMENTS:

Experimental data were analyzed for statistical variance using the REML (Restricted maximum likely-hood) analysis. The GENSTAT package (Genstat Manual, 1983) in a vax mainframe computer system was also used. For this the four hydrological units were treated as different locations, and the data were analyzed by following the procedure of multilocation analysis. Whereas, the data in rainy season was analyzed for each sampling date separately as per the following linear additive random effects model:

Landform + soil depth + landform. soil depth + landform. soil depth. replication + cropping system + cropping system. landform + cropping system. soil depth + cropping system. landform. soil depth.

Whereas, the data in post-rainy season was analyzed for each sampling data separately as per the following linear additive random effects model

Landform + soil depth + landform soil depth + landform soil depth replication

5. LAB EXPERIMENT

5.1 Potentially mineralizable N (N_0)

AIM

Estimation of the Nitrogen mineralization potentials (N_0) of Vertic Inceptisol by the incubation leaching method

Principle of Method

The method is based on the incubation of soil in a column at 30°C At proper time intervals the mineral N is leached and determined

Objectives

The overall objective of this study was to measure nitrogen release through decomposition of the added organic residues as influenced by their position on soil The specific objectives were

1 Study effect of residues application on nitrogen potential

2 To model the patterns of nitrogen mineralization potential

Materials and Methods

Site description and cropping system

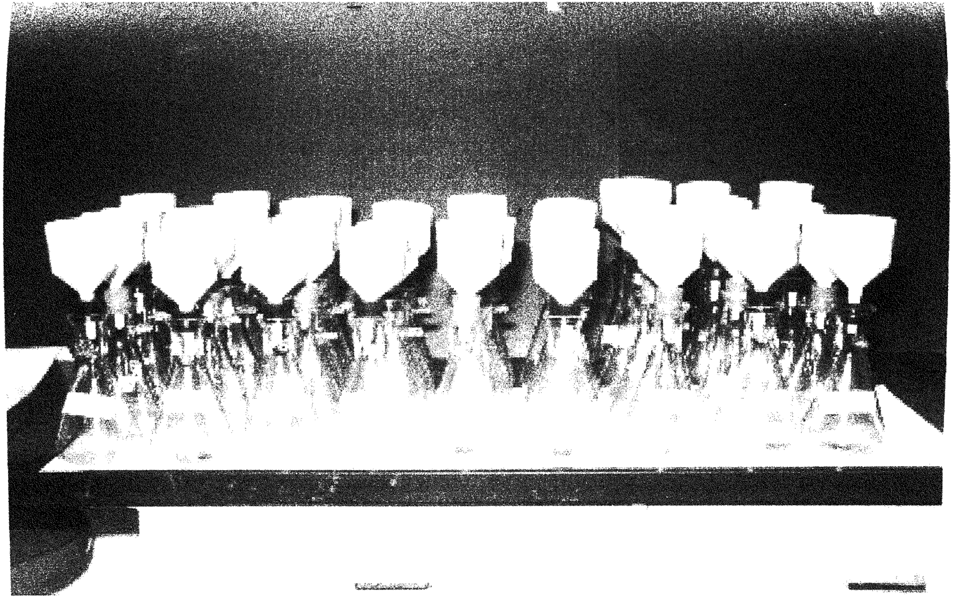


Plate 8 . Lab experiment - 1 Potentially mineralizable N (No)

The soils used in this study were from the main field of BW7 watershed (Vertic Inceptisol) at ICRISAT Asia Center, Patancheru, Hyderabad, India The experiment was started in the rainy season of 1995 Two cropping systems with one year rotation were selected i) Soybean / pigeonpea system during the rainy season ii) soybean + chickpea system during the post rainy season All the crops were grown rainfed and no mineral N was applied to any plot for the duration of the study After the harvest of third year crops, soil samples were collected from 0 15 cm depth at different locations from entire field and mixed all the soil samples in early April 1998 Organic residues viz *Glyricidia* stem and *Glyricidia* leaves were collected from contour bunds of BBF landforms and pigeonpea fallen leaves and roots were collected from the main field of all landforms after harvesting of the third year crop

Treatments 9

1) Organic residue levels 4

2) Application levels 2

3) Control

Organic residue levels 4	Dryweight basis
1 Glyricidia Stem	2 t ha^{1}
2 Glyricidia leaves	2 t ha^{1}
3 Pigeonpea roots	2 t ha^{1}
4 Pigeonpea leaves	3 t ha^{1}

II Application levels - 2

1 Incorporation into the soil

2 Application on the soil surface

III Replications 4

Treatment details

1 Control

2 *Glyricidia* stem on surface soil

3 *Glyricidia* stem incorporation in the soil

4 *Glyricidia* leaf on surface soil

5 *Glyricidia* leaf incorporation in the soil

6 Pigeonpea root on surface soil

7 Pigeonpea root incorporation in the soil

8 Pigeonpea leaf on surface soil

9 Pigeonpea leaf incorporation in the soil

Procedure

Mineralizable N was determined in 4 replications from each treatment using a leaching incubation procedure (Wani *et al* 1995 b) Nonserved soil (50 g) and acid-washed sand (50 g) were mixed and placed in a Buchnner funnel (7 5 cm dia) on top of a fine layer of glass wool on a fibre glass filter paper The soil surface was covered with a glass wool layer to avoid disturbance to the soil surface during extractions The soils were leached with 150 ml 0 01 M $CaCl_2$ with 25 mL increments followed with 50 ml N-free nutrient solution containing 0 002M $CaSO_4$ $2H_2O$, 0 002M $MgSO_4$ $7H_2O$, 0 005 M Ca $(HPO_4)_2$ 2H O and 0 0025 M K SO_4 (Wani *et al* 1995 b) at 0, 5, 10 15, 25, 50 75, 100 and 150 days The soils were incubated at 30 C in the dark with the moisture content maintained at 70% water holding capacity (Wani *et al* 1995 b)

Chemical analysis

The aliquot of CaCl leachates was analyzed for NO_3 -N and NH_4 -N by distilling the aliquot in a microkjeldahl apparatus using MgO and Devarda s alloy (Jackson 1973)

Mathematical and statistical analysis

The data were subjected to an analysis of variance and treatments were compared using the F test of significance and least square difference (Panse and Sukhatme 1957) A non-linear least squares fitting procedure was used for the exponential model, a linear regression package was used for the linear model (SAS 1987)

1) The first was linear $Nt = \chi x t$

Where Nt is the net quantity of N mineralized (mg kg^{-1}) χ is the zero order rate constant (mg $kg^{-1}wk^{-1}$) and t is time (day) The second was an exponential model describing net accumulation of mineral N during first order decomposition of N from a potentially mineralizable N source

$$Nt = N_o[1-\exp(-kxt)]$$

Where Nt is the cumulative net N mineralized (mg kg^{-1}) over time t (day), K is the first order rate constant (day^{-1}) and No is the potentially mineralizable N at t=0

5.2 Carbon mineralization (CO_2 evaluation)

Principle of the method

The method is based on the incubation of soil in a column at 25°C At proper time intervals the CO_2 is released and determined

Objectives

The overall objective of this study was to estimate the CO_2 release through decomposition of the added organic residues as influenced by their position on soil The specific objectives of the study were

1 Study the effect of residues application on decomposition rate (C mineralization)

2 To model the patterns of CO_2 release

Materials and methods

Site description and treatments are same as mentioned in laboratory experiment I

Materials

Airtight screw type lid glass jars 1 L capacity (the lids should be of good quality plastic), glass bottles to hold alkali solution, magnetic stirrer and magnet bar autotitrator or burette

Plate 9 . Lab experiment - 2 Carbon mineralization.

Reagents 1N NaOH 3N $BaCl_2$ phenolphthalein indicator, 0 5N HCl

Procedure

250 g of soil is placed in glass jars and added to the organic residues on the soil surface and incorporated into the soil 75 ml of water is added to the soil (40% water holding capacity) 20 mL of 1N NaOH solution is pipetted into a glass bottle and placed into the same jar closed the lid of the glass jar and make it air tight Incubated the jars for1, 2, 4 6 8 12 16 and 20 weeks at 25°C At the end of incubation period removed the alkali bottles from the jars labelled them and closed with parafilm to avoid CO_2 absorption from the atmosphere Pipetted out an aliquot of the alkali and added an excess amount of $BaCl_2$ to precipitate the carbonate as $BaCO_3$ Added few drops of phenolphthalein indicator and titrated the un-neutralized alkali with standard HCl directly

Mathematical and Statistical analyses are same as mentioned in laboratory experiment I

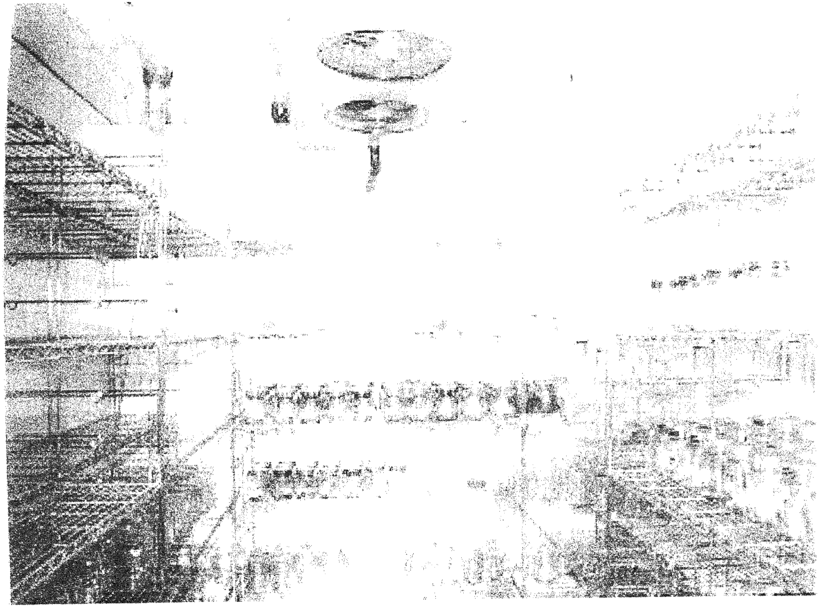


Plate 10. Incubator (at 25^{0}c)

Results

CHAPTER IV

RESULTS

The results of the field experiments carried out on a Vertic Inceptisol watershed at ICRISAT, Patancheru Center during the rainy, and postrainy cropping seasons of 1997 and 1998 to evaluate the impact of the land management practices on nutrient (N, P) budgets of soybean-based cropping systems, nitrogen and organic matter dynamics in soil and systems productivity are reported here The results of laboratory experiments with Vertic Inceptisol to study patterns of C and N release from pigeonpea and *Glyricidia sepium* residues are also described in this chapter

4.1 WEATHER

4.1.1. Weather during 1997-98

In 1997, during the rainy season, 523 mm and during post-rainy seasons, 111 mm rainfall was recorded at the agrometeorological observatory at ICRISAT Patancheru Center The monsoon rains arrived in the first week of Jul Earlier 64 mm of rainfall was received during the period 17 Apr to 6 May which helped in tillage operations During Jun, there were only 6 rainy days (19mm) In the rainy cropping season 82% of the rainfall was received from Jul to Sep Soil water balance of a Vertic Inceptisol was estimated using Ritchie's model (Fig 3a) During the entire rainy season, soil moisture did not reach to a level of 150 mm In the month of Jun, only 19 mm of rain was received which delayed the sowing of rainfed crops 52 mm of rainfall was received in the first week of Jul, which helped sowing of the crops Crops suffered from moisture stress during the rainy season in

Figure 3a. Water balance at ICRISAT during 1997

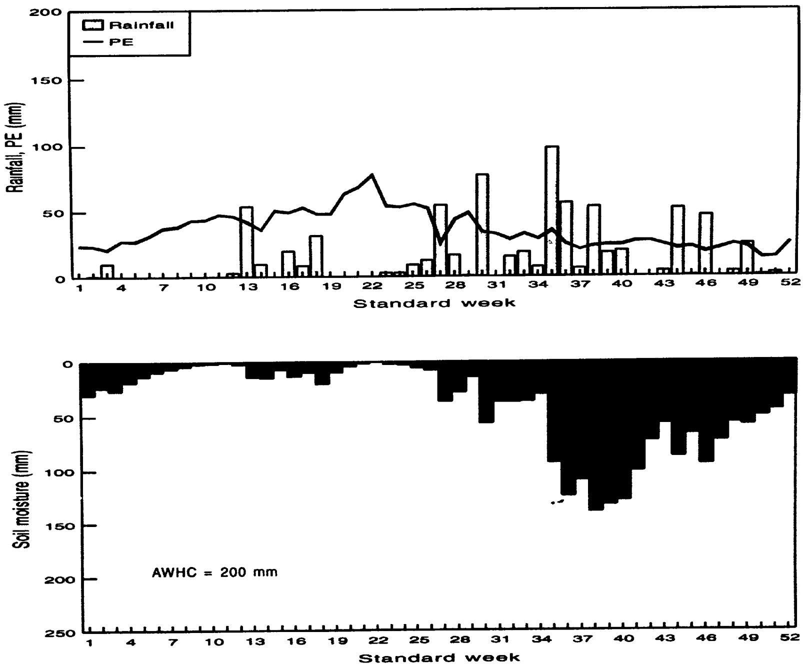
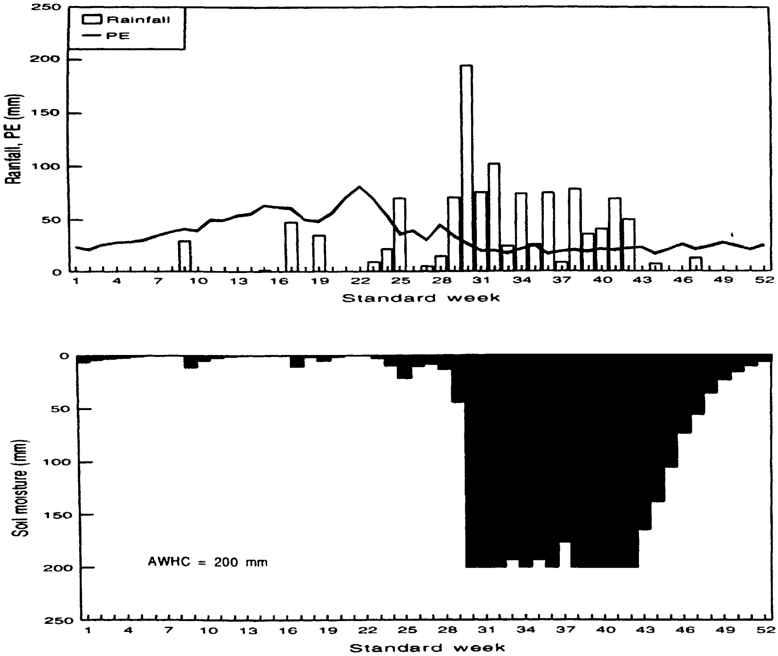


Figure 3b. Water balance at ICRISAT during 1998



1997 Therefore, *Helicoverpa* infestation on pigeonpea was high Overall, 1997 was not a good year for rainfed crop production in the Hyderabad area

In the post-rainy season (November – March) a total of 111 mm rainfall in 13 rainy days was recorded In November and December, only 81 mm of rain was received, no rains January and February in 1998 were received

4.1.2 Weather during 1998-99

In 1998, during the rainy season a total of 1053 mm in seventy nine rainy days and during the post-rainy season, 20 mm rainfall in seven rainy days was recorded at the agrometeorological observatory at ICRISAT Patancheru Center Soil water balance was estimated using Ritchie's model (Fig 3b) From the first 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 Crops did not suffer from water deficit at any time during the rainy season Overall 1998 was a good year for rainfed crop production

4.2 Soil chemical and biological properties

4.2.1 Rainy season (Sole soybean and soybean/pigeonpea intercropping)

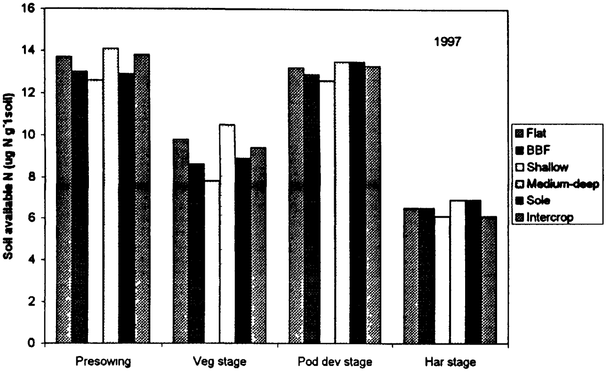
4.2.1.1 Available N (μg N g ^{1} soil) during 1997 (Table 6, Fig. 4)

Available N content in soil varied at different growth stages of sole and intercropped soybean At the pre-sowing highest mean available N content (13 4) in soil was observed and then it was decreased (9 2) at the vegetative stage Subsequently available N content in

Table.6 Soil available ($NH_4^+ + NO_3^-$) nitrogen content (µg N g^{-1} soil) under sole and intercropped soybean grown on flat and BBF landforms and shallow and medium-deep Vertic Inceptisols during rainy season 1997

Landform	Soil depth						
	Shallow			Medium - deep			
	Sole Soybean	Soybean/ Pigeonpea	Mean	Sole Soybean	Soybean/ Pigeonpea	Mean	Total mean
			1) Presowing				
Flat	12 5	13 4	12 9	13 9	14 9	14 4	13 7
BBF	11 8	12 7	12 3	13 3	14 3	13 8	13 0
Mean	12 2	13 1	12 6	13 6	14 6	14 1	13 4
	L	**S**	**C**	**LS**	**LC**	**SC**	**LSC**
S Ed ±	0 32	0 34	0 33	0 48	0 46	0 47	0 58
CD(0 05)	0 70	0 75	0 73	1 06	1 01	1 03	1 28
			2) Vegetative stage (36-41 DAS)				
Flat	8 2	8 6	8 4	10 8	11 3	11 1	9 8
BBF	7 0	7 5	7 3	9 5	10 0	9 8	8 6
Mean	7 6	8 1	7 8	10 1	10 7	10 5	9 2
S Ed ±	0 23	0 24	0 22	0 34	0 32	0 32	0 41
CD(0 05)	0 51	0 53	0 48	0 75	0 70	0 70	0 90
			3) Pod development stage (71-75 DAS)				
Flat	12 4	13 1	12 8	13 2	13 8	13 5	13 2
BBF	12 2	12 4	12 3	13 3	13 5	13 4	12 9
Mean	12 3	12 8	12 6	13 3	13 7	13 5	13 1
S Ed ±	0 27	0 30	0 28	0 41	0 39	0 41	0 54
CD(0 05)	NS	0 66	NS	0 90	NS	0 90	1 19
			4) At harvest (96-112 DAS)				
Flat	6 5	5 7	6 1	7 3	6 5	6 9	6 5
BBF	6 5	5 7	6 1	7 2	6 5	6 9	6 5
Mean	6 5	5 7	6 1	7 3	6 5	6 9	6 5
S Ed ±	0 55	0 75	0 74	0 94	0 92	1 05	1 20
CD(0 05)	NS	NS	NS	NS	NS	NS	NS

[1] L=landform, S=soil depth, C=cropping system, LS=landform x soil depth, LC=landform x cropping system, SC=soil depth x cropping system, LSC=landform x soil depth x cropping system



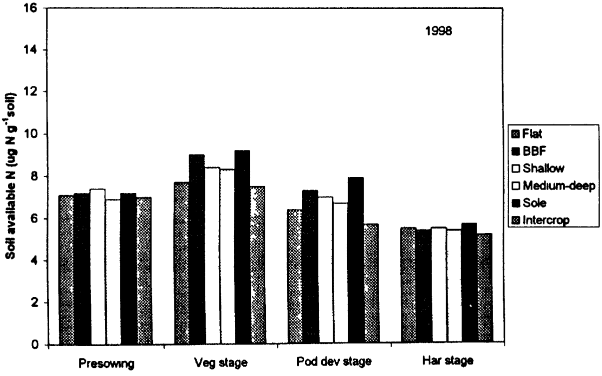


Fig.4: Soil available N content under sole and intercropped soybean as infleuenced by landform and soil depth treatments in Vertic Inceptisols during rainy season 1997 and 1998

soil increased (13 1) at pod development stage and then decreased (6 5) at the maturity stage of the crop

At the pre-sowing, the available N content varied significantly in soil under different landform, soil depth and cropping system treatments and their interactions The soil under flat landform showed a significantly higher available N content (13 7) compared to the BBF landform (13 0) Available N content was significantly higher in the medium-deep soil (14 1) compared to the shallow soil (12 6) The flat landform on the medium deep soil showed the highest (14 4) available N content and the BBF landform on the shallow Vertic Inceptisol showed the lowest (12 3) available N content Significantly higher available N content (13 8) was observed in the plots used for soybean/pigeonpea intercropping compared to the sole soybean treatment (12 9) The flat landform plots with soybean/pigeonpea showed the highest (14 2) available N content whereas the BBF landform with sole soybean plots showed the lowest (12 6) available N The medium deep soil under soybean/pigeonpea showed the highest (14 6) available N content and the shallow Vertic Inceptisol with sole soybean showed the lowest (12 2) available N content The flat landform on the medium deep soil with soybean/pigeonpea system resulted in the highest (14 9) available N content whereas the BBF landform on the shallow soil with sole soybean system showed the lowest (11 8) available N content

At the vegetative stage, the available N content in the soil varied significantly in the landform, soil depth, cropping systems treatments and their interactions The soil in flat landform treatment showed a significantly higher available N (9 8) content compared to the soil under BBF landform treatment (8 6) Available N content was significantly higher in the medium deep soil (10 5) compared to the shallow soil (7 8) The flat landform on the medium deep soil showed highest amount of available N content (11 1) and the BBF landform on the shallow soil recorded the lowest amount of available N content (7 3) Significantly higher available N content (9 4) in the soil was observed in the soybean/pigeonpea cropping system as compared to the sole soybean treatment (8 9) The flat landform with intercropping system showed highest available N content (13 5) while lowest available N content (12 7) was observed in the BBF landform with sole soybean system The medium-deep soil with soybean/pigeonpea system showed a high available N content (10 7) whereas the shallow soil under sole soybean showed the lowest available N content (7 6) The soil under flat landform on the medium deep soil with soybean/pigeonpea cropping system showed the highest (11 3) available soil N whereas the BBF landform on the shallow soil under sole soybean showed the lowest available N content (7 0)

At the pod development stage, the available N content was significantly differed in soils of different depths The soil depth interacted with landforms and cropping systems The interaction of landform x cropping system was significant as far as the available soil N content was concerned The medium-deep soil showed a significantly higher (13 5) available N content compared to the shallow soil (12 6) The flat landform on the medium deep soil recorded the highest (13 5) available N content and the BBF landform on the shallow Vertic Inseptisol showed the lowest available N content (12 3) The medium deep soil with soybean\pigeonpea cropping system showed the highest available N content (13 7) whereas the shallow soil with sole soybean showed the lowest available N content (12 3) The flat landform on the medium-deep soil with intercropping system resulted in the highest available N content (13 8) whereas the BBF landform on the shallow soil with sole soybean system showed the lowest (12 2) available N content

At harvest, the differences in available soil N content under the various landform, soil depth, cropping systems and their interactions were not significant

4.2.1.2 Available N (µg N g ^{1} soil) during 1998 (Table 7, Fig. 4)

Available N status in soil under sole and intercropped soybean was influenced by crop growth stages Mean available N content increased from pre-sowing to the vegetative stage, and then decreased at the harvest stage Highest soil available N content (8 4) amongst the various growth stages was recorded at the vegetative growth stage

At the pre-sowing stage, the available N content was not significantly influenced by landform, soil depth, cropping system treatments or their interactions

At the vegetative stage, the variations in available soil N due to landform, cropping system treatments and their interactions were significant except for soil depth treatments The soil under BBF had a significantly higher available N content (9 0) than the soil under flat landform treatment (7 7) The shallow soil under BBF landform showed highest available N content (9 1) and the flat landform on the medium-deep soil showed lowest available N (7 6) A significantly higher available N status (9 2) was observed in the sole soybean treatments as compared to the intercropped soybean (7 5) Sole soybean grown on BBF showed the highest available N status (9 9) and the intercropped soybean grown on flat resulted in the lowest available N content (6 8) in the soil The medium deep soil under soybean/pigeonpea system showed a lower soil available N content (7 4) compared to the other combinations The BBF landform on the shallow soil with sole soybean resulted in the highest nitrogen content (9 9) whereas the flat landform on the medium deep soil with intercropped soybean showed the lowest nitrogen status (6 7) in soil during 1998

Table.7: Soil available (NH_4^++NO_3) nitrogen content (µg N g^{1} soil) under sole and intercropped soybean grown on flat and BBF landforms and shallow and medium-deep Vertic Inceptisols duing rainy season 1998

Landform	**Soil depth**						
	Shallow			Medium - deep			
	Sole Soybean	Soybean/ Pigeonpea	Mean	Sole Soybean	Soybean/ Pigeonpea	Mean	Total mean
			1) Presowing				
Flat	6 9	7 9	7 4	7 3	6 3	6 8	7 1
BBF	7 1	7 4	7 3	7 4	6 6	7 0	7 2
Mean	7 0	7 7	7 4	7 4	6 4	6 9	7 2
	L	**S**	**C**	**LS**	**LC**	**SC**	**LSC**
S Ed ±	0 41	0 53	0 53	0 68	0 68	0 76	0 94
CD(0 05)	NS	NS	NS	NS	NS	NS	NS
			2) Vegetative stage (36-41 DAS)				
Flat	8 5	6 9	7 7	9 5	6 7	7 6	7 7
BBF	9 9	8 3	9 1	9 8	8 0	8 9	9 0
Mean	9 2	7 6	8 4	9 2	7 4	8 3	8 4
S Ed ±	0 53	0 37	0 53	0 65	0 75	0 65	0 87
CD(0 05)	1 17	0 81	1 17	1 43	1 65	1 43	1 91
			3) Pod development stage (71-75 DAS)				
Flat	7 2	5 1	6 2	7 7	5 5	6 6	6 4
BBF	8 8	6 6	7 7	7 9	5 7	6 8	7 3
Mean	8 0	5 9	7 0	7 8	5 6	6 7	6 9
S Ed ±	0 46	0 44	0 5	0 66	0 69	0 67	0 84
CD(0 05)	NS	NS	1 1	1 45	1 52	1 47	1 85
			4) At harvest (96-112 DAS)				
Flat	5 3	5 4	5 4	5 8	5 2	5 5	5 5
BBF	6 0	5 0	5 5	5 5	5 0	5 3	5 4
Mean	5 7	5 2	5 5	5 7	5 1	5 4	5 5
S Ed ±	0 25	0 26	0 26	0 36	0 36	0 37	0 52
CD(0 05)	NS	NS	0 57	NS	0 79	NS	NS

1, Refer Table 1

At the pod development stage of the crop, the available N soil content was significantly influenced by the cropping system and all treatment interactions Landform and soil depth treatments did not show a significant effect on the available N status The BBF on shallow soil resulted in the highest available N content (7 7) and the flat landform on shallow soil showed the lowest available N status (6 2) Higher available N content (7 9) was observed in the sole soybean treatment It was significantly higher than the soybean / pigeonpea system (5 7) The BBF landform under sole soybeans showed the highest available N content (8 4) while the flat landform with intercropping system showed the lowest soil available N (5 3) The sole soybean grown on the shallow soil resulted in the highest available N status (8 0) whereas the intercropped soybean grown on medium deep soil showed the lowest available N content (5 6) The BBF landform on the shallow Vertic Inseptisol with sole soybean showed the highest available N status (8 8) while the flat landform on the shallow soil with soybean / pigeonpea system contained the lowest available N content (5 1) in the soil

At the harvest stage during1998, the available N content in the soil varied significantly in the two cropping systems The landform x cropping system interaction was also significant, but soil N in other treatments and their interactions was not influenced significantly A significantly higher available soil N status (5 7) was recorded in the sole soybean compared to the intercropped soybean (5 2) The highest available soil N status was recorded under the BBF landform with sole soybean whereas the lowest soil nitrogen content (5) was observed under the BBF landform with intercropped soybean land used system

4.2.2 Post-rainy season (Pigeonpea after harvesting of soybean)

4.2.2.1 Available N (μg N g^{1} soil) during 1997 (Table 16).

At pod development stage of pigeonpea the differences in soil available N content due to landform, soil depth and their interaction were not significant At harvest, soil depth and landform x soil depth interaction significantly influenced the available N status in the soil Landforms had no significant effect on soil available N content Medium-deep soil contained significantly higher available N content (5 8) compared to the shallow soil (4 9) The BBF landform on the medium-deep soil recorded the highest available N status (5 8) whereas the flat landform on the shallow soil resulted lowest available N status (4 8) under pigeonpea

4 2 2 2 Available N (μg N g^{1} soil) during 1998 (Table 16)

In pigeonpea during both stages (pod development and harvest), there were no significant difference in available N content due to landform, soil depth and their interaction

4.2.3 Post-rainy season (Chickpea)

4.2.3.1 Available N (μg N g^{1} soil) during 1997 (Table 17)

Mean available N status of soil was not influenced significantly by landform, soil depth and their interaction under chickpea crop during different stages viz , presowing, vegetative and harvest

4.2.3.2 Available N (μg N g^{-1} soil) during 1998 (Table 18)

Mean available N contents in soil due to landform, soil depth and their interaction were not significantly influenced during different stages of chickpea growth (presowing, vegetative and harvest).

4.2.4. Rainy season (Sole soybean and soybean / pigeonpea intercropping)

4.2.4.1 Net N mineralization (µg N g^{-1} soil 10 d^{-1}) during 1997 (Table 8, Fig. 5)

Net N mineralization in the soil under sole and intercropped soybean changed during the plant growth stage. Mean net N mineralization in soil increased from presowing to vegetative stage and then decreased at pod development stage, and then again increased at harvest. Highest net N mineralization (11.4) was recorded at vegetative stage amongst the growth stages in soybean.

At presowing, net N mineralization in the soil was significantly influenced by cropping systems only. However, other treatments and their interactions had no significant effect. Mean net N mineralization was two fold higher under the sole soybean than under soybean/pigeonpea system (1.8 vs 0.9).

At vegetative and pod development stages, net N mineralization in soil was not changed significantly by the landform, soil depth, cropping system treatments and their interactions.

At the harvest stage during 1997, net N mineralization in soil was changed significantly by the interaction of soil depth x cropping system. Soybean / pigeonpea intercrop grown on medium-deep soil showed the highest net N mineralization (5.9) whereas the sole soybean grown on shallow soil resulted in the lowest net N mineralization (3.9).

Table.8: Soil net N mineralization (µg N g^{-1} soil 10 d^{-1}) under sole and intercropped soybean grown on flat and BBF landforms and shallow and medium-deep Vertic Inceptisols during rainy season 1997

Landform	Soil depth						
	Shallow			Medium -deep			
	Sole Soybean	Soybean/ Pigeonpea	Mean	Sole Soybean	Soybean/ Pigeonpea	Mean	Total mean
			1) Presowing				
Flat	1 7	0 9	1 3	1 9	0 9	1 4	1 4
BBF	1 8	1 0	1 4	1 8	0 9	1 4	1 4
Mean	1 8	1 0	1 4	1 9	0 9	1 4	1 4
	L	**S**	**C**	**LS**	**LC**	**SC**	**LSC**
S Ed ±	0 26	0 28	0 38	0 38	0 45	0 47	0 56
CD(0 05)	NS	NS	0 84	NS	NS	NS	NS
			2) Vegetative stage (36-41 DAS)				
Flat	10 6	10 7	10 7	11 3	11 4	11 4	11 1
BBF	11 1	11 2	11 2	11 9	12 1	12 0	11 6
Mean	10 9	11 0	11 0	11 6	11 8	11 7	11 4
S Ed ±	0 53	0 56	0 37	0 79	0 64	0 67	0 87
CD(0 05)	NS	NS	NS	NS	NS	NS	NS
			3) Pod development stage (71-75 DAS)				
Flat	3 3	2 8	3 1	3 7	3 2	3 5	3 3
BBF	3 2	2 7	3 0	3 5	3 0	3 3	3 2
Mean	3 3	2 8	3 1	3 6	3 1	3 4	3 3
S Ed ±	0 35	0 41	0 42	0 54	0 55	0 59	0 69
CD(0 05)	NS	NS	NS	NS	NS	NS	NS
			4) At harvest (96-112 DAS)				
Flat	3 7	5 1	4 4	3 7	5 7	4 7	4 6
BBF	4 1	4 4	4 3	5 2	6 1	5 7	5 0
Mean	3 9	4 8	4 4	4 5	5 9	5 2	4 8
S Ed ±	0 62	0 61	0 63	0 89	0 88	0 88	1 21
CD(0 05)	NS	NS	NS	NS	NS	1 94	NS

1, Refer Table 1

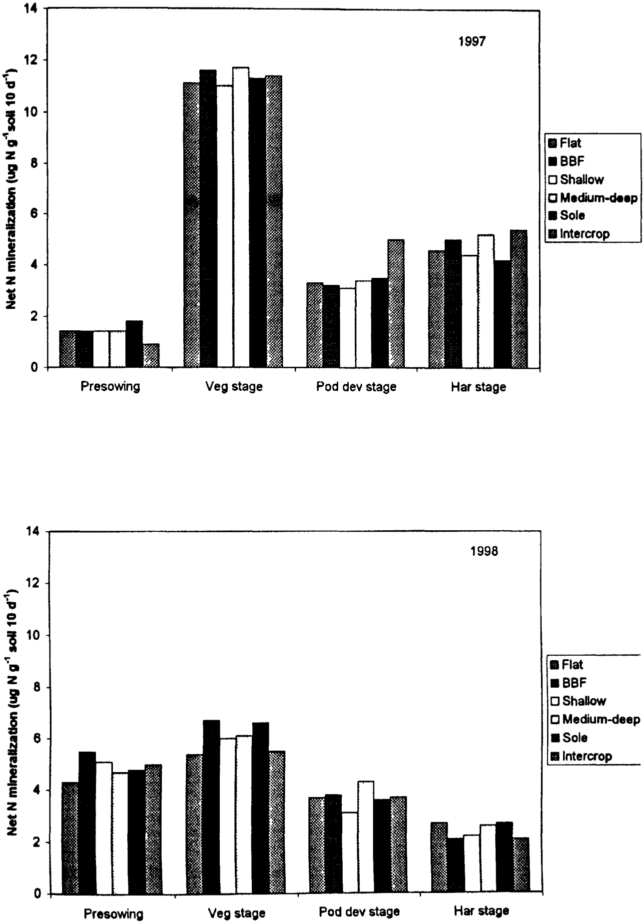


Fig.5: Soil net N mineralization under sole and intercropped soybean as influenced by landform and soil depth treatments in Vertic inceptisols during rainy season 1997 and 1998

4.2.4.2 Net N mineralization (μg N g^{-1} soil 10 d^{-1}) during 1998 (Table 9, Fig. 5)

Mean net N mineralization in the soil increased from presowing to vegetative stage and then decreased up to harvest Highest net N mineralization (6 1) amongst growth stages was recorded at vegetative stage

At presowing during 1998, the differences in net N mineralization in the soil due to landform treatment and interactions between landform and other treatments were significant Mean net N mineralization in BBF system was higher (5 5) as compared to the flat system (4 3) The BBF landform on the shallow soil recorded the highest net N mineralization (5 7) and the flat landform on the medium-deep soil showed the lowest (4 1) net N mineralization The BBF under soybean / pigeonpea system showed the highest (5 8) net N mineralization whereas the flat system with soybean / pigeonpea recorded the lowest net N mineralization (4 2) The BBF on the shallow soil with intercropping system showed the highest net N mineralization (6 0) whereas the flat on medium-deep soil with intercropping system resulted in the lowest net N mineralization (3 9)

At the vegetative stage in soybean during 1998, landform x soil depth and landform x soil depth x cropping system interactions significantly changed the net N mineralization in the soil The BBF landform on the medium-deep soil showed highest amount of net N mineralization (7 9) and the lowest amount of net N mineralization (4 2) was observed under the flat landform on the medium-deep soil The highest net N mineralization (9 3) in the soil was observed under the sole soybean grown on BBF on medium-deep soil and the lowest net N mineralization (3 4) in soil was observed under the soybean/ pigeonpea intercrop grown on flat landform on the medium-deep soil

Table.9: Soil net N mineralization (µg N g^{-1} soil 10 d^{-1}) under sole and intercropped soybean grown on flat and BBF landforms and shallow and medium-deep Vertic Inceptisols during rainy season 1998

Landform	**Soil depth**						
	Shallow			**Medium - deep**			
	Sole Soybean	Soybean/ Pigeonpea	Mean	Sole Soybean	Soybean/ Pigeonpea	Mean	Total mean
	1) Presowing						
Flat	4.5	4.5	4.5	4.3	3.9	4.1	4.3
BBF	5.3	6.0	5.7	5.1	5.5	5.3	5.5
Mean	4.9	5.3	5.1	4.7	4.7	4.7	4.9
	L	**S**	**C**	**LS**	**LC**	**SC**	**LSC**
S.Ed.±	0.38	0.35	0.33	0.61	0.53	0.51	0.84
CD(0.05)	0.84	NS	NS	1.34	1.17	NS	1.85
	2) Vegetative stage (36-41 DAS)						
Flat	7.7	5.2	6.5	4.9	3.4	4.2	5.4
BBF	4.4	6.5	5.5	9.3	6.5	7.9	6.7
Mean	6.1	5.9	6.0	7.1	5.0	6.1	6.1
S.Ed.±	0.97	0.97	0.96	1.41	1.36	1.36	1.97
CD(0.05)	NS	NS	NS	3.10	NS	NS	4.34
	3) Pod development stage (71-75 DAS)						
Flat	3.3	3.4	3.4	3.8	3.9	3.9	3.7
BBF	2.7	2.8	2.8	4.6	4.7	4.7	3.8
Mean	3.0	3.1	3.1	4.2	4.3	4.3	3.8
S.Ed.±	0.93	1.08	0.58	1.44	1.10	1.23	1.56
CD(0.05)	NS	NS	NS	NS	NS	NS	NS
	4) At harvest (96-112 DAS)						
Flat	3.2	2.6	2.9	2.7	2.1	2.4	2.7
BBF	1.7	1.1	1.4	3.1	2.5	2.8	2.1
Mean	2.5	1.9	2.2	2.9	2.3	2.6	2.4
S.Ed.±	0.63	0.63	0.58	0.92	0.86	0.86	1.10
CD(0.05)	NS	NS	NS	NS	NS	NS	NS

1, Refer Table 1

At both the pod development and harvest stages the differences in net N mineralization in soil under the various landform, soil depth, cropping system treatments and their interactions were not significant

4.2.5 Post-rainy season (Pigeonpea after harvesting soybean)

4.2.5.1 Net N mineralization (μg N g^{1} soil 10 d^{1}) during 1997 (Table 16)

In pigeonpea during pod development stage, net N mineralization was not significantly influenced by landform, soil depth and their interaction

At harvest during 1997, net N mineralization in soil was significantly influenced by the soil depth treatment and the interaction of landform x soil depth Landform treatment had no significant effect The medium-deep soil showed a significantly higher net N mineralization (5 5) compared to the shallow soil (4 2) The BBF on medium-deep soil resulted in a higher net N mineralization (5 4) and the flat on the shallow Vertic Inceptisol showed a lower net N mineralization (4 1) compared to the other combinations

4.2.5.2. Net N mineralization (μg N g^{1} soil 10 d^{1}) during 1998 (Table 16)

At pod development stage of pigeonpea, net N mineralization was influenced significantly by the interaction of landform x soil depth There were no significant difference in net N due to landform and soil depth treatments The highest net N mineralization (8 0) was recorded significantly under the BBF landform on the shallow soil and the lowest net N mineralization (3 4) was observed under the flat landform on the shallow soil

At harvest stage, in pigeonpea during 1998 net N mineralization was not influenced significantly by landform, soil depth and their interaction

4.2.6. Post-rainy season (Chickpea)

4.2.6.1. Net N mineralization (μg N g^{1}soil 10 d^{-1}) during 1997 (Table 17)

Mean net N mineralization was not significantly differed by landform, soil depth and their interaction during different stages of chickpea growth (presowing, vegetative and harvest)

4.2.6.2 Net N mineralization (μg N g^{1}soil 10 d^{1}) during 1998 (Table 18)

Mean net N contents in soil due to landform, soil depth and their interaction were not significantly influenced during different stages of chickpea growth (presowing, vegetative and harvest)

4.2.7. Rainy season (Sole soybean and soybean/pigeonpea intercropping)

4.2.7.1 Soil respiration (μg C g^{1}soil 10 d^{1}) during 1997 (Table 10, Fig. 6)

The amount of carbon respired from the soil varied at different growth stages of sole and intercropped soybean At the presowing, highest mean amount of C (148) respired from the soil was observed and then decreased (81) during the vegetative stage Subsequently the amount of C respired from the soil again increased (125) at pod development stage and then decreased (58) at maturity stage

Table.10: Soil respiration (µg C g^{-1} soil 10 d^{-1}) under sole and intercropped soybean grown on flat and BBF landforms and shallow and medium-deep Vertic Inceptisols during rainy season 1997

Landform	**Soil depth**						
	Shallow			**Medium - deep**			
	Sole Soybean	Soybean/ Pigeonpea	Mean	Sole Soybean	Soybean/ Pigeonpea	Mean	Total mean
			1) Presowing				
Flat	148	146	147	135	135	135	141
BBF	145	144	145	162	162	162	154
Mean	147	145	146	149	149	149	148
	L	**S**	**C**	**LS**	**LC**	**SC**	**LSC**
S.Ed.±	2.0	2.0	1.4	2.9	2.5	2.5	3.5
CD(0,05)	4.4	NS	NS	6.4	5.5	NS	7.7
			2) Vegetative stage (36-41 DAS)				
Flat	78	76	77	90	98	94	86
BBF	68	64	66	87	85	86	76
Mean	73	70	72	89	92	90	81
S.Ed.±	2.1	2.2	1.9	3.1	2.9	2.9	4.1
CD(0,05)	4.6	4.8	NS	6.8	6.4	6.4	9.0
			3) Pod development stage (71-75 DAS)				
Flat	113	121	117	142	141	142	130
BBF	102	110	106	131	130	131	119
Mean	108	116	112	137	136	137	125
S.Ed.±	3.1	3.2	2.9	4.6	4.2	4.3	5.5
CD(0,05)	6.8	7.0	NS	10.1	9.2	9.5	12.1
			4) At harvest (96-112 DAS)				
Flat	49	45	47	81	66	74	61
BBF	49	30	40	75	58	67	54
Mean	49	38	44	78	62	71	58
S.Ed.±	3.6	3.9	3.8	5.5	5.3	5.4	7.4
CD(0,05)	NS	8.6	8.4	12.1	11.7	11.9	16.3

1, Refer Table 1

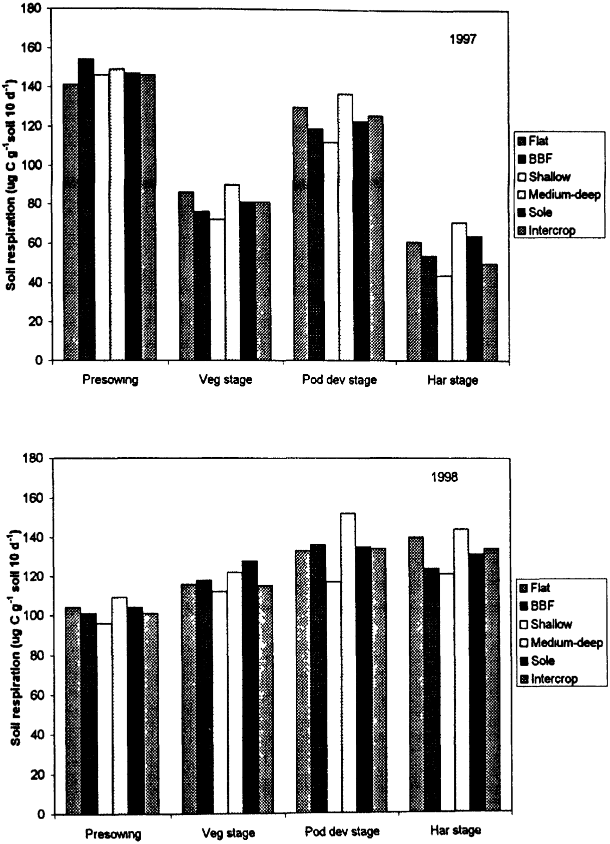


Fig.6: Soil respiration under sole and intercropped soybean as influenced by landform and soil depth treatments in Vertic Inceptisols during rainy season 1997 and 1998

At the presowing, the amount of C respired from the soil varied significantly due to landform treatment and interactions viz , landform x soil depth, landform x cropping system and landform x soil depth x cropping system

The soil under BBF landform treatment showed a significantly more soil respiration (154) than compared to the flat landform (141) The medium-deep soil under BBF landform released the highest amount of carbon (162) and the medium-deep soil under flat landform released the lowest of carbon (135) The BBF landform plots with sole soybean, influenced the highest soil respiration (154) whereas the flat landform plots with intercropped soybean showed the lowest soil respiration (140) The soil released the highest amount of C (162) under the BBF landform on the medium-deep soil with both sole and intercropped soybean and the lowest amount of C was respired (135) under the flat landform on the medium-deep soil with both the sole and intercropped soybean

At the vegetative stage, in soybean during 1997, except cropping systems treatment, remaining all treatments and their interactions significantly influenced the soil respiration The soil under flat landform showed a more soil respiration (86) than compared to the BBF landform treatment (76) The medium deep soil released a significantly higher amount of carbon (90) as compared to the shallow soil (72) The soil under flat landform on the medium-deep soil released the highest amount of carbon (94) and the lowest amount of carbon (66) was released in the BBF landform in the shallow Vertic Inceptisol The flat landform plots with soybean / pigeonpea showed the highest soil respiration (87) whereas the BBF landform plots with soybean / pigeonpea influenced the lowest soil respiration (75) The medium-deep soil with intercropped soybean released the highest amount of carbon (92) and the shallow soil with intercropped soybean released the lowest amount of carbon

(70) The soil under flat landform on the medium-deep soil with soybean / pigeonpea system showed the highest soil respiration (98) whereas the BBF landform on the shallow soil with soybean / pigeonpea showed the lowest soil respiration (64)

At the pod development stage during 1997, the soil respiration was significantly influenced by all the treatments and their interactions (except cropping system treatment) The soil under flat landform showed a significantly higher soil respiration (130) than compared to the soil under BBF landform treatment (119) Significantly higher amount of carbon (137) was respired from the medium-deep soil when compared to the shallow soil (112) Highest amount of C (142) was released from the medium-deep soil under flat landform while lowest amount of C (106) was released from the shallow soil under BBF landform treatment The intercropped soybean grown on flat landform resulted in the highest soil respiration (131) whereas the sole soybean grown on BBF landform resulted in the lowest soil respiration (117) The medium-deep soil under sole soybean released the highest amount of carbon (137) and the shallow soil under sole soybean released the lowest amount of carbon (108) The flat landform on the medium-deep soil with sole soybean resulted in the highest soil respiration (142) while the BBF landform on the shallow soil with sole soybean showed the lowest soil respiration (102)

At the harvest stage in soybean during 1997, the soil respiration was significantly influenced by all the treatments and their interactions (except landform treatment)

The medium-deep soil released a significantly higher amount of carbon (71) than compared to the shallow soil (44) Highest amount of carbon (74) was released under the flat landform on the medium-deep soil and the lowest amount of carbon (40) was released under the BBF landform on the shallow Vertic Inceptisol Significantly higher soil respiration (64) in the soil was observed in the sole soybean treatment as compared to the intercropped soybean (50) The flat landform plots with sole soybean showed the highest soil respiration (65) whereas the BBF landform plots with soybean / pigeonpea showed the lowest soil respiration (44) The medium-deep soil under sole soybean system released the highest amount of carbon (78) and the shallow soil under intercropped soybean respired the lowest amount of carbon (38) The soil respired the highest amount of C (81) under the flat landform on the medium-deep soil with sole soybean system while the lowest amount of C (30) was respired under the BBF landform on the shallow soil with soybean / pigeonpea system

4.2.7.2 Soil respiration (μg C g^{1} soil 10 d^{1}) during 1998 (Table 11, Fig. b)

The soil respiration varied at different growth stages of sole and intercropped soybean The soil released amount of C increased from presowing to pod development stage and then decreased at the harvest stage Highest amount of C was released (135) in the soil at the pod development stage of the crop

At the presowing during 1998 the soil respiration was changed significantly by the soil depth treatment and the interactions viz, landform x soil depth soil depth x cropping system, and landform x soil depth x cropping system Medium-deep soil released a significantly higher amount of carbon (109) as compared to the shallow soil (96) The medium-deep soil under flat landform released the highest amount of carbon (111) and the lowest amount of carbon (95) was respired from the shallow soil under BBF landform The medium-deep soil under sole soybean treatment released the highest amount of carbon (111) and the shallow soil under intercropped soybean respired the lowest amount of carbon (95)

Table.11: Soil respiration (µg C g^{-1} soil 10 d^{-1}) under sole and intercropped soybean grown on flat and BBF landforms and shallow and medium-deep Vertic Inceptisols during rainy season 1998

Landform	**Soil depth**						
	Shallow			Medium - deep			
	Sole Soybean	Soybean/ Pigeonpea	Mean	Sole Soybean	Soybean/ Pigeonpea	Mean	Total mean
1) Presowing							
Flat	97	96	97	113	109	111	104
BBF	95	94	95	109	105	107	101
Mean	96	95	96	111	107	109	103
	L	**S**	**C**	**LS**	**LC**	**SC**	**LSC**
S Ed ±	2 4	2 6	2 2	3 6	3 3	3 5	4 4
CD(0 05)	NS	5 7	NS	7 9	NS	7 7	9 7
2) Vegetative stage (36-41 DAS)							
Flat	112	109	111	122	119	121	116
BBF	114	111	113	124	121	123	118
Mean	113	110	112	123	120	122	117
S Ed ±	5 1	6 4	5 0	8 3	7 1	8 1	9 7
CD(0 05)	NS	NS	NS	NS	NS	NS	NS
3) Pod development stage (71-75 DAS)							
Flat	114	114	114	160	142	151	133
BBF	119	118	119	145	161	153	136
Mean	117	116	117	152	152	152	135
S Ed ±	3 1	3 2	3 0	4 7	4 4	4 4	6 5
CD(0 05)	NS	7 0	NS	10 3	9 7	9 7	14 3
4) At hrvest (96-112 DAS)							
Flat	125	141	133	155	139	147	140
BBF	116	100	108	126	153	140	124
Mean	121	121	121	141	146	144	132
S Ed ±	7 2	7 2	7 2	10 7	10 5	10 4	15 5
CD(0 05)	15 8	15 8	NS	23 5	NS	22 9	34 1

\# 1, Refer Table 1

Highest amount of C was respired (113) under the flat landform on the medium-deep soil with sole soybean treatment and the lowest amount of C was released (94) under the BBF landform on the shallow soil with intercropping system

At the vegetative stage in soybean during 1998, the variations in the soil respiration under the various landform, soil depth, cropping system treatments and their interactions were not significant

At the pod development stage, the soil respiration was changed significantly by the soil depth treatment and interactions viz , landform x soil depth, landform x cropping system, soil depth x cropping system and landform x soil depth x cropping system The medium-deep soil released a significantly more amount of carbon (152) than compared to the shallow soil (117) Highest amount of C (153) was released from the medium-deep soil under BBF landform while the lowest amount of C (114) was released from the shallow soil under flat landform treatment The BBF landform plots with soybean / pigeonpea system showed the highest soil respiration (140) whereas the flat landform plots with soybean / pigeonpea showed the lowest soil respiration (128) The intercropping system grown on BBF on medium-deep soil recorded the higher soil respiration (161) compared with the other combinations

At the harvest stage in soybean during 1998, the soil respiration was significantly changed by the landform, soil depth treatments and interactions viz , landform x soil depth, soil depth x cropping system and landform x soil depth x cropping system Cropping system treatment and the interaction of landform x cropping system did not significantly influence the soil respiration The soil under flat landform showed a significantly more soil respiration (140) as compared to the soil under BBF landform (124) The medium-deep soil respired a significantly higher amount of carbon (144) than compared to the shallow soil (121) Highest amount of C (147) was released from the medium-deep soil under flat landform while lowest amount of C (108) was released form the shallow soil under BBF landform The medium-deep soil under intercropped soybean released a significantly more amount of carbon (146) compared to the other combinations The flat landform on the medium-deep soil with soybean / pigeonpea resulted in the highest soil respiration (155) while the BBF on shallow soil with sole soybean resulted in the lowest soil respiration (116)

4.2.8 Post-rainy season (Pigeonpea after harvesting of soybean)

4.2.8.1 Soil respiration (μg C g^{-1} soil 10 d^{-1}) during 1997 (Table 16)

At the pod development stage in pigeonpea, the soil respiration was significantly changed by the soil depth treatment and the interaction of landform x soil depth The landforms did not vary the soil respiration significantly The medium-deep soil released a significantly higher amount of C (266) than compared to the shallow soil (247) Highest amount of carbon (271) was respired from the medium-deep soil under BBF landform and the lowest amount of carbon (240) was released from the shallow soil under BBF landform treatment

At the harvest stage in pigeonpea during 1997, soil depth treatment and the interaction of landform x soil depth significantly influenced the soil respiration The medium-deep released a significantly higher amount of C (77) than compared to the shallow Vertic Inceptisol (61) The medium-deep soil under flat landform treatment respired a significantly higher amount of carbon (77) whereas the shallow soil under BBF landform released a lesser amount of carbon (54) compared with the other combinations

4.2.8.2. Soil respiration (μg C g^{1} soil 10 d^{-1}) during 1998 (Table 16)

At the pod development stage, in pigeonpea, a significantly higher amount of C was released (102) from the medium-deep soil than compared to the shallow soil (75) The medium-deep soil under BBF landform showed a significantly maximum soil respiration (106) than compared to the other combinations

At the harvest stage in pigoenpea crop during 1998, the soil respiration was significantly influenced by the landform, soil depth treatments, and their interaction The soil in BBF landform showed a significantly more soil respiration (79) than compared to the soil in flat landform treatment in pigeonpea The medium-deep soil released a significantly higher amount of carbon (100) than compared to shallow soil (51) The flat landform treatment on the medium-deep soil showed the highest soil respiration (112) and the BBF landform on the shallow soil showed the lowest amount of carbon (46)

4.2.9 Post-rainy season (Chickpea)

4.2.9.1 Soil respiration (μg C g^{1} soil 10 d^{-1}) during 1997 (Table 17)

The amount of carbon was respired from the soil under chickpea crop was increased from presowing to vegetative stage and then decreased at harvest stage of the crop The highest amount of C was released (262) at the vegetative stage amongst the various growth stages in chickpea

At presowing, the soil respiration was influenced significantly by the soil depth treatment and the interaction of landform x soil depth Landform did not significantly vary the soil respiration The medium-deep soil respired a significantly higher amount of carbon (71) than compared to the shallow soil (44) Highest amount of C (74) was released from the medium-deep soil under flat landform while lowest amount of C (40) was released from the shallow soil under BBF landform treatment

At the vegetative stage in chickpea the soil respiration was significantly influenced by the soil depth treatment and the interaction of landform x soil depth Medium-deep soil released more amount of C (276) than compared to the shallow soil (248) Higher amount of C was released (284) from the medium-deep soil under BBF landform than compared to the other combinations

At the harvest stage in chickpea during 1997, soil depth and landform x soil depth interaction significantly influenced the soil respiration Higher amount of C was released (74) from the medium-deep soil than compared to shallow soil (55) The BBF landform on the medium-deep soil showed the highest soil respiration (77) whereas the BBF landform on the shallow soil showed the lowest soil respiration (54)

4.2.9.2 Soil respiration ($\mu g\ C\ g^{1}$ soil 10 d^{1}) during 1998 (Table 18)

Soil respiration varied at different growth stages of chickpea Soil respiration decreased from presowing to harvest stage Amongst the various growth stages, highest mean amount of C (132) was released at presowing

At the presowing growth stage, the soil respiration varied significantly due to landform, soil depth treatments and their interaction The soil in flat landform released a significantly more amount of C (140) than compared to the BBF landform The medium-deep soil respired a significantly higher amount of C (144) as compared to the shallow soil (121) Highest amount of C (147) was released from the medium-deep soil under flat landform while the lowest amount of C (108) was released from the shallow soil under BBF landform treatment

At the vegetative stage in chickpea during 1998, the variations in soil respiration due to soil depth treatment and the interaction of landform x soil depth were significant The medium-deep showed a maximum soil respiration (103) than compared to the shallow soil (77) The soil under BBF landform treatment on the medium-deep soil released a significantly more amount of C (105) whereas the soil under BBF landform on the shallow soil respired a lesser amount of C (75)

At the harvest stage in chickpea, the soil respiration was changed significantly by soil depth and landform x soil depth interaction More C was released (87) from the medium-deep soil than compared to shallow soil (56) The medium-deep soil under BBF respired a significantly higher amount of C (94) and the shallow soil under BBF landform treatment released a lesser amount of C (54) than compared to the other combinations

4.2.10 Rainy season (Sole soybean and soybean / pigeonpea intercropping)

4.2.10.1 Microbial biomass C (μg C g^{-1} soil) during 1997 (Tab 12, Fig.7)

Microbial biomass C content in soil varied at different growth stages of sole and intercropped soybean Mean amount of microbial biomass C content was decreased from presowing to pod development stage and then again increased at the harvest stage Highest mean microbial biomass C content (134) was observed at presowing

Table.12: Soil microbial biomass C (μg C g^{-1} soil) under sole and intercropped soybean grown on flat and BBF landforms and shallow and medium-deep Vertic Inceptisols during rainy season 1997

Landform	Soil depth						
	Shallow			Medium - deep			
	Sole Soybean	Soybean/ Pigeonpea	Mean	Sole Soybean	Soybean/ Pigeonpea	Mean	Total mean
			1) Presowing				
Flat	128	134	131	132	138	135	133
BBF	127	134	131	133	139	136	134
Mean	128	134	131	133	139	136	134
	L	**S**	**C**	**LS**	**LC**	**SC**	**LSC**
S Ed ±	4 0	5 2	5 4	6 6	6 7	7 5	8 7
CD(0 05)	NS	NS	NS	NS	NS	NS	NS
			2) Vegetative stage (36-41 DAS)				
Flat	107	134	121	113	150	132	127
BBF	114	119	117	116	126	121	119
Mean	111	127	119	115	138	127	123
S Ed ±	4 4	4 1	4 5	6 1	6 5	6 1	8 4
CD(0 05)	NS	NS	9 9	13 4	14 3	13 4	18 5
			3) Pod development stage (71-75 DAS)				
Flat	55	76	66	75	93	84	75
BBF	55	64	60	81	88	85	73
Mean	55	70	63	78	91	85	74
S Ed ±	5 5	6 1	5 9	8 4	8	8 5	11 2
CD(0 05)	NS	13 4	12 9	18 5	17 6	18 7	24 7
			4) At harvest (96-112 DAS)				
Flat	75	99	87	94	119	107	97
BBF	76	89	83	95	108	102	93
Mean	76	94	85	95	114	105	95
S Ed ±	6 2	7 4	7 4	9 9	9 7	10 4	12 8
CD(0 05)	NS	16 3	16 3	21 8	21 3	22 9	28 2

\# 1, Refer Table 1

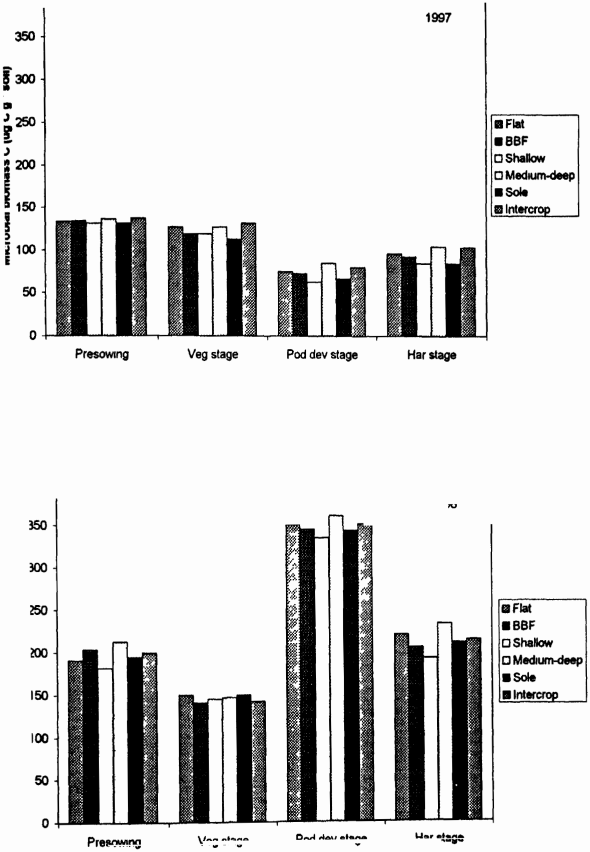


Fig.7: Soil microbial biomass C content under sole and intercropped soybean as influenced by landform and soil depth treatments in Vertic Inceptisols during rainy season 1997 and 1998

At the presowing growth stage, microbial biomass C content in soil was not significantly influenced by landform, soil depth, cropping system treatments or their interactions during 1997

At the vegetative stage in soybean during 1997, the microbial biomass C content in soil was influenced significantly by the cropping system treatment and the interactions viz , landform x soil depth, landform x cropping system, soil depth x cropping system and landform x soil depth x cropping system Landform and soil depth treatments did not show significant effect on microbial biomass C content in soil A significantly higher microbial biomass C content (132) was observed in the soybean/pigeonpea intercropping system compared to the sole soybean (113) The flat landform treatment on the medium-deep soil showed the highest amount of microbial biomass C (132) whereas the BBF landform on the shallow Vertic Inceptisol showed the lowest amount of microbial biomass C (117) The flat landform plots with intercropped soybean showed the highest microbial biomass C content (142) whereas the flat landform with sole soybean plots showed the lowest microbial biomass C content (110) The medium-deep soil under soybean / pigeonpea recorded the highest microbial biomass C content (138) and the shallow soil under sole soybean showed the lowest microbial biomass C content (111) The flat landform on the medium-deep soil with soybean / pigeonpea system resulted in the highest amount of microbial biomass C (150) whereas the flat landform on the shallow soil with sole soybean showed the lowest (107) microbial biomass C content in the soil

At the pod development stage in soybean during 1997, the microbial biomass C content in soil was significantly influenced by all the treatments and their interactions (except landform treatment) A significantly higher amount of microbial biomass C content (85) was observed in the medium-deep soil than compared to the shallow soil (63)

The BBF landform on the medium-deep soil showed a more microbial biomass C status (85) and BBF landform on the shallow soil showed a less microbial biomass C content (60) compared to the other combinations A significantly higher microbial biomass C content (80) was observed in the soybean / pigeonpea system as compared to the sole soybean (67) The intercropped soybean grown on flat landform showed the highest microbial biomass C content (85) in the soil and the sole soybean grown on flat showed the lowest microbial biomass C (65) The medium deep soil under soybean / pigeonpea system showed the highest amount of microbial biomass C (91) and the lowest microbial biomass C (55) was observed in the shallow soil under sole soybean The flat landform on the medium deep soil with soybean / pigeonpea showed a significantly higher microbial biomass C content (93) in the soil compared to the other combinations

At the harvest stage in soybean during 1997, soil microbial biomass C content was significantly influenced by all the treatments and the interactions (except landform treatment) Medium-deep soil showed a significantly higher microbial biomass C content (114) than compared to the shallow soil (76) The flat landform on the medium-deep soil recorded the highest microbial biomass C content (107) and the lowest biomass C status (83) was recorded in the shallow soil under BBF landform A significantly higher microbial biomass C content (104) was observed in the intercropped soybean as compared to the sole soybean system (85) The intercropped soybean grown on the flat landform showed the highest amount of microbial biomass C (109) and the sole soybean grown on the flat resulted in the lowest microbial biomass C content (84) in the soil The medium-deep soil with soybean / pigeonpea showed the highest microbial biomass C content (114) and then it was lowest (76) in the shallow soil under sole soybean treatment The flat landform on the medium deep soil with soybean / pigeonpea system showed highest microbial biomass C content (119) while lowest soil microbial biomass C content (75) was observed in the flat landform on the shallow soil with sole soybean system during 1997

4.2.10.2 Microbial biomass C (μg C g^{-1} soil) during 1998 (Table 13, Fig. 7)

Mean microbial biomass C content in soil varied at different growth stages of sole and intercropped soybean Highest microbial biomass C content in soil was observed at the pod development stage amomgst the various growth stages during 1998

At the presowing growth stage, the amount of soil microbial biomass C was significantly influenced by the soil depth treatment and the treatment interactions viz, landform x soil depth, soil depth x cropping system and landform x soil depth x cropping system Higher microbial biomass C content (213) was observed in the medium-deep Vertic Inceptisol than compared to the shallow soil (182) The highest amount of microbial biomass C content (216) was observed in the medium-deep soil under flat landform while lowest amount of microbial biomass C content (165) was observed in the shallow soil under flat landform The medium-deep soil with soybean / pigeonpea system showed highest soil microbial biomass C content (225) while lowest microbial C content (174) was observed in the shallow soil with soybean / pigeonpea intercropping system The flat landform on the medium-deep soil with soybean / pigeonpea system resulted in the highest amount of microbial biomass C (231) whereas the lowest amount of soil microbial biomass C status

Table.13: Soil microbial biomass C (μg C g^{1} soil) under sole and intercropped soybean grown on flat and BBF landforms and shallow and medium-deep Vertic Inceptisols during rainy season 1998

Landform	**Soil depth**						
	Shallow			Medium - deep			
	Sole Soybean	Soybean/ Pigeonpea	Mean	Sole Soybean	Soybean/ Pigeonpea	Mean	Total mean
			1) Presowing				
Flat	169	160	165	200	231	216	191
BBF	209	187	198	201	218	210	204
Mean	189	174	182	201	225	213	198
	L	**S**	**C**	**LS**	**LC**	**SC**	**LSC**
S Ed ±	11 8	12 3	11 9	17 4	17 5	17 9	24 9
CD(0 05)	NS	27 0	NS	38 3	NS	39 4	54 8
			2) Vegetative stage (36-41 DAS)				
Flat	153	145	149	155	147	151	150
BBF	144	136	140	145	138	142	141
Mean	149	141	145	150	143	147	146
S Ed ±	9 7	7 0	9 2	12 2	13 4	11 5	15 3
CD(0 05)	NS	NS	NS	NS	NS	NS	NS
			3) Pod development stage (71-75 DAS)				
Flat	335	334	335	358	372	365	350
BBF	335	333	334	348	363	356	345
Mean	335	334	335	353	368	361	348
S Ed ±	7 8	10 6	8 1	13 5	11 3	13 4	15 8
CD(0 05)	NS	23 3	NS	29 7	NS	29 5	34 8
			4) At harvest (96-112 DAS)				
Flat	193	193	193	249	249	249	221
BBF	189	195	192	216	222	219	206
Mean	191	194	193	232	236	234	214
S Ed ±	11 4	12 9	7 9	17 9	14 0	15 3	20 7
CD(0 05)	NS	28 4	NS	39 4	NS	33 7	45 6

\# 1, Refer Table 1

(160) was observed under the flat landform on the shallow soil with soybean / pigeonpea system

At the vegetative stage the differences in soil microbial biomass C content under the various landform, soil depth, cropping systems and their interactions were not significant

At the pod development and harvest stages in soybean, during 1998, the amount of soil microbial biomass C content varied significantly due to soil depth treatment and the treatment interactions viz, landform x soil depth, soil depth x cropping system A significantly higher microbial biomass C content (361 and 234) was observed in the medium-deep soil as compared to the shallow soil (335 and 193) during both the pod development and harvest stages respectively The flat landform on the medium-deep soil showed the highest (365 and 249) microbial biomass C status and the lowest (334 and 192) microbial biomass C in the soil was recorded under BBF landform on the shallow soil during both the pod development and harvest stages respectively The medium-deep soil under intercropping system showed a higher microbial biomass C status compared to the other combinations during both the pod development and harvest stages The flat landform on the medium-deep soil with soybean / pigeonpea resulted in the highest microbial biomass C (372) and the lowest microbial biomass C (333) was observed under the BBF landform on the shallow soil with soybean / pigeonpea system during the pod development stage The BBF landform on the shallow soil with sole soybean showed a lower soil microbial biomass C content (189) compared with the other combinations during the harvest stage 1998

4.2.11. Post-rainy season (Pigeonpea after harvest of soybean)

4.2.11.1 Microbial biomass C (μg C g ^{1}soil) during 1997 (Table 16)

During both the pod development and harvest stages, the microbial biomass C content in soil under pigeonpea was not influenced significantly by landform, soil depth treatments and their interaction

4.2.11.2 Microbial biomass C (μg C g^{1} soil) during 1998 (Table 16)

At the pod development stage in pigeonpea, the differences in soil microbial biomass C content under the various landform, soil depth treatments and their interaction were not significant

At harvest stage of pigeonpea during 1998, soil depth and the interaction of landform x soil depth significantly influenced the microbial biomass C The medium-deep soil showed a significantly higher microbial biomass C (190) than the shallow Vertic Inceptisol (148) The BBF landform on the medium-deep soil showed highest microbial biomass C content (193) while lowest microbial biomass C content (147) was observed under the flat landform on the shallow soil

4.2.12 Post-rainy season (Chickpea)

4.2.12.1. Microbial biomass C (μg C g^{1} soil) during 1997 (Table 17)

The microbial biomass C content in the soil under chickpea crop was influenced by crop growth stages Mean microbial biomass C content increased from presowing to upto the harvest stage

At the presowing growth stage, the microbial biomass C content was significantly differed in soils of different depths The interaction of landform x soil depth was significant on the soil microbial biomass content Landform did not show significant effect on the microbial biomass C content in the soil

Both at vegetative and harvest stages, the variations in microbial biomass C content in the soil due to landform, soil depth and their interactions were not significant

4.2.12.2. Microbial biomass C ($\mu g\ C\ g^{-1}$ soil) during 1998 (Table 18)

Mean microbial biomass C content in soil under chickpea crop was influenced by crop growth stage Mean microbial biomass C content increased from presowing to vegetative stage and then it was decreased at the harvest stage Amongst the various growth stages, highest amount of microbial biomass C content (285) was recorded at the vegetative stage

At the presowing, mean microbial biomass C content in the soil was significantly influenced by soil depth and landform x soil depth interaction Landform had no significant effect on microbial biomass C content in the soil Medium-deep soil contained a significantly higher microbial biomass C (234) compared to the shallow soil (193) The flat landform on the medium-deep soil showed the highest microbial biomass C content (249) and the lowest microbial biomass C status (192) was observed under the BBF on the shallow soil

At the vegetative stage of chickpea during 1998, soil depth and landform x soil depth interaction significantly influenced the microbial biomass C content in the soil Shallow soil contained significantly more amount of microbial biomass C (338) compared to the medium deep Vertic Inceptisol (231) Highest amount of microbial biomass C content (410) was observed in the shallow soil under BBF landform whereas the lowest amount of microbial biomass C (146) was recorded in the medium-deep soil under BBF landform treatment

At the harvest stage of chickpea crop during 1998, mean microbial biomass C content varied significantly by soil depth and landform x soil depth Landform had no significant effect on microbial biomass C content Medium-deep soil contained significantly higher microbial biomass C content (205) compared to the shallow soil (139) The BBF landform on the medium-deep soil showed a significantly higher microbial biomass C content (209) whereas the BBF landform on the shallow soil showed a lower microbial biomass C content (137) as compared to the other combinations

4.2.13 Rainy season (Sole soybean and soybean / pigeonpea intercropping)

4.2.13.1 Microbial biomass N (μg N g^{-1} soil) during 1997 (Table 14, Fig. 8)

Soil microbial biomass N content under sole and intercropped soybean was influenced by crop growth stages Mean microbial biomass N content decreased from presowing to the pod development stage and then it increased at the harvest stage

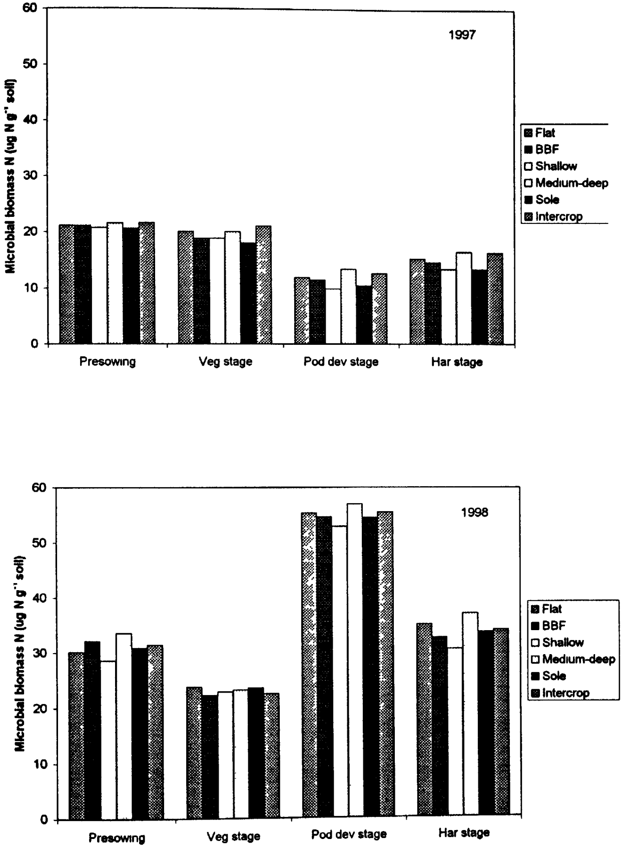
At the presowing growth stage, mean microbial biomass N content in soil was not significantly influenced by landform, soil depth, cropping system treatments or their interactions

Mean microbial biomass N content status of soil under sole and intercropped soybean during both stages (vegetative and harvest) varied significantly due to cropping system treatment and interactions viz, landform x soil depth, landform x cropping system, soil depth x cropping system and landform x soil depth x cropping system Mean microbial biomass N content in soil was not changed significantly by landform and soil depth

Table.14 Soil microbial biomass N (μg N g^{1} soil) under sole and intercropped soybean grown on flat and BBF landforms andshallow and medium-deep Vertic Inceptisols during rainy season 1997

Landform	**Soil depth**						
	Shallow			**Medium - deep**			
	Sole Soybean	Soybean/ Pigeonpea	Mean	Sole Soybean	Soybean/ Pigeonpea	Mean	Total mean
			1) Presowing				
Flat	20 2	21 2	20 7	20 9	21 9	21 4	21 1
BBF	20 1	21 2	20 6	21 0	22 0	21 5	21 1
Mean	20 2	21 2	20 7	21 0	22 0	21 5	21 1
	L	**S**	**C**	**LS**	**LC**	**SC**	**LSC**
S Ed ±	0 63	0 83	0 86	1 05	1 07	1 19	1 38
CD(0 05)	NS	NS	NS	NS	NS	NS	NS
			2) Vegetative stage (36-41 DAS)				
Flat	17 0	21 2	19 1	17 9	23 7	20 8	20 0
BBF	18 1	18 8	18 5	18 3	19 9	19 1	18 8
Mean	17 6	20 0	18 8	18 1	21 8	20 0	19 4
S Ed ±	0 69	0 65	0 71	0 97	1 02	0 96	1 30
CD(0 05)	NS	NS	1 56	2 13	2 25	2 11	2 86
			3) Pod development stage (71-75 DAS)				
Flat	8 8	12 0	10 4	11 8	14 7	13 3	11 9
BBF	8 8	10 2	9 5	12 8	13 9	13 4	11 5
Mean	8 8	11 1	9 9	12 3	14 3	13 4	11 7
S Ed ±	0 87	0 97	0 93	1 34	1 27	1 34	1 77
CD(0 05)	NS	2 13	2 05	2 95	2 80	2 95	3 90
			4) At harvest (96-112 DAS)				
Flat	11 8	15 6	13 7	14 9	18 8	16 9	15 3
BBF	12 1	14 1	13 1	15 0	17 0	16 0	14 6
Mean	12 0	14 9	13 4	15 0	17 9	16 5	15 0
S Ed ±	0 98	1 17	1 16	1 56	1 53	1 65	2 03
CD(0 05)	NS	NS	2 55	3 43	3 37	3 63	4 47

1, Refer Table 1



g.8: Soil microbial biomass N content under sole and intercropped soybean as influenced by landform and soil depth treatments in Vertic Inceptisols during rainy season 1997 and 1998 treatments The flat landform on the medium-deep soil showed the highest amount of microbial biomass N status and the BBF on the shallow soil recorded the lowest amount of microbial biomass N content at both the vegetative and harvest stages of sole and intercropped soybean A significantly higher microbial biomass N content was observed in the soybean / pigeonpea intercropping system as compared to the sole soybean during both the vegetative and harvest stages The flat landform plots with intercropped soybean resulted in the highest microbial biomass N content whereas the flat landform plots with sole soybean showed the lowest microbial biomass N content during both the vegetative and harvest stages The medium-deep soil under soybean / pigeonpea showed the highest amount of microbial biomass N and the shallow soil with sole soybean showed the lowest microbial biomass N during both stages The flat landform on the medium deep soil under intercropped soybean resulted in the highest amount of microbial biomass N while the flat landform on the shallow soil with sole soybean showed the lowest microbial biomass N content during both the vegetative and harvest stages

At the pod development stage the microbial biomass N status in soil was changed significantly by the soil depth, cropping system treatments and interactions viz , landform x soil depth, landform x cropping system, soil depth x cropping system and landform x soil depth x cropping system Landform treatment did not show significant effect on microbial biomass N content Medium deep soil contained a significantly higher microbial biomass N content (13 4) as compared to the shallow soil (9 9) The BBF landform on the medium deep soil showed highest amount of microbial biomass N content (13 4) and the lowest amount of microbial biomass N status (9 5) was observed under the BBF landform on the shallow Vertic Inceptisol A significantly higher microbial biomass N content (12 7) was observed in the plots used for soybean / pigeonpea intercropping than compared to the sole soybean treatment (10 5) The flat landform plots with soybean / pigeonpea showed the highest microbial biomass N content (13 4) and the BBF landform with sole soybean plots recorded the lowest microbial biomasssN (10 3) in the soil Medium-deep soil under soybean/pigeonpea showed the highest microbial biomass N (14 3) whereas the shallow soil with sole soybean showed the lowest microbial biomass N status (8 8) The flat landform on the medium-deep soil with intercropping system recorded a higher microbial biomass N content (14 7) as compared to the other combinations during pod development stage 1997

4.2.13.2. Microbial biomass N (μg N g^{1} soil) during 1998 (Table 15, Fig. 8)

Microbial biomass N content in soil varied at different growth stages of sole and intercropped soybean Mean microbial biomass N content was decreased from presowing to vegetative stage and then increased at the pod development stage and then again decreased at the harvest stage Amongst various growth stages the highest mean microbial biomass N content (55 0) in soil was observed at the pod development stage

At the presowing, soil microbial biomass N content was significantly differed in soils of different depths The soil depth interacted with landforms and cropping systems Medium-deep soil contained a significantly more amount of microbial biomass N content (33 6) as compared to the shallow Vertic Inceptisol (28 6) The flat landform on the medium-deep soil recorded the highest microbial biomass N content (36 5) and the flat landform on the shallow showed the lowest microbial biomass N status (25 2) The medium-deep soil under soybean / pigeonpea showed a higher microbial biomass N content (35 4) compared to the other combinations The flat landform on the medium-deep soil with

Table.15: Soil microbial biomass N (μg N g^{-1} soil) under sole and intercropped soybean grown on flat and BBF landforms and shallow and medium-deep Vertic Inceptisols during rainy season 1998

Landform	Soil depth						
	Shallow			Medium - deep			
	Sole Soybean	Soybean/ Pigeonpea	Mean	Sole Soybean	Soybean/ Pigeonpea	Mean	Total mean
			1) Presowing				
Flat	26 7	25 2	26 0	31 7	36 5	34 1	30 1
BBF	33 1	29 5	31 3	31 8	34 4	33 1	32 2
Mean	29 9	27 4	28 6	31 8	35 4	33 6	31 2
	L	**S**	**C**	**LS**	**LC**	**SC**	**LSC**
S Ed ±	1 87	1 94	1 89	2 75	2 77	2 83	3 94
CD(0 05)	NS	4 27	NS	6 05	NS	6 22	8 67
			2) Vegetative stage (36-41 DAS)				
Flat	24 2	23 0	23 6	24 4	23 3	23 9	23 8
BBF	22 7	21 6	22 2	23 0	21 8	22 4	22 3
Mean	23 5	22 3	22 9	23 7	22 6	23 2	23 1
S Ed ±	1 54	1 11	1 45	1 93	2 12	1 83	2 41
CD(0 05)	NS	NS	NS	NS	NS	NS	NS
			3) Pod development stage (71-75 DAS)				
Flat	53 0	52 8	52 9	56 6	58 8	57 7	55 3
BBF	52 9	52 7	52 8	55 1	57 4	56 3	54 6
Mean	53 0	52 8	52 9	55 9	58 1	57 0	55 0
S Ed ±	1 23	1 68	1 28	2 13	1 78	2 11	2 50
CD(0 05)	NS	3 69	NS	4 69	NS	4 64	5 50
			4) At harvest (96-112 DAS)				
Flat	30 6	30 5	30 6	39 4	39 3	39 4	35 0
BBF	29 9	30 9	30 4	34 2	35 1	34 7	32 6
Mean	30 3	30 7	30 5	36 8	37 2	37 0	
S Ed ±	1 80	2 00	1 20	2 80	2 20	2 40	3 30
CD(0 05)	NS	4 4	NS	6 16	NS	5 28	7 26

\# 1, Refer Table 1

soybean / pigeonpea intercropping system resulted in the highest microbial biomass N (36 5) and the lowest microbial biomass N (25 2) was observed under the flat landform on the shallow soil with soybean / pigeonpea intercropping system

At the vegetative stage in soybean during 1998, the differences in microbial biomass N content under the various landform, soil depth, cropping systems and their interactions were not significant

At the pod development stage in sole and intercropped soybean the amount of microbial biomass N significantly differed in soils of different depths The soil depth interacted with landforms and cropping systems Landform, cropping system treatments and their interaction had no significant effect on soil microbial biomass N content Medium-deep soil contained a significantly more microbial biomass N content (57 0) than compared to the shallow Vertic Inceptisol (52 9) The flat landform on the medium-deep soil showed the highest microbial biomass N content (57 7) and the lowest microbial biomass N (52 8) was observed under the BBF landform on the shallow soil The medium-deep soil with soybean / pigeonpea intercropping system showed a high microbial biomass N status (58 1) and the shallow soil under intercropping system recorded the lowest microbial biomass N content (52 8) The flat landform on the medium-deep soil with intercropped soybean resulted in the highest microbial biomass N status (58 8) whereas the BBF landform on the shallow soil with intercropped soybean showed the lowest microbial biomass N content (52 7) in the soil

At the harvest stage in sole and intercropped soybean during 1998, soil microbial biomass N content was significantly differed in soils of different depths The soil depth interacted with landform and cropping systems Landform, cropping system treatments and their interaction did not show a significant effect on the microbial biomass N status A significantly higher microbial biomass N content (37 0) was observed in the medium-deep Vertic Inceptisol as compared to the shallow soil (30 5) The highest amount of microbial biomass N (39 4) was observed in the medium-deep soil under the flat landform and lowest microbial biomass N status (30 4) was recorded in the shallow soil under the BBF landform The medium-deep soil under soybean / pigeonpea system showed the highest microbial biomass N content (37 2) and the lowest microbial biomass N content (30 3) was observed in the shallow soil under sole soybean The soil under flat landform on the medium-deep soil with sole soybean showed the highest amount of microbial biomass N (39 4) whereas the BBF landform on the shallow soil under sole soybean showed the lowest microbial biomass N content (29 9)

4.2.14 Post-rainy season (Pigeonpea after harvest of soybean)

4.2.14.1 Microbial biomass N (μg N g^{1} soil) during 1997 (Table 16)

During both the pod development and harvest stages of pigeonpea, the soil microbial biomass N content was not influenced significantly by landform, soil depth and their interaction

4.2.14.2. Microbial biomass N (μg N g^{1} soil) during 1998 (Table 16)

At the pod development stage in pigeonpea during 1998, landform, soil depth treatments and their interaction had no significant effect on soil microbial biomass N content

Table.16: Soil chemical and biological properties under pigeonpea grown on flat and BBF landforms and shallow and medium-deep Vertic Inceptisols during post-rainy season 1997 and 1998

Landform	Soil depth														
	Available N (NH_4^++NO3) (µg N g^{-1} soil)			Net N mineralization (µg N g^{-1} soil 10 d^{-1})			Soil respiration (µg C g^{-1} soil 10 d^{-1})			Microbial biomass C (µg C g^{-1} soil)			Microbial biomass N (µg N g^{-1} soil)		
	Shallow	Medium-deep	Mean	Shallow	Medium deep	Mean	Shallow	Medium-deep	Mean	Shallow	Medium-deep	Mean	Shallow	Medium-deep	Mean
1997															
1) Pod development stage (135-168 DAS)															
Flat	11.5	11.9	11.7	4.3	4.5	4.4	254	262	258	158	160	159	24.9	25.3	25.1
BBF	11.2	12.3	11.8	4.3	4.5	4.4	240	271	256	158	160	159	24.9	25.3	25.1
Mean	11.4	12.1	11.8	4.3	4.5	4.4	247	266	257	158	160	159	24.9	25.3	25.1
	L	S	LS	L	S	LS	L	S	LS	L	S	LS	L	S	LS
S E d±	0.69	0.91	1.16	0.04	0.52	0.52	6.8	7.3	10.3						
CD(0.05)	NS	NS	NS	NS	NS	NS	NS	16.1	22.7						
2) At harvest (205-219 DAS)															
Flat	4.8	5.7	5.3	4.1	5.3	4.7	67	77	72	222	244	233	35.0	38.6	36.8
BBF	4.9	5.8	5.4	4.2	5.4	4.8	54	76	65	222	244	233	35.0	38.6	36.8
Mean	4.9	5.8	5.4	4.2	5.5	4.8	61	77	69	222	244	233	35.0	38.6	36.8
S E d±	0.26	0.22	0.26	0.28	0.51	0.58	3.5	3.8	5.3	0.79	19.2	19.3	0.12	3.0	3.0
CD(0.05)	NS	0.48	0.57	NS	1.12	1.28	NS	8.4	11.7	NS	NS	NS	NS	NS	NS
1998															
1) Pod development stage (135-168 DAS)															
Flat	5.0	4.3	4.7	3.4	4.4	3.9	75	97	86	273	288	281	43.0	45.0	44.0
BBF	5.0	4.3	4.7	8.0	5.9	7.0	75	106	91	284	281	283	45.0	44.0	44.0
Mean	5.0	4.3	4.7	5.7	5.2	5.5	75	102	89	279	285	282	44.0	45.0	44.0
S E d±	0.13	0.41	0.43	1.6	1.4	2.1	3.9	5.0	6.5	22.7	22.7	32.3	3.5	3.5	5.1
CD(0.05)	NS	NS	NS	NS	NS	4.6	NS	11.0	14.3	NS	NS	NS	NS	NS	NS
2) At harvest (205-219 DAS)															
Flat	5.8	5.8	5.8	4.5	4.5	4.5	55	88	72	147	187	167	23.3	29.7	26.5
BBF	5.9	5.9	5.9	4.1	4.1	4.1	46	112	79	149	193	171	23.5	30.6	27.1
Mean	5.9	5.9	5.9	4.3	4.3	4.3	51	100	76	148	190	169	23.4	30.2	26.8
S E d±	0.30	0.20	0.39	0.81	0.05	0.81	2.9	3.0	4.4	4.5	6.9	8.7	0.72	1.10	1.39
CD(0.05)	NS	NS	NS	NS	NS	NS	6.4	6.6	9.7	NS	15.2	19.1	NS	2.42	3.06

At the harvest stage, the microbial biomass N status in soil varied significantly due to soil depth treatment and the interaction of landform x soil depth. Medium-deep soil under pigeonpea contained a significantly higher microbial biomass N (30.2) than the shallow Vertic Inceptisol (23.4). The pigeonpea grown on BBF on medium-deep soil resulted in the highest microbial biomass N content (30.6) and the lowest microbial biomass N status (23.3) was observed under the flat landform on the shallow soil.

4.2.15 Post-rainy season (Chickpea)

4.2.15.1 Microbial biomass N (μg N g^{-1} soil) during 1997 (Table 17)

At the presowing growth stage of chickpea, the soil microbial biomass N content was influenced significantly by the interaction of landform x soil depth. There were no significant difference in microbial biomass N content due to landform and soil depth treatments. The soil in flat landform on the medium-deep soil with chickpea, showed the highest microbial biomass N (16.9) and the lowest amount of microbial biomass N (13.1) was recorded under the BBF landform on the shallow Vertic Inceptisol.

During both the pod development and harvest stages of chickpea, the variations in soil microbial biomass N content under the various landform, soil depth and their interaction were not significant.

4.2.15.2 Microbial biomass N (μg N g^{-1} soil) during 1998 (Table 18)

The soil microbial biomass N status under chickpea was influenced by crop growth stages. Mean available N content increased from presowing to the vegetative stage and then

Table.17: Soil chemical and biological properties under chickpea grown on flat and BBF landforms and shallow and medium-deep Vertic Inceptisols during post-rainy season 1997

Landform	Soil depth														
	Available N (NH_4^++NO3) (µg N g^{1} soil)			Net N mineralization (µg N g^{1} soil 10 d^{1})			Soil respiration (µg C g^{1} soil 10 d^{1})			Microbial biomass C (µg C g^{1} soil)			Microbial biomass N (µg N g^{1} soil)		
	Shallow	Medium-deep	Mean	Shallow	Medium-deep	Mean	Shallow	Medium-deep	Mean	Shallow	Medium-deep	Mean	Shallow	Medium-deep	Mean
1) Presowing															
Flat	6 1	6 9	6 5	4 4	4 7	4 6	47	74	61	87	107	97	13 7	16 9	15 3
BBF	6 1	6 9	6 5	4 3	5 7	5 0	40	67	54	83	102	93	13 1	16 0	14 6
Mean	6 1	6 9	6 5	4 4	5 2	4 8	44	71	58	85	105	95	13 4	16 5	15 0
	L	S	LS	L	S	LS	L	S	LS	L	S	LS	L	S	LS
S E d ±	0 55	0 75	0 94	0 62	0 61	0 89	3 6	3 9	5 5	6 2	7 4	9 9	0 98	1 17	1 56
CD(0 05)	NS	NS	NS	NS	NS	NS	NS	8 6	12 1	NS	16 3	21 8	NS	NS	3 43
2)Vegetative stage (40-43 DAS)															
Flat	12 9	12 9	12 9	3 2	4 7	4 0	248	267	258	137	150	144	21 6	23 8	22 7
BBF	12 1	12 1	12 1	3 5	5 0	4 3	248	284	266	137	150	144	21 6	23 8	22 7
Mean	12 5	12 5	12 5	3 4	4 9	4 2	248	276	262	137	150	144	21 6	23 8	22 7
S E d ±	1 21	0 06	1 22	0 67	0 99	1 21	5 4	6 2	8 5	-	-	-	-	-	-
CD(0 05)	NS	NS	NS	NS	NS	NS	NS	13 6	18 7	-	-	-	-	-	-
3) At harvest (105-113 DAS)															
Flat	5 5	5 5	5 5	4 9	5 2	5 1	55	71	63	136	220	178	21 5	34 8	28 2
BBF	5 5	5 5	5 5	3 9	5 1	4 5	54	77	66	148	208	178	23 3	32 9	28 1
Mean	5 5	5 5	5 5	4 4	5 2	4 8	55	74	65	142	214	178	22 4	33 9	28 2
S E d.±	-	-	-	0 49	0 53	0 73	3 4	4 5	5 8	-	-	-	-	-	-
CD (0 05)	-	-	-	NS	NS	NS	NS	9 9	12 8	-	-	-	-	-	-

1, Refer Table 1

Table.18: Soil chemical and biological properties under chickpea grown on flat and BBF landforms and shallow and medium-deep Vertic Inceptisols during post-rainy season 1998

Landform	Soil depth														
	Available N (NH_4^++NO3) (µg N g^{1} soil)			Net N mineralization (µg N g^{1} soil 10 d^{1})			Soil respiration (µg C g^{1} soil 10 d^{1})			Microbial biomass C (µg C g^{1} soil)			Microbial biomass N (µg N g^{1} soil)		
	Shallow	Medium-deep	Mean	Shallow	Medium-deep	Mean	Shallow	Medium-deep	Mean	Shallow	Medium-deep	Mean	Shallow	Medium-deep	Mean
1) Presowing															
Flat	5 4	5 5	5 5	2 9	2 4	2 7	133	147	140	193	249	221	30 5	39 4	35 0
BBF	5 5	5 3	5 4	1 4	2 8	2 1	108	140	124	192	219	206	30 4	34 7	32 6
Mean	5 5	5 4	5 5	2 2	2 6	2 4	121	144	132	193	234	214	30 5	37 0	33 8
	L	S	LS	L	S	LS	L	S	LS	L	S	LS	L	S	LS
S E d ±	0 25	0 26	0 36	0 63	0 63	0 92	7 2	7 2	10 7	11 4	12 9	17 9	1 80	2 00	2 8
CD(0 05)	NS	NS	NS	NS	NS	NS	15 8	15 8	23 5	NS	28 4	39 4	NS	4 40	6 16
2) Vegetative stage (40-43 DAS)															
Flat	6 0	5 4	5 7	7 0	9 1	8 1	79	101	90	265	316	291	41 9	50 1	46 0
BBF	5 7	7 3	6 5	7 0	9 1	8 1	75	105	90	410	146	278	64 9	23 1	44 0
Mean	5 9	6 4	6 1	7 0	9 1	8 1	77	103	90	338	231	285	53 4	36 6	45 0
S E d ±	0 88	0 88	1 28	0 06	1 60	1 64	3 2	4 1	5 4	43 0	43 0	63 0	6 81	6 81	9 97
CD(0 05)	NS	NS	NS	NS	NS	NS	NS	9 0	11 9	NS	94 6	138 7	NS	14 98	21 94
3) At harvest (105-113 DAS)															
Flat	6 0	6 2	6 1	4 9	4 9	4 9	58	80	69	140	201	171	22 2	31 9	27 1
BBF	8 1	8 4	8 2	4 7	4 7	4 7	54	94	74	137	209	173	21 7	33 1	27 4
Mean	7 1	7 3	7 2	4 8	4 8	4 8	56	87	72	139	205	172	22 0	32 5	27 3
S E d.±	1 09	0 69	1 35	0 77	0 05	0 77	5 9	6 8	9 7	6 2	9 3	11 4	0 97	1 47	1 80
CD(0 05)	NS	NS	NS	NS	NS	NS	NS	14 9	21 3	NS	20 5	25 1	NS	3 24	3 96

 # 1, Refer Table 1

decreased at the harvest stage Amongst the various growth stages, highest amount of microbial biomass N content (45 0) was recorded at the vegetative stage

At the presowing growth stage, mean microbial biomass N content in soil varied significantly due to soil depth treatment and landform x soil depth interaction Landform did not show a significant effect on soil microbial biomass N Medium-deep soil contained a significantly higher microbial biomass N content (39 4) than the shallow soil (30 4) under chickpea crop The soil under flat landform on the medium-deep soil with chickpea showed the highest microbial biomass N content (39 4) and the lowest microbial biomass N status (30 4) was observed under the BBF landform on the shallow Vertic Inceptisol

At the vegetative stage in chickpea during 1998, soil depth and landform x soil depth interaction significantly influenced the microbial biomass N content in the soil A significantly higher amount of microbial biomass N status (53 4) was recorded in shallow soil as compared to the medium-deep soil (36 6) The highest amount of microbial biomass N (64 9) was observed in the shallow soil under BBF landform treatment whereas the lowest amount of microbial biomass N status (23 1) was recorded in the medium-deep soil under the BBF landform treatment in chickpea crop

At the harvest stage in chickpea crop, soil microbial biomass N content was changed significantly by soil depth and landform x soil depth Landform had no significant effect Microbial biomass N content (32 5) was significantly higher in the medium-deep soil compared to the shallow soil (21 7) under chickpea crop The BBF landform on the medium-deep soil with chickpea recorded the highest microbial biomass N content (33 1) and the BBF landform on the shallow soil with chickpea resulted in the lowest microbial biomass N content (21 7) in the soil

4.3 Quantification of BNF

4.3.1 Nodulation and nitrogenase activity of sole and intercropped soybean grown in rainy season : 1997

4.3.1.1 Number of nodules(m^{-2}) (Table 19)

The number of soybean nodules increased with plant age. Mean nodule number increased from 431 at the vegetative stage to 1614 at the pod development stage. During vegetative and pod development stages, in the sole and intercropped soybean, the nodule number was not significantly influenced by the landform, soil depth, cropping system treatments or their interactions.

4.3.1.2 Weight of nodules (mg m^{-2}) (Table 19)

Nodule weight increased from vegetative to pod development stages by eight times in soybean. At the vegetative stage, in the sole and intercropped soybean, changed in nodule weight due to the various treatments imposed showed that : landform x soil depth, landform × cropping system and landform × soil depth x cropping system interactions were significant . Landform, soil depth, cropping system treatments and soil depth × cropping system interaction did not result in any significant effect on the nodule weight. The BBF landform in the shallow soil showed a higher weight of nodules (366); while the lowest nodule weight (220) was observed in the flat landform treatment on the shallow soil. The sole soybeans grown on the BBF landform showed the highest (339) nodule weight, while the lowest nodule weight (200) was observed in sole soybean grown on the flat landform treatment. The highest nodule weight (382) was observed in sole soybean grown on the BBF landform on the shallow soil.

At the pod development stage, both sole and intercropped soybean grown during 1997 showed a significant effect of the cropping systems, on nodule weight. The interactions of landform × soil depth, landform × cropping system and landform × soil depth × cropping system were also significant. Landform, soil depth and soil depth × cropping system did not show significant effect the nodule weight. Sole soybean showed a higher nodule weight (2703) than compared to the intercropped soybean (1878).

The flat landform on the medium-deep soil resulted in the highest nodule weight (2832) and the BBF landform on the medium-deep soil recorded the lowest nodule weight (1809). The sole soybean on the flat landform had the highest nodule weight (2913) and intercropped soybean on the BBF landform had the lowest nodule weight (1667). The flat landform on the medium deep soil with sole soybean showed the highest nodule weight (3244) and the lowest nodule weight (1396) was recorded in the intercropped soybean in the BBF landform treatment on the medium deep soil.

4.3.1.3 Nitrogenase activity (μmol C_2 H_4 m^{-2} h^{-1}) (Table 19)

Nitrogenase activity in soybean increased by 17 times from the vegetative to pod development stages. At the vegetative stage in both the sole and intercropped soybean nitrogenase activity varied significantly under different landform × soil depth and landform × soil depth × cropping system treatment interactions. The other treatments and their interactions were, however, not affected significantly. The BBF landform on the shallow soil recorded the highest nitrogenase activity (12 times) in soybean; the lowest activity (5

Table.19: *Nodulation and nitrogenase(C_2H_4 reduction) activity of sole and intercropped soybean grown on flat and BBF landforms and shallow and medium-deep Vertic Inceptisols during rainy season 1997*

Landform	**Soil depth**													
	Vegetative stage (36 DAS)							Pod development stage (70 DAS)						
	Shallow			**Medium - deep**				**Shallow**			**Medium - deep**			
	Sole	Inter crop	Mean	Sole	Inter crop	Mean	Total mean	Sole	Inter crop	Mean	Sole	Inter crop	Mean	Total mean
1) Number of nodules(m ^{2})														
Flat	373	312	343	507	446	477	410	1410	1304	1357	2044	1938	1991	1674
BBF	559	498	529	404	343	374	452	1682	1586	1634	1520	1424	1472	1553
Mean	466	405	436	456	395	426	431	1546	1445	1496	1782	1681	1732	1614
	L	**S**	**C**	**LS**	**LC**	**SC**	**LSC**	**L**	**S**	**C**	**LS**	**LC**	**SC**	**LSC**
S Ed ±	74 5	74 5	66 1	108 7	99 6	99 6	127 0	214 6	214 4	160 9	312 5	268 0	268 0	355 9
CD(0 05)	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
2) Weight of nodules(mg m ^{2})														
Flat	187	252	220	214	286	250	235	2582	1757	2170	3244	2419	2832	2501
BBF	382	350	366	296	272	284	325	2763	1938	2351	2221	1396	1809	2080
Mean	285	301	293	255	279	267	280	2673	1848	2261	2733	1908	2321	2291
S Ed ±	45 8	42 8	41 9	64 3	62 1	59 9	86 1	312 9	312 9	325	455 6	451 1	451 1	559 7
CD(0 05)	NS	NS	NS	141 5	136 7	NS	189 5	NS	NS	715 3	1002 7	992 8	NS	1231 9
3) Nitrogenase activity (µmol c_2h_4 m ^{2}h ^{1})														
Flat	5 0	4 7	4 9	9 7	10 0	9 9	7 4	151 4	80 9	116 2	223 5	89 7	156 6	136 4
BBF	12 0	11 6	11 8	5 7	6 0	5 9	8 9	250 4	111 6	181	154 8	54 8	104 8	142 9
Mean	8 5	8 2	8 4	7 7	8 0	7 9	8 2	200 9	96 3	148 6	189 1	72 3	130 7	139 7
S Ed ±	1 02	1 02	0 53	1 51	1 14	1 14	1 68	11 52	11 52	11 64	16 92	16 41	16 41	24 10
CD(0 05)	NS	NS	NS	3 32	NS	NS	3 69	NS	NS	25 62	37 24	36 11	36 11	53 00
4) Specific nitrogenase activity (µmol c_2h_4 g ^{1}nodule h ^{1})														
Flat	32 5	32 9	32 7	84 5	49 0	66 8	49 8	65 9	59 2	62 6	71 9	51 4	61 7	62 .2
BBF	44 6	34 8	39 7	29 6	47 6	38 6	39 2	79 1	62 3	70 7	77 7	46 9	62 3	66 5
Mean	38 5	33 9	36 2	57 1	48 3	52 7	44 5	72 5	60 8	66 7	74 8	49.2	62 0	64 4
S Ed ±	14 1	15 31	14 9	21 1	20 61	21 4	29 4	7 22	7 50	8 31	10 6	11 03	11 22	14 59
CD(0 05)	NS	NS	NS	NS	NS	NS	NS	NS	NS	18 29	NS	NS	24 69	32 11

1, Refer Table 1

times) was observed in the flat landform treatment on the shallow soil. Highest nitrogenase activity (12.0) was observed in sole soybean grown on the BBF landform on the shallow soil and the lowest (5.0) was recorded in intercropped soybean grown on flat landform on the shallow soil.

At the pod development stage in both the sole and intercropped soybean during 1997 the nitrogenase activity was affected significantly due to the cropping systems and its interactions viz., landform × soil depth, landform × cropping system, soil depth × cropping system and landform × soil depth × cropping system. Highest nitrogenase activity (195.0) was observed in the sole soybean compared to the intercropped soybean treatment (84.3). Soybean grown on the BBF landform on the shallow soil showed the highest nitrogenase activity (181.0) while the lowest activity (104.8) was observed on the BBF landform on the medium deep soil. Sole soybean grown on BBF landform showed the highest (203.0) nitrogenase activity while the lowest (83.2) activity was recorded in intercropped soybean grown on BBF landform. Highest nitrogenase activity (200.9) was observed in sole soybean grown on shallow soil and the lowest (72.3) was recorded in intercropped soybean grown on medium deep soil. Highest nitrogenase activity (250.4) was recorded on the BBF landform on shallow soil with sole soybean while the lowest activity (54.8) was observed on the BBF landform on medium deep soil with intercropped soybean.

4.3.1.4 Specific nitrogenase activity (μmol C_2H_4 g^{-1} nodule h^{-1}) (Table 19)

In soybean, the specific nitrogenase activity increased from vegetative stage (44.5) to the pod development stage (66.4). During vegetative stage in both the sole and intercropped soybean the specific nitrogenase activity was not significantly influenced due to the landform, soil depth, cropping system treatments or their interactions.

At the pod development stage the specific nitrogenase activity in sole and intercropped soybean was affected significantly by the following treatments : cropping system, soil depth × cropping system and landform × soil depth × cropping system. The specific nitrogenase activity was not affected significantly by the landform, soil depth treatments and the interaction of landform × soil depth, landform × cropping system. Higher (74.0) specific nitrogenase activity was recorded in sole soybean and a much lesser activity (55.0) was observed in the intercropped soybean.

Highest specific nitrogenase activity (74.8) was observed in the sole soybean grown on the medium-deep soil; the specific nitrogenase activity recorded was lowest (49.2) in the intercropped soybean grown on the medium deep soil. The BBF landform on the shallow soil with sole soybean showed the highest (79.1) specific nitrogenase activity while the lowest (51.4) activity was observed in intercropped soybean grown on flat landform treatment on the medium deep soil.

4.3.2 Nodulation and nitrogenase activity of sole and intercropped soybean grown in rainy season : 1998

4.3.2.1 Number of nodules (m^{-2}) (Table 20, Fig. 9)

Mean nodule number in soybean increased from vegetative stage (506) to pod development stage (1571). During vegetative stage in sole and intercropped soybean, nodule number varied significantly due to landform, soil depth, interactions viz., landform × soil depth, landform × cropping system, soil depth x cropping system and landform × soil

Table.20: Nodulation and nitrogenase(C_2H_4 reduction) activity of sole and intercropped soybean grown on flat and BBF landforms and shallow and medium-deep Vertic Inceptisols during rainy season 1998

Landform	**Soil depth**													
	Vegetative stage (36 DAS)							Pod development stage (70 DAS)						
	Shallow			Medium - deep				Shallow			Medium - deep			
	Sole	Inter crop	Mean	Sole	Inter crop	Mean	Total mean	Sole	Inter crop	Mean	Sole	Inter crop	Mean	Total mean
1) Number of nodules(m^{-2})														
Flat	171	254	213	381	415	398	306	1192	1306	1249	1779	1893	1836	1543
BBF	395	470	433	937	1016	977	705	1533	1078	1305	2120	1666	1893	1599
Mean	283	362	323	659	716	688	506	1363	1192	1277	1950	1780	1865	1571
	L	**S**	**C**	**LS**	**LC**	**SC**	**LSC**	**L**	**S**	**C**	**LS**	**LC**	**SC**	**LSC**
S.Ed.±	81.8	81.5	65.3	119.8	104.7	104.5	140.5	202.2	218.7	196.4	305.0	284.5	294.0	391.4
CD(0.05)	180.0	179.3	NS	263.7	230.4	230.0	309.2	NS	481.3	NS	NS	NS	647.0	861.5
2) Weight of nodules(mg m^{-2})														
Flat	62	131	97	172	241	207	152	2639	2732	2686	3819	3912	3866	3276
BBF	136	299	218	374	537	456	337	2614	2209	2412	3981	3577	3779	3096
Mean	99	215	157	273	389	331	244	2627	2471	2549	3900	3745	3823	3186
S.Ed.±	46.3	46.2	44.5	67.9	64.2	64.1	87.0	430.6	506.7	373.4	674.1	570.0	629.5	827.8
CD(0.05)	101.9	101.7	97.9	149.4	141.3	141.1	191.5	NS	1115.2	NS	NS	NS	1385.5	NS
3) Nitrogenase activity (µmol c_2h_4 m-^{2}h^{-1})														
Flat	5.7	9.4	7.6	25.7	26.4	26.1	16.9	43.8	74.6	59.2	197.4	148.0	172.7	116.0
BBF	14.5	17.2	15.9	35.6	41.1	38.4	27.2	51.7	52.0	51.9	225.1	145.1	185.1	119.0
Mean	10.1	13.3	11.7	30.7	33.8	32.3	22.0	47.8	63.3	55.5	211.2	146.6	178.9	118.0
S.Ed.±	7.03	7.51	5.94	10.34	9.35	9.75	12.58	23.26	26.56	24.48	35.99	33.77	36.12	47.89
CD(0.05)	NS	16.5	NS	22.75	NS	21.45	27.69	NS	58.45	NS	79.21	NS	79.50	105.40
4) Specific nitrogenase activity (µmol $c_2h_4\,g^{-1}$nodule h^{-1})														
Flat	45.6	90.8	68.2	132.6	95.6	114.1	91.2	18.5	25.1	21.8	43.3	35.7	39.5	30.7
BBF	121.1	64.3	92.7	73.3	74.8	74.1	83.4	19.2	25.3	22.3	46.3	38.2	42.3	32.3
Mean	83.4	77.6	80.5	102.9	85.2	94.1	87.3	18.9	25.2	22.1	44.8	37.0	40.9	31.5
S.Ed.±	19.87	20.52	21.27	29.24	29.53	30.38	43.25	3.88	5.81	5.18	7.03	6.47	7.78	9.12
CD(0.05)	NS	NS	NS	NS	NS	NS	NS	NS	12.78	NS	15.47	NS	17.12	20.07

1, Refer Table 1

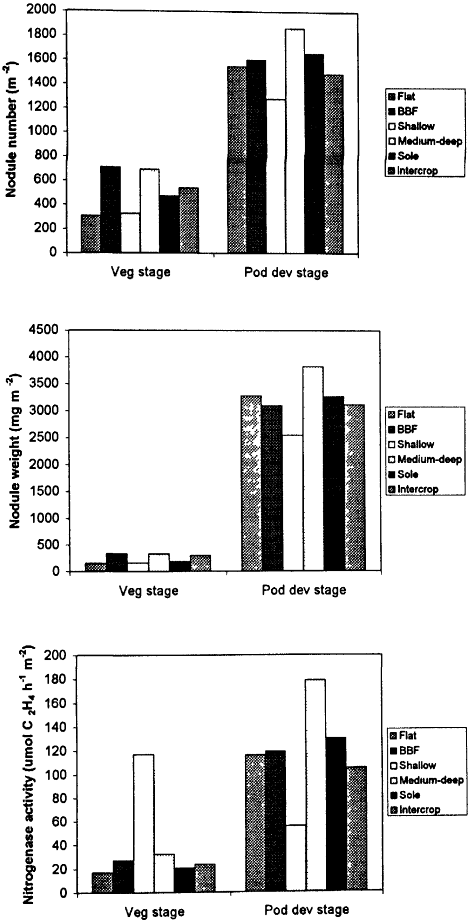


Fig.9: Nodulation and nitrogenase activity of sole and intercropped soybean as influenced by landform and soil depth treatments during rainy season 1998

depth × cropping system. The nodule number was not changed significantly by the cropping systems. Soybean grown on BBF landform had more nodule numbers (705) than compared to the soybean grown on flat landform (306). Maximum nodule number (688) was observed in case of soybean grown on medium deep soil than the soybean grown on shallow soil (323). The BBF landform on the medium-deep soil showed a significantly more nodule number (977) and the lower nodule number (213) was observed in the flat landform on the shallow Vertic Inceptisol compared to the other combinations. The intercropped soybean grown on the BBF landform showed the maximum nodule number (744) and the minimum nodule number (276) was observed in case of sole soybean grown on the flat landform treatment than compared to the other combinations. The highest nodule number (716) was recorded in intercropped soybean on the medium-deep soil whereas the lowest nodule number (283) was observed in sole soybean grown on the shallow soil. More number of nodules (1016) were observed in intercropped soybean grown on BBF on the medium-deep Vertic Inseptisol while the lower number of nodules (171) were recorded in sole soybean grown on the flat landform on the shallow soil compared with the other combinations.

At pod development stage in sole and intercropped soybean during 1998 the variations in nodule number due to soil depth and interactions viz., soil depth × cropping system, and landform × soil depth × cropping system were significant. Nodule number was not influenced significantly by landform, cropping system and interactions like landform × soil depth and landform × cropping system. The medium-deep soil produced more number of nodules (1865) in soybean than compared to the soybean on shallow soil (1277). Maximum number of nodules (1950) were observed in sole soybean grown on medium-deep soil and the minimum number of nodules (1192) were recorded in intercropped soybean grown on shallow soil The sole soybean grown on BBF landform on the medium-deep soil showed the highest number of nodules (2120) whereas the lowest nodule number (1078) was recorded in intercropped soybean grown on BBF landform on the shallow soil

4.3.2.2 Weight of nodules: (mg m^{-2}) (Table 20, Fig. 9)

In soybean, nodule weight increased from vegetative to pod development stage by 13 times During vegetative stage in sole and intercropped soybean nodule weight was affected significantly by landform, soil depth, cropping system and their interactions The BBF landform influenced the higher nodule weight (337) than compared to the flat landform (157) Higher weight of nodules (331) was recorded in the medium-deep soil than compared to the shallow soil (157) for soybean The weight of nodules was higher (302) in intercropped soybean than in sole soybean (186)

The BBF landform on the medium-deep soil influenced the maximum weight of nodules (456) and the minimum nodule weight (97) was observed in the flat landform treatment on the shallow Vertic Inseptisol compared to the other combinations The intercropped soybean grown on the BBF landform showed the highest nodule weight (418) and the lowest weight of nodules (117) were recorded in sole soybean grown on the flat landform The intercropped soybean grown on medium-deep soil recorded more weight of nodules (389) where the lower weight of nodules (99) was observed in sole soybean grown on shallow soil compared to the other combinations A maximum weight of nodules (537) was observed in intercropped soybean grown on BBF landform on the medium deep soil while the minimum weight (62) was recorded in sole soybean grown on flat landform on the shallow soil compared to the other combinations

At pod development stage in sole and intercropped soybean during 1998 the weight of nodules was significantly influenced due to soil depth and soil depth × cropping system, but remaining treatments and their interactions were not affected significantly. Soybean grown on medium-deep soil recorded the maximum weight of nodules (3823) than the soybean grown on shallow soil (2549). More weight of nodules (3900) was recorded in sole soybean grown on medium deep soil and the lesser weight (2471) was observed in intercropped soybean grown on shallow soil compared to the other combinations.

4.3.2.3 Nitrogenase activity (µmol $C_2 H_4$ m^{-2} h^{-1}) (Table20, Fig. 9)

In soybean nitrogenase activity was increased by five times from vegetative to pod development stage. At vegetative stage nitrogenase activity varied significantly due to soil depth, interactions like landform × soil depth, soil depth × cropping system and landform × soil depth × cropping system but other treatments and their interactions did not affect significantly. Soybean grown on medium-deep soil recorded higher nitrogenase activity (32.3) than the soybean grown on shallow soil. The BBF landform on the medium deep soil showed the highest nitrogenase activity (38.4) and the lowest activity (7.6) was observed on the flat landform on the shallow soil in case of soybean. Maximum nitrogenase activity (33.8) was observed in intercropped soybean grown on medium deep soil and lowest nitrogenase activity (10.1) was resulted in sole soybean grown on the shallow Vertic Inceptisol compared with the other combinations. Highest nitrogenase activity (41.1) was observed in the intercropped soybean grown on BBF landform on the medium-deep soil while the lowest (5.7) activity was recorded in sole soybean grown on flat landform on shallow soil.

At the pod development stage during 1998, the nitrogenase activity in sole and intercropped soybean was influenced significantly by soil depth and interactions viz., landform × soil depth, soil depth × cropping system and landform × soil depth × cropping system. Higher nitrogenase activity (178.9) was recorded on medium-deep soil than compared to the shallow soil (55.5) for soybean. The BBF landform on the medium-deep Vertic Inceptisol found the maximum (185.1) nitrogenase activity and minimum nitrogenase activity (51.9) was observed on the BBF landform on the shallow soil compared with the other combinations. Highest nitrogenase activity (211.2) was observed in sole soybean grown on medium-deep soil and the lowest (47.8) was observed in sole soybean grown on shallow soil. Maximum nitrogenase activity (225.1) was recorded on the BBF landform on medium-deep soil with sole soybean while the minimum nitrogenase activity (43.8) was observed on the flat landform on the shallow soil with sole soybean compared to the other combinations during 1998.

4.3.2.4 Specific nitrogenase activity (μmol $C_2 H_4$ g^{-1} nodule h^{-1}) (Table 20)

In soybean specific nitrogenase activity decreased from vegetative stage (87.3) to pod development stage during 1998. At vegetative stage in sole and intercropped soybean the specific nitrogenase activity was not influenced by landform, soil depth, cropping system and their interactions.

At pod development stage in soybean during 1998, the specific nitrogenase activity changed significantly due to soil depth treatment and interactions viz., landform × soil depth, soil depth × cropping system and landform × soil depth × cropping system. The specific nitrogenase activity was not affected significantly by the landform, cropping system treatments and their interaction The medium-deep soil had a more specific nitrogenase activity (40 9) than the shallow soil (22 1) for soybean The BBF landform on the medium-deep soil showed the maximum specific nitrogenase activity (42 3) for soybean and the flat landform on the shallow soil showed the minimum specific nitrogenase activity (21 8) compared to the other combinations Highest specific nitrogenase activity (44 8) was recorded in sole soybean grown on medium-deep Vertic Inceptisol and the lowest (18 9) was recorded in sole soybean grown on shallow soil The BBF landform on the medium-deep soil with sole soybean showed a more (46 3) specific nitrogenase activity and a lesser activity (18 5) was observed in sole soybean grown on flat landform on shallow soil compared with the other combinations during 1998

4.3.3 Nodulation and nitrogenase activity of pigeonpea grown in rainy and post rainy season : 1997

4.3.3.1 Number of nodules (m^{2}) (Table 21)

Nodule number in pigeon pea during vegetative stages viz , 36 and 70 DAS was not changed significantly by the landform, soil depth treatments and their interaction During flowering stage (133 DAS) in pigeonpea the nodule number was significantly influenced by landform × soil depth interaction Landform and soil depth treatments had no significant effect on nodule number Significantly the BBF on the shallow soil influenced more number of nodules (61) and lower number of nodules (17) was observed in the BBF landform on the medium-deep Vertic Inceptisol compared with the other combinations in pigeonpea

4.3.3.2 Weight of nodules: (mg m^{-2}) (Table 21)

Table.21: Nodulation and nitrogenase(C_2H_4 reduction) activity of pigeonpea grown on flat and BBF landforms and shallow and medium-deep Vertic Inceptisols during rainy and post-rainy seasons 1997

Landform	**Soil depth**								
	Vegetative stage (36 DAS)			Vegetative stage (70 DAS)			Flowering stage (133 DAS)		
	Shallow	**Medium-deep**	**Mean**	**Shallow**	**Medium-deep**	**Mean**	**Shallow**	**Medium-deep**	**Mean**
1) Number of nodules(m^{-2})									
Flat	128	88	108	106	179	143	18	28	23
BBF	128	88	108	154	121	138	61	17	39
Mean	128	88	108	130	150	140	40	23	31
	L	**S**	**LS**	**L**	**S**	**LS**	**L**	**S**	**LS**
S.Ed.±	1 0	26 2	26 2	37 7	37 7	54 7	9 3	9 3	13 7
CD(0 05)	NS	NS	NS	NS	NS	NS	NS	NS	30 1
2) Weight of nodules(mg m^{2})									
Flat	78	71	74	237	237	237	42	66	54
BBF	78	71	74	237	237	237	87	111	99
Mean	78	71	74	237	237	237	65	89	77
S Ed ±	0 8	13 7	13 7	3 0	3 0	4 2	23 1	20 7	31 8
CD(0 05)	NS	NS	NS	NS	NS	NS	NS	NS	NS
3) Nitrogenase activity (µmol $c_2h_4\,m^{-2}\,h^{-1}$)									
Flat	1 9	1 9	1 9	10 8	19 0	14 9	0 5	0 9	0 7
BBF	2 3	2 3	2 3	20 4	7 9	14 1	1 2	0 7	1 0
Mean	2 1	2 1	2 1	15 6	13 5	14 5	0 9	0 8	0 9
S Ed ±	0 55	0 02	0 56	3 64	3 64	5 32	0 16	0 16	0 24
CD(0 05)	NS	NS	NS	NS	NS	11 7	NS	NS	0 52
4) Specific nitrogenase activity (µmol $c_2h_4\,g^{-1}$nodule h^{-1})									
Flat	26 8	29 9	28 3	84 5	62 1	73 3	18 5	13 8	16 1
BBF	43 0	46 2	44 6	84 5	62 1	73 3	15 1	10 4	12 8
Mean	34 9	38 1	36 5	84 5	62 1	73 3	16 8	12 1	14 5
S Ed ±	17 20	10 40	20 30	0 68	17 16	17 17	2 62	2 81	3 94
CD(0 05)	NS	NS	NS	NS	NS	NS	NS	NS	NS

1, Refer Table 1

During vegetative stages (36 and 70 DAS) and flowering stage in pigeonpea crop during 1997, landform, soil depth and their interaction did not result in any significant effect on the nodule weight

4.3.3.3 Nitrogenase activity (µmol $C_2 H_4 m^{-2} h^{-1}$) (Table 21)

At vegetative stages (36 DAS) in pigeonpea the nitrogenase activity was not affected significantly due to landform, soil depth and their interaction At vegetative stage (70 DAS) in pigeonpea the nitrogenase activity was influenced significantly by the interaction of landform × soil depth Landform and soil depth treatments had no significant effect on the nitrogenase activity The BBF landform on the shallow soil showed the highest nitrogenase activity (20 4) and the BBF landform on the medium-deep soil showed the lowest nitrogenase activity (7 9) in pigeonpea

During flowering stage in pigeonpea during 1997, the variations in nitrogenase activity due to landform × soil depth interaction was significant Landform and soil depth treatments had no significant effect on nitrogenase activity Maximum nitrogenase activity (1 2) was recorded on the BBF landform on the shallow soil and the flat landform on the shallow soil showed the minimum (0 5) nitrogenase activity compared with the other combinations in pigeonpea during 1997

4.3.3.4 Specific nitrogenase activity (µmol $C_2 H_4 g^{-1}$ nodule h^{-1}) (Table 21)

The specific nitrogenase activity in pigeonpea during vegetative (36 and 70 DAS) and flowering stages was not influenced significantly by landform, soil depth, cropping system treatments or their interaction during 1997

4.3.4 Nodulation and nitrogenase activity of pigeonpea grown in rainy and post-rainy season : 1998

Number of nodules (m^{2}), weight of nodules (mg m^{2}), nitrogenase activity (µmol C_2H_4 m^{2} h^{1}) and specific nitrogenase activity (µmol C_2H_4 g^{1} nodule h^{1}) (Table 22) in pigeonpea during vegetative (36 and 70 DAS) and flowering stages were not influenced significantly by landform, soil depth and their interaction

4.3.5. Nodulation and nitrogenase activity of chickpea grown during post-rainy season : 1997

4.3.5.1. Number of nodules (m^{2}) (Table 23, Fig. 10)

In chickpea crop mean nodule number increased by seven times from vegetative stage to flowering stage and then decreased to two times at pod development stage During vegetative stage of chickpea, the nodule number varied significantly due to landform, soil depth and their interaction At the flowering stage the differences in nodule number due to soil depth and landform x soil depth were significant The nodule number was not changed significantly by the landforms A significantly more nodule number (1382) was observed in the medium-deep soil than the shallow soil (570) for chickpea The BBF landform on the medium-deep Vertic Inceptisol had the maximum (1618) nodule number and minimum number of nodules (170) was observed in the BBF landform on the shallow Vertic Inceptisol compared with the other combinations in chickpea

At pod development stage in chickpea during 1997, the nodule number varied significantly due to soil depth and landform x soil depth interaction Landform had no

Table.22: Nodulation and nitrogenase(C_2H_4 reduction) activity of pigeonpea grown on flat and BBF landforms and shalow and medium-deep Vertic Inceptisols during rainy and post-rainy seasons 1998

Landform	Soil depth								
	Vegetative stage (36 DAS)			Vegetative stage (70 DAS)			Flowering stage (133 DAS)		
	Shallow	Medium-deep	Mean	Shallow	Medium-deep	Mean	Shallow	Medium-deep	Mean
1) Number of nodules(m^{-2})									
Flat	61	28	45	115	215	165	18	24	21
BBF	35	70	52	123	223	173	21	28	25
Mean	48	49	49	119	219	169	20	26	23
	L	**S**	**LS**	**L**	**S**	**LS**	**L**	**S**	**LS**
S.Ed.±	15 9	15 9	23 1	27 8	56 8	63 9	6 8	8 4	10 8
CD(0 05)	NS	NS	NS	NS	NS	NS	NS	NS	NS
2) Weight of nodules(mg m ^{2})									
Flat	53	28	41	199	297	248	42	81	62
BBF	33	53	43	259	357	308	48	87	68
Mean	43	41	42	229	327	278	45	84	65
S Ed ±									
CD(0 05)	18 0	18 0	26 0	74 8	83 3	114 4	22 8	38 5	44 7
	NS	NS	NS	NS	NS	NS	NS	NS	NS
3) Nitrogenase activity (μmol $c_2h_4\,m^{-2}\,h^{-1}$)									
Flat	8 2	3 8	6 0	12 9	25 8	19 4	0 6	0 9	0 8
BBF	4 8	6 0	5 4	13 2	26 2	19 7	1 0	0 8	0 9
Mean	6 5	4 9	5 7	13 1	26 0	19 6	0 8	0 9	0 9
S Ed ±	2 86	2 86	4 11	3 21	9 07	9 68	0 21	0 21	0 29
CD(0 05)	NS	NS	NS	NS	NS	NS	NS	NS	NS
4) Specific nitrogenase activity (μmol $c_2h_4\,g^{-1}$nodule h^{-1})									
Flat	164 5	136 8	150 6	59 1	90 2	74 7	206 4	139 3	172 9
BBF	165 6	137 8	151 7	59 1	90 2	74 7	94 4	27 3	60 8
Mean	165 0	137 3	151 2	59 1	90 2	74 7	150 4	83 3	116 9
S Ed ±	17 62	49 69	52 90	0 72	18 96	18 98	63 14	59 49	86 75
CD(0 05)	NS	NS	NS	NS	NS	NS	NS	NS	NS

1, Refer Table 1

significant effect on nodule number Medium-deep soil produced more number of nodules (670) in chickpea than compared to the chickpea on shallow soil (263) The flat landform on the medium-deep soil showed the maximum nodule number (675) and the minimum nodule number (258) was recorded in the flat landform on the shallow soil compared with the other combinations in chickpea

4.3.5.2 Weight of nodules (mg m^{-2}) (Table 23, Fig. 10)

In chickpea mean nodule weight increased from vegetative stage to flowering stage and then decreased at pod development stage During vegetative stage, the differences in nodule weight due to landform, soil depth and their interaction were not significant At flowering stage the nodule weight varied significantly due to soil depth and landform x soil depth interaction Landform had no significant effect on the nodule weight More weight of nodules (924) was observed in the medium-deep soil for chickpea than the shallow soil (365) Chickpea grown on BBF landform on the medium-deep Vertic Inceptisol showed the maximum (941) nodule weight and the minimum nodule weight (327) was observed in the BBF landform on the shallow Vertic Inceptisol

At pod development stage, in chickpea during 1997, the variations in nodule weight due to soil depth treatment and landform x soil depth interaction were significant The medium-deep soil showed a more weight of nodules (524) than compared to the shallow soil (227) Highest nodule weight (524) was observed in the medium-deep soil in both landforms (BBF and flat) and the lowest nodule weight (227) was recorded in the shallow soil in both landform treatments in chickpea

Table.23: Nodulation and nitrogenase(C_2H_4 reduction) activity of chickpea grown on flat and BBF landforms and shallow and medium-deep Vertic Inceptisols during post-rainy season 1997

Landform	Soil depth								
	Vegetative stage(38 DAS)			Flowering stage (58 DAS)			Pod development stage (73 DAS)		
	Shallow	Medium-deep	Mean	Shallow	Medium-deep	Mean	Shallow	Medium-deep	Mean
1) Number of nodules(m^{-2})	103	175	139	970	1146	1058	258	675	467
Flat	101	172	137	170	1618	894	267	664	466
BBF	102	174	138	570	1382	976	263	670	467
Mean	**L**	**S**	**LS**	**L**	**S**	**LS**	**L**	**S**	**LS**
	17 5	42 4	46 2	205 5	209 0	318 7	37 7	140 2	145 8
S.Ed.±	NS	NS	NS	NS	460 0	701 4	NS	308 5	320 9
CD(0.05)									
2) Weight of nodules (mg m^2	133	242	188	402	906	654	227	524	375
Flat	152	129	141	327	941	634	227	524	375
BBF	143	186	165	365	924	644	227	524	375
Mean									
	55 4	55 4	80 1	105 6	208 8	241 1	100 6	100 6	100 7
S Ed ±	NS	NS	NS	NS	459 5	530 6	NS	221 4	221 6
CD(0 05)									
3) Nitrogenase activity (μmol c_2h_4 m^{-2} h^{-1})									
Flat	1 6	3 1	2 4	19 1	46 2	32 7	11 7	31 6	21 7
BBF	0 5	0 8	0 7	15 9	43 0	29 5	22 6	42 5	32 6
Mean	1 1	2 0	1 6	17 5	44 6	31 1	17 2	37 1	27 2
S Ed ±	1 1	0 95	1 53	6 91	12 46	14 45	8 89	9 78	13 57
CD(0 05)	NS	NS	NS	NS	NS	NS	NS	NS	29 86
4) Specific nitrogenase activity (μmol c_2h_4 g^{1}nodule h^{-1})									
Flat	10 9	10 9	10 9	50 1	50 1	50 1	65	65	65 0
BBF	3 6	3 6	3 6	39 5	39 5	39 5	79 9	79 9	79 9
Mean	7 3	7 3	7 3	44 8	44 8	44 8	72 5	72 5	72 5
S Ed ±	3 7	0 13	3 76	8 16	0 31	8 17	16 28	0 71	16 3
CD(0 05)	NS	NS	NS	NS	NS	NS	NS	NS	NS

1, Refer Table 1

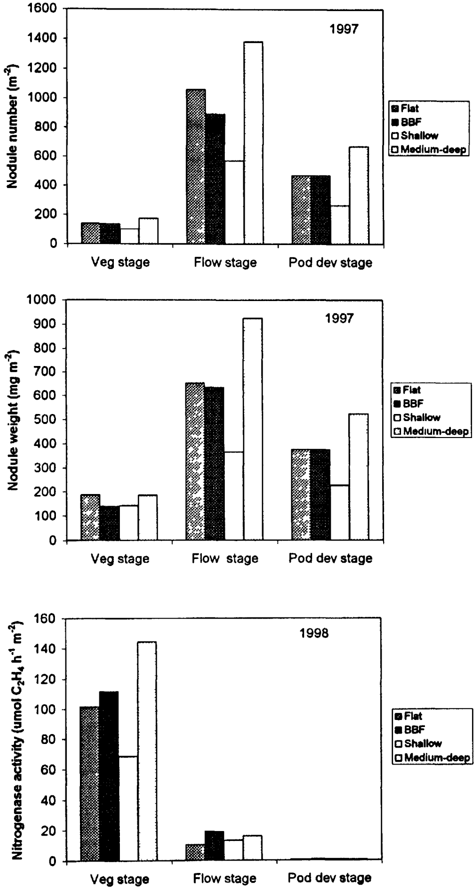


Fig.10: Nodulation and nitrogenase activity of chickpea as influenced by landform and soil depth treatments during post-rainy season 1997 and 1998

4.3.5.3. Nitrogenase activity (µmol C_2H_4 m^{-2} h^{-1}) (Table 23)

In chickpea, the nitrogenase activity was not influenced significantly by landform, soil depth and their interaction during both vegetative and flowering stage during 1997 At the pod development stage the nitrogenase activity varied significantly due to landform x soil depth interaction However, landform and soil depth treatments had no significant effect The BBF landform on the medium-deep soil showed the highest nitrogenase activity (42 5) and lowest nitrogenase activity (11 7) was observed on the flat landform on the shallow soil

4.3.5.4. Specific nitrogenase activity (µmol C_2H_4 g^{-1} nodule h^{-1}) (Table 23)

The specific nitrogenase activity in chickpea was not influenced significantly by landform, soil depth and their interaction during crop growth stages viz , vegetative, flowering and pod development

4.3.6 Nodulation and nitrogenase activity of chickpea grown in post-rainy season : 1998

4.3.6.1 Number of nodules (m^{-2}) (Table 24)

Mean nodule number in chickpea decreased from vegetative stage to pod development stage At vegetative stage, the nodule number in chickpea was influenced significantly by soil depth and landform x soil depth interaction Landform had no significant effect on nodule number The medium-deep soil produced more (1145) number of nodules in chickpea than the shallow soil (598) The BBF landform on the medium-deep soil influenced the maximum number of nodules (1218) and the flat landform on the shallow

Table.24: Nodulation and nitrogenase(C_2H_4 reduction) activity of chickpea grown on flat and BBF landforms and shallow and medium-deep Vertic Inceptisols during post-rainy season 1998

Landform	**Soil depth**								
	Vegetative stage(38 DAS)			Flowering stage (58 DAS)			Pod development stage (73 DAS)		
	Shallow	**Medium-deep**	**Mean**	**Shallow**	**Medium-deep**	**Mean**	**Shallow**	**Medium-deep**	**Mean**
1) Number of nodules(m^2)									
Flat									
BBF	524	1071	798	186	475	331	168	173	171
Mean	671	1218	945	630	390	510	281	286	284
	598	1145	872	408	433	421	225	230	228
S Ed ±	**L**	**S**	**LS**	**L**	**S**	**LS**	**L**	**S**	**LS**
CD(0 05)	151 9	185 4	245 9	102 9	102 9	150 3	79 9	34 6	87 8
	NS	408	541 2	NS	NS	330 8	NS	NS	NS
2) Weight of nodules(mg m^2									
Flat	1198	2017	1608	799	799	799	754	754	754
BBF	1135	2075	1605	1373	1373	1373	1143	1143	1143
Mean	1167	2046	1607	1086	1086	1086	949	949	949
S Ed ±	143 5	342 4	374 8	313 2	11 9	313 4	182 6	6 71	182 7
CD(0 05)	NS	753 6	824 9	NS	NS	NS	NS	NS	NS
3) Nitrogenase activity (µmol c_2h_4 m^2 h^1)									
Flat	67 2	135 8	101 5	2 3	18 2	10 3	0 1	0 7	0 4
BBF	69 7	153 0	111 4	23 9	13 5	18 7	1 1	0 4	0 8
Mean	68 5	144 4	106 5	13 1	15 9	14 5	0 6	0 6	0 6
S Ed ±	15 33	26 67	31 25	6 33	6 32	9 44	0 35	0 35	0 51
CD(0 05)	NS	58 7	68 78	NS	NS	20 7	NS	NS	NS
4) Specific nitrogenase activity (µmol c_2h_4 g^1 nodule h^1)									
Flat	54 4	62 7	58 6	0 7	21 7	11 2	0 2	0 7	0 5
BBF	64 7	73 1	68 9	14 8	8 4	11 6	0 8	0 5	0 7
Mean	59 5	67 9	63 7	7 8	15 1	11 4	0 5	0 6	0 6
S Ed ±	7 57	7 28	10 77	5 33	5 32	7 98	0 35	0 35	0 49
CD(0 05)	NS	NS	NS	NS	NS	17 56	NS	NS	NS

1, Refer Table 1

soil showed the minimum number of nodules compared with the other combinations (524) in chickpea crop. During flowering stage, the difference in nodule number due to interaction of landform x soil depth was significant.

The BBF landform on the shallow soil recorded more number of nodules (630) while the flat landform on the shallow soil showed a lesser number of nodules (186) compared to the other combinations in chickpea.

During pod development stage, the landform, soil depth and their interaction had not significant effect on the nodule number in chickpea.

4.3.6.2 Weight of nodules (mg m^{2}) (Table 24)

In chickpea during 1998, the variations in nodule weight due to soil depth and interaction of landform x soil depth were significant during the vegetative stage. A significantly more weight of nodules (2046) was observed in the medium-deep soil than the shallow soil (1167) in chickpea crop. The BBF landform treatment on the medium-deep soil showed the highest (2075) nodule weight while the lowest nodule weight (1135) was observed in chickpea grown on BBF landform on the shallow soil.

During both the flowering and pod development stages, the nodule weight was not significantly influenced by landform, soil depth and their interaction.

4.3.6.3. Nitrogenase activity (μmol C_2H_4 m^{-2} h^{-1}) (Table 24, Fig. 10)

The nitrogenase activity in chickpea during 1998 decreased from vegetative stage (106.5) to pod development stage (0.58). Soil depth and landform x soil depth interaction had significant effect on the nitrogenase activity in chickpea at the vegetative stage.

Landform did not influence nitrogenase activity during vegetative stage Higher nitrogenase activity in chickpea (144 4) was noticed on the medium-deep soil than compared to the shallow soil (68 5) The BBF landform on the medium-deep soil showed the highest nitrogenase activity (153) in chickpea while the lowest activity (67 2) was observed on the flat landform on the shallow soil

During flowering stage the nitrogenase activity was affected significantly by landform x soil depth interaction Landform and soil depth treatment did not influence significantly the nitrogenase activity in chickpea

The BBF landform on the shallow soil recorded the highest nitrogenase activity ((23 9) and the flat landform on the shallow soil showed the lowest nitrogenase activity (2 3) in chickpea

4.3.6.4. Specific nitrogenase activity (μmol C_2 H_4 g^{-1} nodule h^{-1}) (Table 24)

In chickpea crop during both the vegetative and pod development stages, the variations in specific nitrogenase activity under the various landform, soil depths and their interaction were not significant At the flowering stage, the specific nitrogenase activity varied significantly due to landform x soil depth interaction Landform and soil depth treatments had no significant effect on the specific nitrogenase activity in chickpea The flat landform treatment on the medium-deep Vertic Inceptisol showed the highest nitrogenase activity (21 7) and the flat landform on the shallow Vertic Inceptisol recorded the lowest nitrogenase activity (0 7) in chickpea

4.3.7 Quantification of BNF in soybean by N-difference method: 1997

4.3.7.1 Nitrogen fixed (kg ha^{-1}): Soybean (Table 25, Fig. 11)

Nitrogen fixed by soybean as estimated by N-difference method using sorghum as non-fixing plant, was affected significantly by cropping system treatment, and interactions viz , landform x cropping system, soil depth x cropping system and landform x soil depth x cropping system Landform, soil depth treatments and their interaction did not vary significantly the nitrogen fixed by soybean Sole soybean fixed a significantly more nitrogen (58) than the intercropped soybean (16) Sole soybean grown on flat landform, fixed the highest amount of N (58) and the intercropped soybean grown on BBF landform, fixed the lowest amount of N (16) Sole soybean grown on shallow soil, fixed a maximum amount of N (58) while the intercropped soybean grown on medium-deep soil fixed a minimum amount of N (16) compared to the other combinations Sole soybean grown on flat landform on shallow soil, fixed a maximum amount of N (61) compared with the other combinations

4.3.7.2 Percent N derived from atmosphere (%) : Soybean (Table 25)

In soybean, the nitrogen fixation was influenced significantly by cropping system and interactions viz , landform x cropping system, soil depth x cropping system, landform x soil depth x cropping system Landform, soil depth and their interaction did not significantly vary the nitrogen fixation A significantly higher nitrogen fixation (35) was found in sole soybean crop than compared to the intercropped soybean (14) Sole soybean grown on BBF showed the highest proportion of N fixation (35) and it was lowest (13) in case of intercropped soybean grown on BBF landform treatment Sole soybean grown on

Table.25: Nitrogen fixed by soybean grown as sole and intercrop on flat and BBF landforms and shallow and medium-deep Vertic Inceptisols as estimated by N-difference and ^{15}N isotope dilution methods using sorghum as a non fixing crop during rainy seasons 1997 and 1998

Landform	**Soil depth**													
	1997							1998						
	Shallow			Medium-deep				Shallow			Medium-deep			
	Sole	Inter crop	Mean	Sole	Inter crop	Mean	Total mean	Sole	Inter crop	Mean	Sole	Inter crop	Mean	Total mean
							1) N difference method							
a) Nitrogen fixed (kg ha^{1})														
Flat	61	20	41	54	13	34	38	21	13	17	26	19	23	20
BBF	54	13	34	59	18	39	37	12	5	9	28	21	25	17
Mean	58	17	38	57	16	37	38	17	9	13	27	20	24	19
	L	**S**	**C**	**LS**	**LC**	**SC**	**LSC**	**L**	**S**	**C**	**LS**	**LC**	**SC**	**LSC**
S Ed ±	4 8	4 8	6 2	7 0	7 9	7 9	9 3	2 6	2 9	2 8	4 1	3 9	4 1	5 0
CD(0 05)	NS	NS	13 6	NS	17 3	17 3	20 4	NS	6 3	6 1	9 0	8 5	9 0	11 0
b) Percent N derived from atmosphere (%)														
Flat	35	15	25	33	13	23	24	15	14	15	20	19	20	18
BBF	33	11	22	36	14	25	24	9	8	9	22	21	22	16
Mean	34	13	24	35	14	24	24	12	11	12	21	20	21	17
S Ed ±	2 6	2 5	3 3	3 7	4 2	4 2	5 2	2 5	2 8	1 4	3 9	2 9	3 1	4 1
CD(0 05)	NS	NS	7 3	NS	9 2	9 2	11 4	NS	6 1	NS	8 5	NS	6 8	9 0
							2) ^{15}N isotope dilution method							
a) Nitrogen fixed (kg ha^{1})														
Flat	47	27	37	55	29	42	40	42	36	39	50	45	48	44
BBF	50	26	38	55	25	40	39	41	37	39	53	49	51	45
Mean	49	27	38	55	27	41	40	42	37	39	52	47	50	45
S Ed ±	3 5	3 6	4 4	5 1	5 6	5 7	7 2	4 5	6 2	5 2	7 7	6 9	8 1	9 5
CD(0 05)	NS	NS	9 6	NS	12 3	12 5	15 8	NS	NS	NS	NS	NS	NS	NS

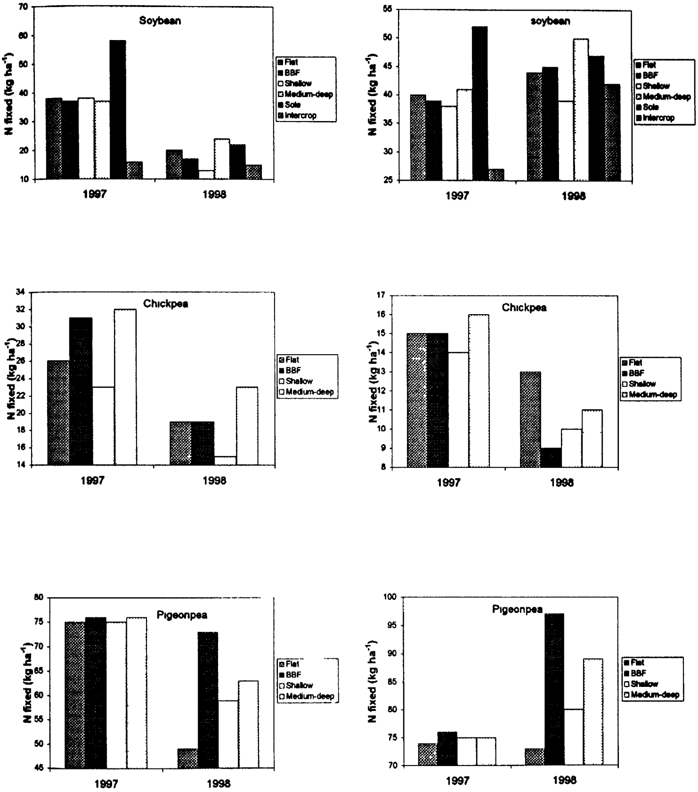
1, Refer Table 1

medium-deep soil showed the highest proportion of N fixation (35) whereas the intercropped soybean grown on shallow soil recorded the lowest proportion of N fixation (13) Highest proportion of N fixation (36) was observed in sole soybean grown on BBF landform on medium-deep soil while the lowest proportion of N fixation (11) was estimated in intercropped soybean grown on BBF landform on shallow Vertic Inceptisol

4.3.8 Quantification of BNF in soybean by N-difference method: 1998

4.3.8.1. Nitrogen fixed (kg ha ^{1}) : Soybean (Table 25, Fig. 11))

The differences in amount of nitrogen fixed by soybean due to soil depth, cropping system treatments and interactions viz , landform x soil depth, landform x cropping system, soil depth x cropping system and landform x soil depth x cropping system were significant Landform did not significantly influence the nitrogen fixed by soybean Medium deep soil influenced the more amount of nitrogen fixed (24) by soybean than compared to the shallow soil (13) A significantly maximum amount of nitrogen fixed (22) was by sole soybean as compared to the intercropped soybean (15) The BBF landform on the medium-deep soil showed the highest nitrogen fixed (25) by soybean, and the BBF landform on the shallow Vertic Inceptisol showed the lowest nitrogen fixed (9) by soybean Sole soybean grown on flat landform fixed a more nitrogen (24)whereas intercropped soybean grown on BBF landform fixed a lesser nitrogen (13) than compared to the other combinations Sole soybean grown on medium-deep soil fixed the highest nitrogen (27) and the intercropped soybean grown on shallow Vertic Inceptisol fixed the lowest nitrogen (9) Sole soybean grown on BBF on medium-deep soil fixed the highest nitrogen (28) biologically, while the intercropped soybean grown on BBF on shallow depth soil fixed the lowest nitrogen (5)



N - difference method

^{15}N isotope dilution method

Fig.11: Nitrogen fixed by soybean, chickpea and pigeonpea grown on BBF and flat landforms in shallow and medium-deep Vertic Inceptisols as estimated by N - difference and ^{15}N isotope dilution methods during 1997 and 1998

4.3.8.2. Percent N derived from atmosphere (%): Soybean (Table 25)

In soybean the N-fixation was changed significantly by soil depth treatment and interactions viz , landform x soil depth, soil depth x cropping system and landform x soil depth x cropping system Landform, cropping system treatments and interaction of landform x cropping system did not vary significantly the nitrogen fixation The medium-deep soil influenced a significantly higher proportion of N fixation (21) than the shallow depth soil (12) The BBF landform on the medium-deep soil influenced the highest proportion of nitrogen fixation (22) whereas the BBF landform on the shallow depth soil showed the lowest (9) proportion of N-fixation Sole soybean grown on medium-deep soil noticed the highest proportion of N-fixation (21) and the intercropped soybean grown on shallow depth soil showed the lowest (11) proportion of N-fixation Highest proportion of N fixed (22) was estimated by sole soybean grown on BBF landform on medium-deep soil while the lowest proportion of N fixed (8) was estimated by intercropped soybean grown on BBF landform on shallow Vertic Inceptisol

4.3.9. Quantification of BNF in pigeonpea by N-difference method: 1997

4.3.9.1 Nitrogen fixed (kg ha^{-1}) : Pigeonpea (Table 26, Fig. 11)

Nitrogen fixed by pigeonpea as estimated by N-difference method using long duration sorghum as non-fixing check nitrogen fixation was not influenced significantly by landform, soil depth and their interaction

4.3.9.2 Percent N derived from atmosphere (%): Pigeonpea (Table 26)

Table.26: Nitrogen fixed by chickpea and pigeonpea grown on flat and BBF landforms and shallow and medium-deep Vertic Inceptisols as estimated by N-difference and ^{15}N isotope dilution methods using non-nodulating chickpea and sorghu as non fixing crops respectively during 1997 and 1998

Landform	Soil depth											
	Chickpea						Pigeonpea					
	1997			1998			1997			1998		
	Shallow	Medium deep	Mean	Shallow	Medium deep	Mean	Shallow	Medium deep	Mean	Shallow	Medium deep	Mean
1) N-difference method												
a) Nitrogen fixed (kg ha^{1})												
Flat	25	26	26	15	23	19	73	77	75	47	51	49
BBF	21	40	31	15	23	19	76	75	76	71	75	73
Mean	23	32	28	15	23	19	75	76	76	59	63	61
	L	**S**	**LS**	**L**	**S**	**LS**	**L**	**S**	**LS**	**L**	**S**	**LS**
S Ed ±	3 3	3 3	4 9	0 1	2 4	2 5	4 1	4 1	5 9	7 5	5 4	9 5
CD(0 05)	NS	7 3	10 7	NS	5 2	5 5	NS	NS	NS	16 5	NS	20 9
b) Percent N derived from atmosphere(%)												
Flat	55	53	54	51	58	55	77	79	78	61	61	61
BBF	43	63	53	50	56	53	78	80	79	70	70	70
Mean	49	58	54	51	57	54	78	80	79	66	66	66
S Ed ±	4 4	4 4	6 5	2 3	3 7	4 4	2 1	2 2	3 1	4 8	0 1	4 8
CD(0 05)	NS	NS	14 3	NS	NS	NS	NS	NS	NS	NS	NS	NS
2) ^{15}N isotope dilution method												
a) Nitrogen fixed (kg ha^{1})												
Flat	14	16	15	12	13	13	68	80	74	66	79	73
BBF	14	16	15	8	9	9	82	70	76	94	99	97
Mean	14	16	15	10	11	11	75	75	75	80	89	85
S Ed ±	0 3	2 8	2 8	2 0	1 3	2 4	5 1	5 1	7 5	5 8	5 1	8 0
CD(0 05)	NS	NS	NS	NS	NS	NS	NS	NS	NS	12 7	NS	17 6

1, Refer Table 1

The proportion of N fixed by pigeonpea using N-difference method was not influenced significantly by the landform, soil depth and their interaction during 1997

4.3.10 Quantification of BNF in pigeonpea by N-difference method: 1998

4.3.10.1 Nitrogen fixed (kg ha^{-1}): Pigeonpea (Table 26, Fig. 11)

Estimates of N-fixed by pigeonpea with N-difference method using long duration sorghum as non-fixing plant, varied significantly due to landform treatment and landform x soil depth interaction Soil depth did not significantly influence the N-fixed by pigeonpea Pigeonpea grown on BBF landform fixed a higher (73) amount of N than that of pigeonpea grown on shallow soil (49) The BBF landform on the medium-deep soil recorded the highest N-fixed by pigeonpea (75) and the flat landform on the shallow soil resulted in the lowest amount of N fixed (47) by pigeonpea

4.3.10.2 Percent N derived from atmosphere (%): Pigeonpea (Table 26)

The proportion of N fixation using N-difference method was not changed significantly by landform, sol depth and their interaction in pigeonpea during 1998

4.3.11 Quantification of BNF in chickpea by N-difference method: 1997

4.3.11.1 Nitrogen fixed (kg ha^{-1}): Chickpea (Table26, Fig. 11)

Estimates of N-fixed by chickpea with N-difference method using non-nodulating chickpea as non-fixing plant, varied significantly due to soil depth and interaction of landform x soil depth were significant Landform treatment had no significant effect on nitrogen fixed by chickpea Chickpea grown on medium-deep soil fixed a higher (32) amount of N as compared to the shallow soil (23) The BBF landform on the medium-deep soil recorded the highest N-fixed (40) and the BBF landform on the shallow soil showed the lowest N-fixed (21) by chickpea

4.3.11.2 Percent N derived from atmosphere (%): Chickpea (Table 26)

The proportion of N-fixation using N-difference method was influenced significantly by landform x soil depth interaction The landform, soil depth treatments did not significantly vary the proportion of N fixation The BBF on the medium-deep soil showed the highest proportion of N-fixation (63) Whereas the BBF landform on the shallow soil recorded the lowest proportion of N-fixation (43) by chickpea

4.3.12 Quantification of BNF in chickpea by N-difference method: 1998.

4.3.12.1 Nitrogen fixed (kg ha^{-1}): Chickpea (Table 26, Fig. 11)

The differences in the amount of nitrogen fixed by chickpea as estimated with N-difference method using non-nodulating chickpea as non-fixing check, varied significantly due to soil depth treatments and landform x soil depth interaction Landform had not significant effect on N-fixed A significantly higher amount of N-fixed (23) by chickpea was observed in case of medium-deep soil compared to the shallow soil (15) Both landforms (BBF and flat) on medium-deep soil recorded the highest amount of N-fixed (23) and the both landforms on shallow soil recorded the lowest amount of N-fixed (15) by chickpea during 1998

4.3.12.2 Percent N derived from atmosphere (%): Chickpea (Table26)

The proportion of N-fixation by chickpea using N-difference method was not changed significantly by landform, soil depth and their interaction during 1998

4.3.13 Quantification of nitrogen fixation in soybean by ^{15}N isotope dilution method: 1997

4.3.13.1 Nitrogen fixed (kg ha^{-1}): Soybean (Table 25, Fig. 11)

Nitrogen fixed by soybean as estimated by ^{15}N isotope dilution method using sorghum as non-fixing plant, was influenced significantly by cropping system treatment and treatment combinations viz , landform x cropping system, soil depth x cropping system and landform x soil depth x cropping system Landform, soil depth and their interaction did not vary significantly the amount of nitrogen fixed by soybean Sole soybean fixed a significantly more amount of nitrogen (52) as compared to the intercropped soybean (27) Sole soybean grown on BBF landform fixed the highest amount of N (53) and the intercropped soybean grown on BBF landform fixed the lowest amount of N (26) Sole soybean grown on shallow soil fixed the highest amount of N (55) while the intercropped soybean grown on both depth soils (shallow and medium-deep soils) fixed the lowest amount of N (27) Sole soybean grown on both landforms (BBF and flat) on the medium-deep soil, fixed the highest amount of N (55) however the intercropped soybean grown on BBF landform on medium-deep soil fixed the lowest amount of N (25)

4.3.14 Quantification of nitrogen fixation in soybean by ^{15}N isotope dilution method: 1998.

Nitrogen fixed (kg ha^{-1}): Soybean (Table 25, Fig. 11)

Estimates of N-fixed by soybean with ^{15}N isotope dilution method using sorghum as non-fixing plant, was not affected significantly by landform, soil depth, cropping system and their interactions

4.3.15 Quantification of nitrogen fixation in pigeonpea by ^{15}N isotope dilution method: 1997.

Nitrogen fixed (kg ha^{-1}): Pigeonpea (Table 26, Fig. 11)

The difference in amount of nitrogen fixed by pigeonpea as estimated by ^{15}N isotope dilution method using long duration sorghum as non-fixing plant, due to landform, soil depth and their interaction were not significant during 1997

4.3.16 Quantification of nitrogen fixation in pigeonpea by ^{15}N isotope dilution method: 1998.

Nitrogen fixed (kg ha^{-1}): Pigeonpea (Table 26, Fig. 11)

Nitrogen fixed by pigeonpea as estimated by ^{15}N isotope dilution method using long duration sorghum as non-fixing plant, was changed significantly by landform, and landform x soil depth interaction Soil depth did not significantly vary the nitrogen fixed by pigeonpea The BBF landform influenced a higher nitrogen fixed (97) by pigeonpea as compared to the flat landform treatment (73) The BBF landform on the medium deep soil recorded the highest amount of N-fixed (99) by pigeonpea whereas the flat landform on the shallow soil showed the lowest amount of N-fixed (66)

4.3.17 Quantification of nitrogen fixation in chickpea by ^{15}N isotope dilution method: 1997.

Nitrogen fixed (kg ha^{-1}): Chickpea (Table 26, Fig. 11)

Estimates of N-fixed by chickpea with ^{15}N isotope dilution method using non-nodulating chickpea as non-fixing plant, was not influenced significantly by landform, soil depth and their interaction

4.3.18 Quantification of nitrogen fixation by ^{15}N isotope dilution method: 1998.

Nitrogen fixed (kg ha^{-1}): Chickpea (Table 26, Fig. 11)

The variation in amount of N fixed by chickpea as estimated with ^{15}N isotope dilution method using non-nodulating chickpea as non-fixing plant, due to landform, soil depth treatments and their interaction were not significant

4.4. Nutrient uptake of crops

4.4.1 Rainy season (Soybean)

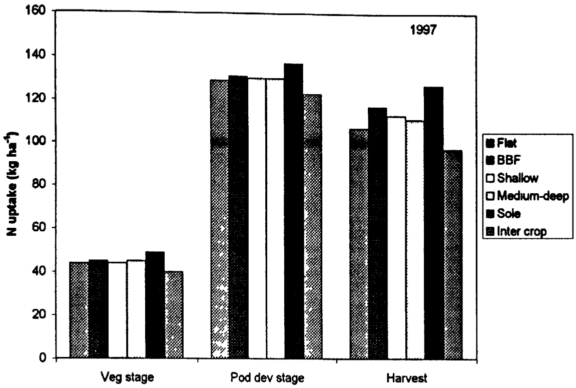
4.4.1.1 N uptake (kg ha^{-1}) during 1997 (Table 27, Fig. 12)

The uptake of N by soybean showed a linear increase from vegetative to pod development stages (45 to 130) and then decrease at harvest (112) At the vegetative stage uptake of N was influenced significantly by the cropping systems treatments and its interactions of landform x soil depth, landform x cropping system, soil depth x cropping system, and landform x soil depth x cropping system Landform and soil depth treatments did not significantly affect the uptake of N by soybean A significantly higher N uptake (49) was observed in sole soybean compared to intercropped soybean (40) The

Table.27: Nitrogen uptake (Kg ha ^{1}) by sole and intercropped soybean grown on flat and BBF landforms and shallow and medium-deep Vertic Inceptisols during rainy season 1997 and 1998

Landform	Soil depth						
	Shallow			Medium - deep			
	Sole	Intercrop	Mean	Sole	Intercrop	Mean	Total mean
1. 1997							
	1) Vegetative stage (34-42 DAS)						
Flat	50	44	47	45	37	41	44
BBF	45	36	41	53	42	48	45
Mean	48	40	44	49	40	45	45
	L	**S**	**C**	**LS**	**LC**	**SC**	**LSC**
S Ed ±	1 9	1 9	1 9	2 8	2 7	2 7	3 7
CD(0 05)	NS	NS	4 1	6 1	5 9	5 9	8 1
	2) Pod development stage (69-77 DAS)						
Flat	131	119	125	135	129	132	129
BBF	146	124	135	135	119	127	131
Mean	139	122	130	135	124	130	130
S Ed ±	4 7	4 6	4 8	6 8	6 7	6 7	9 3
CD(0 05)	NS	NS	10 5	NS	14 7	14 7	20 4
	3) At Harvest (91-112 DAS)						
Flat	121	86	104	122	96	109	107
BBF	135	109	122	129	95	112	117
Mean	128	98	113	126	96	111	112
S Ed ±	2 6	2 5	2 6	3 8	3 7	3 7	5 2
CD(0 05)	5 7	NS	5 7	8 3	8 1	8 1	11 4
2. 1998							
	1) Vegetative stage (34-42 DAS)						
Flat	20	21	21	14	19	17	19
BBF	14	16	15	15	19	17	16
Mean	17	19	18	15	19	17	18
S Ed ±	1 2	1 2	1 2	1 8	1 7	1 7	2 5
CD(0 05)	2 6	NS	2 6	3 9	3 7	3 7	5 5
	2) Pod development stage (69-77 DAS)						
Flat	180	163	172	151	154	153	163
BBF	153	151	152	149	129	139	146
Mean	167	157	162	150	142	146	154
S Ed ±	6 0	6 0	5 9	8 8	8 4	8 4	12 1
CD(0 05)	13 2	13 2	NS	19 3	18 4	18 4	26 6
	3) At harvest (91-112 DAS)						
Flat	141	93	117	138	102	120	119
BBF	130	93	112	138	97	118	115
Mean	136	93	115	138	100	119	117
S Ed ±	4 6	4 6	5 1	6 8	6 9	6 9	9 4
CD(0 05)	NS	NS	11 2	NS	15 1	15 1	20 6

1, Refer Table 1



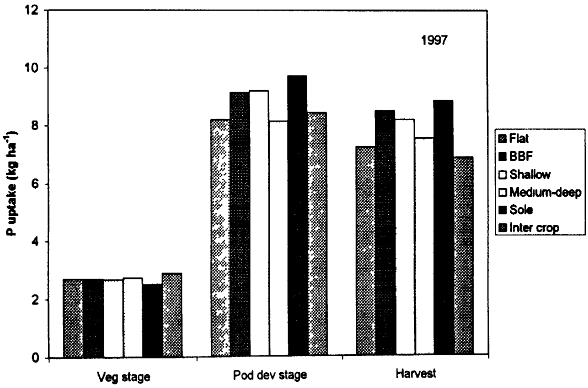


Fig.12: N and P uptake by sole and intercropped soybean as influenced by landform and soil depth treatments during rainy season 1997

BBF landform on the medium-deep soil recorded the maximum N uptake by soybean (48), compared to the other combinations during 1997 Sole soybean grown on BBF landform recorded the highest N uptake (49) while the intercropped soybean grown on BBF showed the lowest N uptake (39) Higher N uptake (49) was observed in sole soybean grown on the medium-deep soil compared to the other combinations Highest N uptake was recorded in sole soybean (50) grown on flat landform on the shallow soil and the lowest N uptake was observed in the intercropped soybean grown on BBF landform on shallow soil during 1997

During the pod development stage in soybean, its N uptake varied significantly in the cropping system treatments and interactions of landform x cropping system, soil depth x cropping system and landform x soil depth x cropping system Landform, soil depth treatments and their interaction did not significantly influence the N uptake by soybean More N uptake (137) was recorded in sole soybean crop than the intercropped soybean (123) Highest uptake of N (141) was observed in sole soybean, grown on BBF landform and the lowest uptake of N (122) was recorded in intercropped soybean grown on the BBF landform Sole soybean on the shallow soil resulted in the maximum N uptake (139) and the intercropped soybean on the shallow soil showed the minimum N uptake (122) compared to the other combinations Sole soybean grown on BBF landform on shallow soil recorded the higher uptake of N (146) compared with the other combinations at the pod development stage in the experiments conducted during 1997

At harvest, the uptake of N by soybean was influenced significantly by all the treatments and their interactions except the soil depth treatment The BBF landform resulted in a higher N uptake (117) by soybean compared to the flat landform treatment

(107) More N uptake (127) was recorded in sole soybean than the intercropped soybean (97) Sole soybean grown on BBF landform showed highest N uptake (133) whereas the intercropped soybean grown on flat landform recorded the lowest N uptake (91) Sole soybean grown on shallow soil was found to have taken up more N (128) while it was lesser (96) in intercropped soybean grown on the medium-deep soil compared to other combinations during 1997

4.4.1.2 N uptake (kg ha^{-1}) during 1998 (Table 27)

Mean N uptake by soybean was increased from vegetative to pod development stage and then decreased at harvest At the vegetative stage the differences in uptake of N by soybean due to landform, cropping system and interactions Viz, landform x soil depth, landform x cropping system, soil depth x cropping system and landform x soil depth x cropping system were significant

Soil depth treatments had no significant effect on uptake of N by soybean Soybean grown on flat landform had more N uptake (19) than that of soybean grown on BBF landform treatment (16) Higher N uptake (19) was recorded in intercropped soybean than compared to the sole soybean (16) Intercropped soybean grown on flat landform recorded the highest uptake of N (21) and it was lowest (15) in case of sole soybean grown on BBF landform treatment Sole soybean grown on medium-deep soil had lower nitrogen uptake (15) compared to the other combinations Intercropped soybean grown on flat landform on shallow soil showed a higher N uptake (21) compared with the other combinations during vegetative stage in the experiments conducted during 1998

During pod development stage, uptake of N by soybean was influenced significantly by all the treatments and their interactions except the cropping system treatments The flat landform treatment resulted in a higher N uptake (163) of soybean than that of BBF landform treatment (146) Shallow soil resulted in more N uptake (162) than compared to the soybean grown on medium-deep depth soil (146) Soybean on flat landform on shallow soil recorded the highest N uptake (172) and soybean grown on BBF landform on medium-deep soil showed lowest N uptake (139) during pod development stage

Sole soybean grown on flat landform had maximum N uptake (166) while the intercropped soybean grown on BBF landform had minimum uptake of N (140) compared to the other combinations Sole soybean grown on shallow depth soil recorded the highest N uptake (167) and it was lowest (142) in case of intercropped soybean grown on medium-deep depth soil Sole soybean grown on flat landform on shallow depth soil was observed the highest N uptake (180) and the intercropped soybean grown on BBF landform on medium-deep soil was recorded the lowest N uptake (129) at the pod development stage in the experiments conducted during 1998

At harvest stage in soybean during 1998 N uptake varied significantly due to cropping systems and interactions Viz, landform x cropping system, soil depth x cropping system and landform x soil depth x cropping system Landform, soil depth treatments and their interaction had no significant effect on N uptake of soybean Higher N uptake (137) was observed in sole soybean than the intercropped soybean (97) Sole soybean grown on flat landform treatment showed the highest N uptake (140) and the intercropped soybean grown on BBF landform treatment recorded the lowest N uptake

(95) Sole soybean grown on medium-deep soil observed the highest N uptake (138) and the intercropped soybean grown on shallow soil showed the lowest N uptake (93) Sole soybean grown on flat landform on shallow Vertic Inceptisol was observed the maximum N uptake (141) compared to the other combinations during harvest stage 1998

4.4.1.3. P uptake (kg ha^{-1}) during 1997 (Table 28, Fig. 12)

In soybean, mean uptake of P was increased from vegetative to pod development stage (2 7 vs 8 7) and then decreased at harvest (7 9) At vegetative stage the variation in uptake of P by soybean due to cropping system and interactions viz, landform x cropping system, soil depth x cropping system, landform x soil depth x cropping system were significant Landform, soil depth treatments and their interaction had no significant effect on P uptake of soybean Higher P uptake 2 9 was observed in intercropped soybean than that of sole soybean (2 5) Sole soybean grown on BBF landform showed the highest P uptake (2 9) while the intercropped soybean grown on BBF recorded the lowest P uptake (2 5) Sole soybean grown on medium-deep soil showed the maximum P uptake (3 0) compared to the other combinations Sole soybean grown on flat landform on medium-deep soil found the highest P uptake (3 1) and it was lowest (2 4) in intercropped soybean grown on BBF landform on shallow soil

During pod development stage P uptake by soybean was influenced significantly by treatment interactions viz, landform x soil depth, landform x cropping system, soil depth x cropping system and landform x soil depth x cropping system Landform, soil depth and cropping system treatments did not influence the P uptake The BBF on shallow depth soil resulted in a more P uptake (10 5) whereas the BBF landform on

Table.28: Phosphorus uptake (kg ha^{1}) by sole and intercropped soybean grown on flat and BBF landforms and shallow and medium-deep Vertic Inceptisols during rainy season 1997 and 1998

Landform	**Soil depth**						
	Shallow			Medium - deep			Total mean
	Sole	Intercrop	Mean	Sole	Intercrop	Mean	
1. 1997							
	1) Vegetative stage (34-42 DAS)						
Flat	2 9	2 6	2 7	2 8	2 5	2 7	2 7
BBF	2 8	2 4	2 6	3 1	2 5	2 8	2 7
Mean	2 8	2 5	2 7	3 0	2 5	2 7	2 7
	L	**S**	**C**	**LS**	**LC**	**SC**	**LSC**
S Ed ±	0 13	0 13	0 14	0 19	0 19	0 19	0 26
CD(0 05)	NS	NS	0 31	NS	0 42	0 42	0 56
	2) Pod development stage (69-77 DAS)						
Flat	7 8	7 9	7 9	8 4	8 7	8 5	8 2
BBF	11 1	10 0	10 5	8 2	7 3	7 8	9 1
Mean	9 5	8 9	9 2	8 3	8 0	8 1	8 7
S Ed ±	0 49	0 49	0 44	0 72	0 66	0 66	0 95
CD(0 05)	NS	NS	NS	1 58	1 45	1 44	2 09
	3) At harvest (91-112 DAS)						
Flat	8 0	5 9	6 9	8 5	6 7	7 6	7 2
BBF	10 3	8 6	9 5	8 7	6 4	7 6	8 5
Mean	9 2	7 2	8 2	8 6	6 5	7 6	7 9
S Ed ±	0 33	0 33	0 33	0 48	0 47	0 47	0 63
CD(0 05)	0 73	0 72	0 74	1 06	1 03	1 03	1 40
2. 1998							
	1) Vegetative stage (34-42 DAS)						
Flat	1 1	1 3	1 2	0 8	1 1	1 0	1 1
BBF	0 8	1 0	0 9	0 9	1 2	1 0	1 0
Mean	1 0	1 1	1 1	0 9	1 1	1 0	1 0
S Ed ±	0 08	0 08	0 08	0 11	0 11	0 11	0 15
CD(0 05)	NS	NS	0 17	0 25	0 24	0 24	0 33
	2) Pod development stage (69-77 DAS)						
Flat	13 6	12 9	13 2	10 7	10 5	10 6	11 9
BBF	13 3	11 6	12 5	10 4	9 3	9 8	11 1
Mean	13 4	12 2	12 8	10 6	9 9	10 2	11 5
S Ed ±	0 63	0 74	0 65	1 00	0 91	0 99	1 24
CD(0 05)	NS	1 63	NS	2 19	NS	2 17	2 73
	3) At harvest (91-112 DAS)						
Flat	10 7	6 9	8 8	10 1	7 2	8 6	8 7
BBF	10 9	7 2	9 1	9 6	6 7	8 2	8 6
Mean	10 8	7 1	8 9	9 9	6 9	8 4	8 7
S Ed ±	0 36	0 40	0 45	0 55	0 58	0 60	0 79
CD(0 05)	NS	NS	0 99	NS	1 27	1 33	1 74

1. Refer Table 1

medium-deep soil recorded the less P uptake (7 7) by soybean compared to the other combinations Sole soybean grown on BBF was observed the highest uptake of P (9 7) and it was lowest (8 1) in sole soybean grown on flat landform treatment Sole soybean grown on shallow Vertic Inceptisol showed a maximum P uptake (9 5) and the intercropped soybean grown on medium-deep Vertic Inceptisol recorded the minimum P uptake (8 0) compared with the other combinations Sole soybean grown on BBF on shallow soil was observed the highest P uptake (11 1) while the intercropped soybean grown on BBF on medium-deep soil showed the lowest P uptake (7 3) during 1997

At harvest stage in soybean, the differences in the uptake of P due to all treatments and their interactions were significant In soybean, a significantly more P uptake (8 5) was recorded on the BBF landform as compared to the flat landform treatment (7 2) In case of soil depth, shallow depth soil resulted in a significantly higher uptake of P (8 2) than the medium-deep soil (7 5) P uptake was more (8 9) in case of sole soybean than the intercropped soybean (6 9) The BBF landform on the shallow soil showed the highest uptake of P (9 5) and the flat landform on the shallow soil recorded the lowest uptake of P (6 9) Sole soybean grown on BBF resulted in the maximum P uptake (9 5) and it was minimum (6 3) in case of intercropped soybean grown on flat landform compared with the other cropping systems and landform combinations Sole soybean grown on shallow depth soil was found the highest P uptake (9 2) while the intercropped soybean grown on medium-deep soil was observed the lowest P uptake (6 5) Sole soybean grown on BBF on shallow depth soil resulted in the highest P uptake (10 3) and the intercropped soybean grown on flat landform on shallow soil showed the lowest P uptake (5 9)

4.4.1.4. P uptake (kg ha^{-1}) during 1998 (Table 28)

The uptake of P by soybean was increased from vegetative to pod development stage and then decreased at the harvest stage At the vegetative stage P uptake by soybean was influenced significantly by cropping system treatment interactions and interactions viz, landform x soil depth, landform x cropping system, soil depth x cropping system and landform x soil depth x cropping system Landform and soil depth treatments effect on P uptake was not significant P uptake was more (1 1) in intercropped soybean than the sole soybean (0 9) Shallow soil under flat landform showed the highest P uptake (1 2) whereas the shallow soil under BBF landform resulted in the lowest P uptake (0 9) Intercropped soybean grown on flat landform had maximum P uptake (1 2) and the sole soybean grown on BBF landform had minimum P uptake (0 9) compared to the other cropping systems and landform combinations Maximum P uptake (1 1) was observed in intercropped soybean grown on shallow soil (1 3) while the sole soybean grown on medium-deep soil showed the lowest (0 9) P uptake Highest uptake of P was observed in intercropped soybean grown on flat on shallow depth soil and it was lowest (0 8) in sole soybean grown on flat on medium-deep soil during 1998

During pod development stage in soybean, soil depth treatments and interactions Viz, landform x soil depth, soil depth x cropping system and landform x soil depth x cropping system significantly influenced the uptake of P Landform and soil depth treatments effect on P uptake was not significant The uptake of P was more (12 8) in case of shallow depth soil than compared to the medium-deep soil (10 2) The flat landform on shallow soil recorded the highest P uptake (13 2) and the BBF landform on medium-deep soil showed the lowest uptake of P (9 8) Sole soybean grown on shallow soil had more P uptake (13.4) while intercropped soybean grown on medium-deep soil had lesser P uptake (9.9) compared to the other cropping system and soil depth combinations in the experiments conducted during 1998. The uptake of P was highest (13.6) incase of sole soybean grown on flat landform treatment on shallow Vertic Inceptisol and it was lowest (9.3) in case of intercropped soybean grown on BBF landform treatment on medium-deep soil during 1998.

At the harvest stage in the experiments conducted during 1998, the uptake of P by soybean was influenced significantly by cropping system treatments and treatment interactions viz, landform x cropping system, soil depth x cropping system and landform x soil depth x cropping system. Landform and soil depth effect on P uptake was not significant. Sole soybean had a higher uptake of P (10.3) than compared to the intercropped and soybean (7.0). Sole soybean grown on flat landform treatment recorded the highest uptake of P (10.4) and the intercropped soybean grown on BBF landform treatment showed the lowest uptake of P (6.9). Sole soybean grown on the shallow depth soil had a maximum uptake of P (10.8) and the intercropped soybean grown on the medium-deep depth soil showed a minimum uptake of P (6.9) compared to the other combinations. The uptake of P was highest (10.9) in case of sole soybean grown on shallow soil on BBF landform treatment and it was lowest (7.0) in case of intercropped soybean grown on medium-deep soil on BBF landform treatment during 1998.

4.4.1.4. K uptake (kg ha^{-1}) during 1997 (Table 29)

At the harvest stage, the uptake of K by soybean was influenced significantly by landform, cropping system treatments and interactions viz, landform x soil depth, landform

Table.29: Potassium uptake (Kg ha^{-1}) by sole and intercropped soybean grown on flat and BBF landforms and shallow and medium-deep Vertic Inceptisols at harvest stage during rainy season 1997 and 1998

Landform	**Soil depth**						
	Shallow			Medium - deep			
	Sole	Intercrop	Mean	Sole	Intercrop	Mean	Total mean
1997							
Flat	33.7	24.6	29.2	34.3	27.5	30.9	30.1
BBF	36.3	29.8	33.1	38.3	29.3	33.8	33.5
Mean	35.0	27.2	31.1	36.3	28.4	32.4	31.8
	L	**S**	**C**	**LS**	**LC**	**SC**	**LSC**
S.Ed.±	1.19	1.13	1.22	1.7	1.71	1.67	2.33
CD(0.05)	2.61	NS	2.68	3.74	3.76	3.67	5.12
1998							
Flat	59.1	42.5	50.8	58.6	42.8	50.7	50.7
BBF	59.2	40.2	49.7	58.7	40.6	49.6	49.7
Mean	59.2	41.3	50.2	58.7	41.7	50.2	50.2
S.Ed.±	2.03	1.53	3.00	2.57	3.68	3.38	4.02
CD(0.05)	NS	NS	6.60	NS	8.09	7.43	8.84

1, Refer Table 1

x cropping system, soil depth x cropping system and landform x soil depth x cropping system Soil depth treatment effect on K uptake was not significant Higher uptake of K (33 5) was observed in case of BBF landform treatment than compared to the flat landform treatment Sole soybean had a higher uptake of K (36) than the intercropped soybean (28) The BBF landform on the medium-deep soil showed the highest uptake of K (33 8) whereas the flat landform on the shallow soil resulted in the lowest uptake of K (29 2) A significantly maximum uptake of K (37 3) was found in case of sole soybean grown on BBF and minimum uptake of K (26 1) was observed incase of intercropped soybean grown on flat compared to the other combinations Sole soybean grown on the medium-deep soil had a more uptake of K (36 3) while the intercropped soybean grown on shallow soil had a lower uptake of K (27 2) compared to the other cropping system and soil depth combinations

The uptake of K was highest (38 3) in case of sole soybean grown on BBF landform treatment on medium-deep soil and it was lowest (24 6) in case of intercropped soybean grown on flat landform treatment on shallow soil at the harvest stage in the experiments conducted during 1997

4.4.1.6. K uptake (kg ha^{-1}) during 1998 (Table 29)

At the harvest stage in soybean cropping system treatments, landform x cropping system, soil depth x cropping system, landform x soil depth x cropping system interactions influenced the uptake of K significantly Landform, soil depth treatments and their interactions effect on K uptake was not significant Sole soybean had a higher uptake of K (50 9) than the intercropped soybean (41 5) Highest uptake of K (58 9) was found incase of sole soybean grown on BBF land form and lowest uptake of K (40 4) was observed in case of intercropped soybean grown on BBF landform treatment The shallow depth Vertic Inceptisol under sole soybean influenced highest uptake of K (59 2) while the shallow soil under intercropped soybean influenced the lowest uptake of K (41 3) The uptake of K was more (59 2) in case of sole soybean grown on BBF landform treatment on shallow depth soil and it was lower (40 2) in case of intercropped soybean grown on BBF landform on shallow soil than compared to the other cropping system and landform configuration combinations at the harvest stage in the experiments conducted during 1998

4.4.2 Rainy and post-rainy season (Pigeonpea)

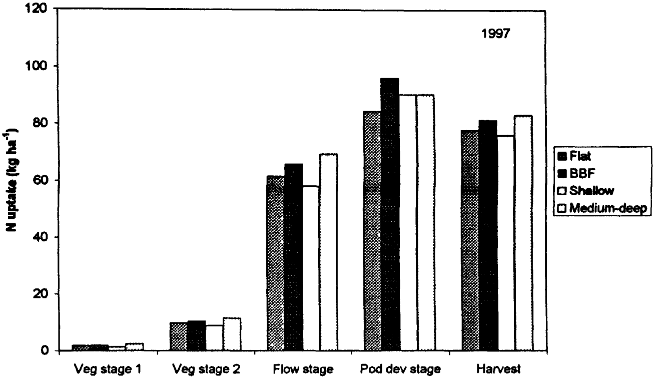
4.4.2.1 N uptake (kg ha ^{1}) during 1997 (Table 30, Fig. 13)

In pigeonpea, mean N uptake was increased from vegetative stage to pod development stage and then decreased at the harvest stage At the vegetative stage (36-42 DAS) N uptake was influenced significantly by the soil depth treatment and the interaction of landform x soil depth Landform had no significant effect on N uptake A significantly more uptake of N (2 4) was observed in case of medium-deep soil than compared to the shallow depth soil (1 3) The BBF landform on the medium-deep soil showed the highest uptake of N (2 6) and the BBF landform on the shallow soil recorded the lowest uptake of N (1 2) During vegetative stage (70-77 DAS) and flowering stages of pigeonpea the uptake of N was influenced significantly by soil depth and landform x soil depth interaction Landform treatments did not vary significantly the N uptake In case of soil depth, medium-deep soil influenced the higher uptake of K than the shallow

Table.30: N,P and K uptake (kg ha ^{1}) by pigeonpea grown on flat and BBF landforms and shallow and medium-deep Vertic Inceptisols during rainy and post-rainy seasons 1997

Landform	Soil depth														
	Vegetative stage			Vegetative stage			Flowering stage			Pod development stage			At harvest		
	(36-42 DAS)			(70-77 DAS)			(111-127 DAS)			(164-168 DAS)			(205-217 DAS)		
	Shallo	edium deep	Mean	Shallo	edium deep	Mean	Shallo	edium deep	Mean	Shallo	edium deep	Mean	Shallo	edium deep	Mean
1) N uptake															
Flat	1 4	2 1	1 8	8 0	11 9	9 9	53 9	69 5	61 7	84 6	84 6	84 6	67 4	88 3	77 9
BBF	1 2	2 6	1 9	9 7	11 1	10 4	62 3	69 4	65 9	96 2	96 2	96 2	84 8	77 9	81 4
Mean	1 3	2 4	1 9	8 9	11 5	10 2	58 1	69 5	63 8	90 4	90 4	90 4	76 1	83 1	79 6
	L	S	LS	L	S	LS	L	S	LS	L	S	LS	L	S	LS
S Ed ±	0 25	0 32	0 42	0 91	1 05	1 43	3 94	4 91	6 45	7 05	0 26	7 05	5 31	5 31	7 75
CD(0 05)	NS	0 70	0 92	NS	2 31	3 14	NS	10 8	14 49	NS	NS	NS	NS	NS	17 05
2) P uptake															
Flat	0 1	0 1	0 1	48 0	0 7	0 6	3 3	4 2	3 7	4 9	5 3	5 1	4 9	6 4	5 6
BBF	0 1	0 2	0 1	0 7	0 7	0 7	4 6	4 1	4 3	6 6	5 9	6 2	6 5	5 1	5 8
Mean	0 1	0 1	0 1	0 6	0 7	0 7	3 9	4 1	4 0	5 8	5 6	5 7	5 7	5 8	5 7
S Ed ±	0 02	0 02	0 03	0 07	0 07	0 11	0 35	0 35	0 51	0 38	0 34	0 53	0 51	0 51	0 75
CD(0 05)	NS	NS	0 06	NS	NS	0 23	NS	NS	1 11	0 84	NS	1 16	NS	NS	1 65
3) K uptake															
		-	-	-	-	-	-	-	-	-	-	-			
Flat	-	-	-	-	-	-	-	-	-	-	-	-	27 2	34 3	30 8
BBF	-												29 3	32 2	30 8
Mean	-	-	-	-	-	-	-	-	-	-	-	-	28 3	33 3	30 8
													1 59	1 87	2 52
S Ed ±	-	-	-	-	-	-	-	-	-	-	-	-	NS	4 11	5 54
CD(0 05)	-	-	-	-	-	-	-	-	-	-	-	-			

1, Refer Table 1



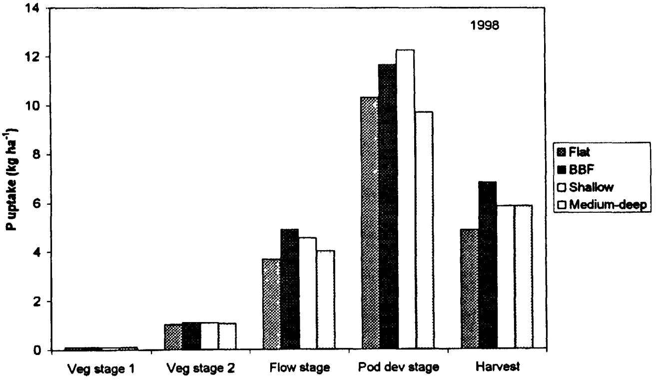


Fig.13: N and P uptake by pigeonpea
as infuenced by landform and soildepth treatmens during 1997 and 1998

depth soil during both the growth stages of pigeonpea 1997 The flat landform on the medium-deep soil showed a significantly maximum uptake of N and the flat landform on the shallow soil was observed the minimum uptake of N than compared with the other combinations during both the vegetative and flowering stages of pigeonpea

At the pod development stage in pigeonpea in the experiments conducted during 1997, the uptake of N was not influenced significantly by landform, soil depth and their interaction

During harvest stage in pigeonpea, landform x soil depth interaction effect on N uptake was significant Landform and soil depth treatments had no significant effect on N uptake The flat on medium-deep soil resulted in a higher uptake of N (88 3) and the flat on shallow soil recorded the lower uptake of N (67 4) than compared to the other landform and soil depth combinations during 1998

4.4.2.2 N uptake (kg ha ^{1}) during 1998 (Table 31)

In pigeonpea, mean N uptake was increased from vegetative to pod development stage and then decreased at the harvest stage At the vegetative stages [(36-42 DAS) and (70-77 DAS)], the uptake of N by pigeonpea was not changed significantly by landform, soil depth and their interaction

At the flowering stage, the differences in N uptake due to landform and landform x soil depth interaction were significant Soil depth effect on N uptake was not significant In comparison of landforms, a significantly higher N uptake was observed in BBF landform (65 0) compared to the flat landform treatment (45 8) Highest uptake of N (69 1) was noticed in pigeonpea grown on BBF on the shallow depth soil and the lowest uptake of N

Table.31: N, P and K uptake (kg ha^{-1}) by pigeonpea grown on flat and BBF landfoms and shallow and medium-deep Vertic Inceptisols during rainy and post-rainy seasons 1998

Landform	Soil depth														
	Vegetative stage			Vegetative stage			Flowering stage			Pod development stage			At harvest		
	(36-42 DAS)			(70-77 DAS)			(111-127 DAS)			(164-168 DAS)			(205-217 DAS)		
	Shallow	Medium-deep	Mean	Shallow	Medium-deep	Mean	Shallow	Medium-deep	Mean	Shallow	Medium-deep	Mean	Shallow	Medium-deep	Mean
1) N uptake															
Flat	1.4	1.4	1.4	14.3	14.3	14.3	49.9	41.7	45.8	154.4	133.4	143.9	71.1	79.8	75.5
BBF	1.6	1.6	1.6	16.5	16.5	16.5	69.1	60.9	65.0	163.8	142.7	153.3	101.8	110.5	106.2
Mean	1.5	1.5	1.5	15.4	15.4	15.4	59.5	51.3	55.4	159.1	138.0	148.6	86.5	95.2	90.9
	L	**S**	**LS**	**L**	**S**	**LS**	**L**	**S**	**LS**	**L**	**S**	**LS**	**L**	**S**	**LS**
S.Ed.±	0.25	0.12	0.28	1.64	0.06	1.64	6.05	5.41	8.35	6.73	7.73	10.53	5.05	4.62	7.06
CD(0.05)	NS	NS	NS	NS	NS	NS	13.31	NS	18.37	NS	17.01	23.17	11.11	NS	15.53
2) P uptake															
Flat	0.1	0.1	0.1	1.1	1.0	1.0	4.0	3.4	3.7	11.6	9.1	10.3	4.9	4.9	4.9
BBF	0.1	0.1	0.1	1.1	1.1	1.1	5.2	4.6	4.9	12.9	10.4	11.7	6.8	6.8	6.8
Mean	0.1	0.1	0.1	1.1	1.1	1.1	4.6	4.0	4.3	12.3	9.7	11.0	5.9	5.9	5.9
S.Ed.±	0.02	0.01	0.02	0.10	0.08	0.13	0.44	0.39	0.60	0.52	0.55	0.78	0.40	0.01	0.40
CD(0.05)	NS	NS	NS	NS	NS	NS	0.96	NS	1.32	1.15	1.20	1.71	0.88	NS	0.89
3) K uptake															
Flat	-	-	-	-	-	-	-	-	-	-	-	-	33.2	40.6	36.9
BBF	-	-	-	-	-	-	-	-	-	-	-	-	47.2	42.3	44.7
Mean	-	-	-	-	-	-	-	-	-	-	-	-	40.2	41.5	40.8
													3.31	3.19	4.74
S.Ed.±	-	-	-	-	-	-	-	-	-	-	-	-	7.28	NS	10.43
CD(0.05)	-	-	-	-	-	-	-	-	-	-	-	-			

 # 1, Refer Table 1

(41 7) was observed in pigeonpea grown on flat landform treatment on the medium-deep soil

At the pod development stage in pigeonpea during 1998, soil depth and landform x soil depth interaction had significant effect on N uptake Landform did not vary the N uptake significantly In case of soil depth, a significantly more N uptake (159 1) was found in pigeonpea grown on shallow depth soil than compared to the medium-deep soil (138 0) Pigeonpea grown on the BBF landform on the shallow soil had a significantly more uptake of N (163 8) whereas the pigeonpea grown on the flat landform on medium-deep soil had a lower uptake of N (133 4) than compared to the other landform and soil depth combinations

At the harvest stage in pigeonpea during 1998, the uptake of N was influenced significantly by landform and landform x soil depth interaction Soil depth effect on N uptake was not significant Pigeonpea grown on BBF showed a higher uptake of N (106 2) than the flat landform treatment (75 5) The uptake of N was highest (110 5) in case of pigeonpea grown on BBF landform on medium-deep soil and it was lowest (71 1) in case of pigeonpea grown on flat landform on shallow depth soil

4.4.2.3. P uptake (kg ha ^{1}) during 1997 (Table 30)

In pigeonpea, mean uptake of P was increased from vegetative stage to up to harvest stage During vegetative stage (36-42 DAS) the uptake of P was changed significantly by the interaction of landform x soil depth Landform had no significant effect on P uptake The BBF landform on the medium-deep soil showed the highest uptake of P (0 2) while the BBF landform on the shallow Vertic Inceptisol recorded the lowest uptake of P (0 1) by pigeonpea

At the vegetative stage (70-77 DAS) in pigeonpea during 1997, landform x soil depth interaction effect on P uptake was significant. Landform and soil depth treatments had no significant effect on P uptake. The highest uptake of P (0.73) was noticed in pigeonpea grown on flat on medium-deep soil and the lowest (0.48) P uptake was observed in pigeonpea grown on flat on shallow soil.

During flowering stage in pigeonpea, the uptake of P was influenced significantly by the interaction of landform x soil depth. Landform and soil depth treatments effect on P uptake was not significant. The BBF landform on the shallow soil showed the highest uptake of P (4.6) and the flat landform on the shallow soil showed the lowest uptake of P (3.3) by pigeonpea.

At the pod development stage in pigeonpea, the variations in P uptake due to landform and landform x soil depth were significant. Soil depth did not vary significantly the P uptake. The BBF landform influenced the higher uptake of P (6.2) than that of flat landform treatment (5.1). The uptake of P was maximum (6.6)incase of shallow depth soil under BBF and it was minimum (4.9) in case of shallow depth soil under flat landform than compared to the other combinations during 1997.

At harvest stage in pigeonpea, landform x soil depth interaction effect on P uptake was significant. Landform and soil depth treatments did not significantly vary the uptake of P. The BBF on shallow soil recorded the highest uptake of P (6.5) while the flat on shallow soil showed the lowest uptake of P (4.9) by pigeonpea.

4.4.2.4 P uptake (kg ha^{-1}) during 1998 (Table 31, Fig. 13)

In pigeonpea, the uptake of P was increased from vegetative stage to pod development stage and then decreased at the harvest stage. During vegetative stages (36-42

DAS and 70-77 DAS) the differences in P uptake under the various landform, soil depth treatments and their interaction were not significant

At the flowering stage in pigeonpea, the uptake of P was changed significantly by the landform treatment and the interaction of landform x soil depth Soil depth had no significant effect on P uptake Pigeonpea grown on BBF had a significantly more uptake of P (4 9) than compared to the flat landform treatment (3 7) Highest uptake of P (5 2) was observed in case of pigeonpea grown on BBF on shallow soil while the lowest uptake of P (3 4) was recorded in case of pigeonpea grown on flat on medium-deep soil

During pod development stage in pigeonpea, landform, soil depth and their interaction significantly influenced the uptake of P In comparison of landforms the BBF showed a higher uptake of P (11 7) than the flat (10 3) landform treatment In case of soils depth, a significantly, more uptake of P (12 3) was observed in the shallow depth soil than compared to the medium-deep soil (9 7) The BBF on shallow soil recorded the maximum uptake of P (12 9) and the flat on medium-deep soil showed the minimum P uptake (9 1) than compared to the other combinations

During harvest stage in pigeonpea the uptake of P was changed significantly by landform and landform x soil depth Soil depth treatment effect on P uptake was not significant In comparison of land configuration, pigeonpea grown on the BBF landform had a higher uptake of P (6 8) than compared to the flat landform treatment (4 9) The uptake of P was highest (6 8) in case of pigeonpea grown on BBF landform on both the soil depths and it was lowest (4 9) in case of pigeonpea grown on flat landform on both the soil depths

4.4.2.5 K uptake (kg ha^{-1}) during 1997 (Table 30)

At harvest stage in pigeonpea, the uptake of K was influenced significantly by soil depth treatment and landform x soil depth interaction Landform had no significant effect on K uptake Pigeonpea grown on medium-deep soil showed a higher uptake of K (33 3) than the shallow depth soil (28 3) The flat on medium-deep soil recorded the highest uptake of K (34 3) and the flat on shallow Vertic Inceptisol influenced the lowest uptake of K (27 2) by pigeonpea

4.4.2.6 K uptake (kg ha^{-1}) during 1998 (Table 31)

In pigeonpea during harvest stage, landform and landform x soil depth had a significant effect on K uptake There was no marked difference in K uptake due to soil depth Higher uptake of K (44 7) was observed in case of BBF than compared to the flat landform treatment (36 9) Pigeonpea grown on BBF on shallow Vertic Inceptisol recorded the maximum uptake of K (47 2) and pigeonpea grown on flat landform on shallow depth soil showed the minimum uptake of K (33 2) than compared to the other combinations during 1998

4.4.3 Post-rainy season (chickpea)

4.4.3.1 N uptake (kg ha^{-1}) during 1997 (Table 32, Fig. 14)

In chickpea, mean uptake of N was increased from vegetative to pod development stage and then decreased at the harvest stage At the vegetative stage, N uptake was influenced significantly by landform treatment and the interaction of landform x soil depth Soil depth treatment did not vary significantly The chickpea grown on flat resulted in a

Table.32: N, P and K uptake (kg ha ^{1}) by chickpea grown on flat and BBF landforms and shallo and medium-deep Vertic Inceptisols during post-rainy season 1997

Landform	**Soil depth**								
	Vegetative stage			Pod devlopment stage			At harvest		
	(40 -41 DAS)			(81 -84DAS)			(105-111 DAS)		
	Shallow	**Medium-deep**	**Mean**	**Shallow**	**Medium-deep**	**Mean**	**Shallow**	**Medium-deep**	**Mean**
1) N uptake									
Flat	12 8	13 4	13 1	45 4	56 4	50 9	39 1	46 7	42 9
BBF	7 3	7 8	7 6	41 0	52 0	46 5	39 9	56 6	48 2
Mean	10 1	10 6	10 4	43 2	54 2	48 7	39 5	51 6	45 6
	L	**S**	**LS**	**L**	**S**	**LS**	**L**	**S**	**LS**
S Ed ±	2 15	1 09	2 44	2 12	2 27	3 20	3 47	3 94	5 41
CD(0 05)	4 73	NS	5 37	NS	4 99	7 04	NS	8 67	11 9
2) P uptake									
Flat	1 1	1 1	1 1	3 9	4 6	4 2	2 9	3 6	3 3
BBF	0 6	0 6	0 6	3 1	3 9	3 5	2 9	4 2	3 5
Mean	0 8	0 9	0 9	3 5	4 2	3 9	2 9	3 9	3 4
S Ed ±	0 16	0 06	0 17	0 22	0 22	0 33	0 26	0 33	0 43
CD(0 05)	0 35	NS	0 38	0 49	0 49	0 72	NS	0 72	0 95
3) K uptake									
Flat	-	-	-	-	-	-	25 9	38 7	32 3
BBF	-	-	-	-	-	-	25 8	41 5	33 7
Mean	-	-	-	-	-	-	25 9	40 1	33 0
S Ed ±	-	-	-	-	-	-	2 51	4 88	5 56
CD(0 05)	-	-	-	-	-	-	NS	10 74	12 23

\# 1, Refer Table 1

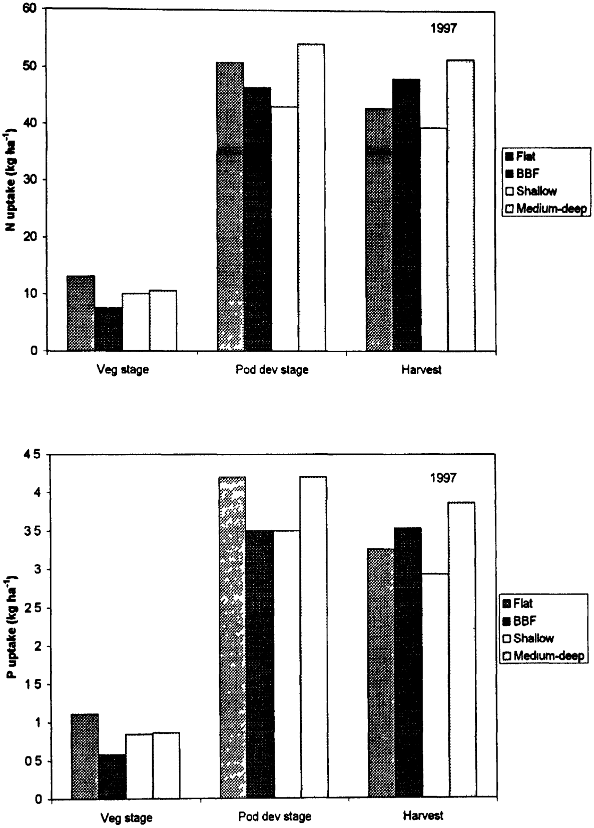


Fig.14: N and P uptake by chickpea as influenced by landform and soil depth treatments during post-rainy season 1997

more uptake of N (13 1) than comapred to the BBF landform treatment (7 6) The flat landform on the medium-deep soil showed the highest uptake of N (13 4) while the BBF landform on the shallow soil recorded the lowest uptake of N (7 3)

At the pod development stage in chickpea, the differences in N uptake due to soil depth and landform x soil depth were significant Landform had no significant effect on N uptake A significantly higher uptake of N (54 2) was observed in case of chickpea grown on medium deep soil than compared to the shallow soil (43 2) The flat landform on the medium-deep soil showed a more uptake of N (56 4) and the BBF landform on the shallow Vertic Inceptisol recorded the lower uptake of N (41 0) than compared to the other landform and soil depth combinations in the experiments conducted during 1997

At the harvest stage, the uptake of N was significantly influenced by soil depth treatment and landform x soil depth interaction Landform had no significant effect on N uptake by chickpea Chickpea grown on medium-deep Vertic Inceptisol had significantly higher uptake of N (51 6) than the shallow depth soil (39 5) Chickpea grown on BBF on medium-deep soil showed the highest uptake of N (56 6) while the lowest N uptake (39 1) was observed in chickpea grown on flat on shallow soil at the harvest stage in the experiments conducted during 1997

4.4.3.2 N uptake (kg ha ^{1}) during 1998 (Table 33)

The uptake of N in chickpea was increased from vegetative to pod development stage and then decreased at the harvest stage At both the vegetative and pod development stages N uptake was not changed significantly by landform, soil depth treatments and their interaction

Table.33: N, P and K uptake (kg ha^{-1}) by chickpea grown on flat and BBF landforms and shallow and medium-deep Vertic Inceptisols during post-rainy season 1998

Landform	**Soil depth**								
	Vegetative stage (40 -41 DAS)			Pod devlopment stage (81 -84DAS)			At harvest (105-111 DAS)		
	Shallow	**Medium-deep**	**Mean**	**Shallow**	**Medium-deep**	**Mean**	**Shallow**	**Medium-deep**	**Mean**
1) N uptake	13 2	15 1	14 2	41 5	46 6	44 0	30 6	37 5	34 1
Flat	13 2	15 1	14 2	41 6	46 6	44 1	31 3	38 3	34 8
BBF	13 2	15 1	14 2	41 6	46 6	44 1	31 0	37 9	34 5
Mean	**L**	**S**	**LS**	**L**	**S**	**LS**	**L**	**S**	**LS**
	0 04	1 16	1 16	0 65	3 35	3 42	1 90	3 12	3 71
S Ed ±	NS	NS	NS	NS	NS	NS	NS	6 89	NS
CD(0 05)									
2) P uptake									
Flat	1 2	1 2	1 2	3 7	3 9	3 8	2 3	3 0	2 7
BBF	1 2	1 2	1 2	3 7	3 9	3 8	2 6	3 4	3 0
Mean	1 2	1 2	1 2	3 7	3 9	3 8	2 4	3 2	2 8
S Ed ±	0 00	0 05	0 05	0 01	0 30	0 30	0 25	0 28	0 39
CD(0 05)	NS	NS	NS	NS	NS	NS	NS	0 62	0 85
3) K uptake									
Flat	-	-	-	-	-	-	18 9	34 1	26 5
BBF	-	-	-	-	-	-	20 7	35 9	28 3
Mean	-	-	-	-	-	-	19 8	35 0	27 4
S Ed ±	-	-	-	-	-	-	2 13	2 82	3 62
CD(0 05)	-	-	-	-	-	-	NS	6 20	7 96

1, Refer Table 1

During harvest stage, soil depth had a significant effect on N uptake by chickpea Chickpea grown on medium-deep soil showed a higher uptake of N (37 9) than compared to the shallow depth soil (31 0) during 1998

4 4 3 3 P uptake (kg ha^{1}) during 1997 (Table 32, Fig 14)

In chickpea, mean P uptake was increased from vegetative to pod development stage and then decreased at the harvest stage During vegetative stage the uptake of P was influenced significantly by landform treatments and landform x soil depth interaction Soil depth treatments did not vary significantly the uptake of P In comparison of landforms, the flat landform influenced the higher P uptake (1 1) than compared to the BBF landform treatment (0 6) The flat landform on the medium-deep soil showed the highest uptake of P (1 1) and the BBF landform on the shallow soil recorded the lowest uptake of P (0 6)

During pod development stage in chickpea, landform, soil depth treatments and their interaction significantly influenced the uptake of P Chickpea grown on the flat landform showed a higher P uptake (4 2) than compared to the BBF landform (3 5) A significantly higher uptake of P (4 2) was noticed in case of medium-deep Vertic Inceptisol than compared to the shallow Vertic Inceptisol (3 5) The chickpea crop grown on flat on medium-deep soil recorded the highest (4 6) P uptake whereas the BBF landform on the shallow soil showed the lowest (3 1) P uptake

At the harvest stage in chickpea during 1997, the uptake of P was significantly changed by soil depth and landform x soil depth The chickpea grown on medium-deep soil showed a higher uptake of P (3 9) than that of shallow soil (2 9) The BBF landform on the medium-deep soil influenced the maximum uptake of P (4 2) and the minimum P uptake

(2 9) was noticed in shallow soil in BBF landform than compared with the other landform and soil depth combinations

4.4.3.4 P uptake (kg ha^{-1}) during 1998 (Table 33)

During both the vegetative and pod development stages in chickpea, the uptake of P was not influenced significantly by landform, soil depth and their interaction At the harvest stage during 1998, soil depth treatment and the interaction of landform x soil depth significantly influenced the P uptake Landform had no significant effect on P uptake A significantly higher uptake of P (3 2) was observed in case of medium-deep soil than compared to the shallow depth soil (2 4) The BBF on medium-deep soil showed the highest uptake of P (3 4) and the flat on shallow soil recorded the lowest uptake of P (2 3) during 1998

4.4.3.5 K uptake (kg ha^{-1}) during 1997 (Table 32)

During harvesting stage in chickpea, the differences in K uptake due to soil depth and landform x soil depth interaction were significant in chickpea Chickpea crop grown on medium-deep soil showed a higher uptake of K (40 1) than the shallow soil (25 9) chickpea grown on the BBF landform on the medium-deep soil recorded the highest uptake of K (41 5) and the lowest P uptake (25 8) was observed in the shallow soil under BBF landform treatment during 1997

4.4.3.5 K uptake (kg ha^{-1}) during 1998 (Table 33)

In chickpea, during harvest stage the uptake of K was changed significantly by soil depth and landform x soil depth interaction Medium-deep soil showed a higher uptake of K (35 0) as compared to the shallow depth soil (19 8) The BBF on medium-deep soil recorded the maximum uptake of K (35 9) and the flat on shallow soil resulted in the minimum uptake of K (18 9) than compared to the other landform and soil depth combinations in the experiments conducted during 1998

4.5 Runoff

4.5.1 In deficit rainfall year 1997 during rainy season 523 mm rainfall was recorded, so runoff events were not recorded.

4.5.2 Runoff during 1998

All the four hydrological units of watershed BW7 were monitored for runoff during 1998 The rainy season was characterized by a large number of medium-intensity long-duration storms and, therefore, relatively high runoff events recorded in all the land management and cropping systems A total of 30 runoff events were recorded in this season (Appendix I) Total seasonal runoff from the BBF system was considerably lower when compared with the flat system on both the shallow and medium-deep soils (Table 34) On the shallow soil, the total seasonal runoff is 251 mm on BBF landform treatment and 283 mm on flat landform Similarly on the medium-deep soil, the total seasonal runoff during the rainy season is 200 mm on BBF landform and 290 mm on flat landform Average runoff observed on flat landform treatment was higher (287 mm) compared to the BBF landform treatment (226 mm), (Table 34) On an average total runoff from the medium soil was 28% of seasonal rainfall, whereas on shallow soil it was

31% of the seasonal rainfall Average runoff from flat treatment was 33% of the seasonal rainfall and from the BBF landform a total of 26% of seasonal rainfall was lost as surface runoff

4.5.3 Loss of nitrate N through runoff

Nitrate N concentration in runoff water varied greatly (2 4 to 9 6 mg N L ^{1}) during the crop growing period The highest N concentration was observed at 64 DAS of the crops (Appendix I) The total amount of N lost in the runoff ranged between 0 01 and 2 53 kg N ha ^{1} for different events (Appendix I) The total nitrate-N lost was 14 4 kg ha ^{1} in medium-deep soil under flat landform and 9 3 kg ha ^{1} in medium-deep soil under BBF landform (Table 34) The N loss was 12 6 kg ha ^{1} in shallow soil under flat landform and 10 3 kg ha ^{1} in shallow soil under BBF system (Table 34) Higher NO_3 loss was measured in the flat landform system compared to the BBF landform system An average amount of NO_3-N lost in runoff was higher in the flat landform (13 5 kg N ha ^{1}) than the BBF landform treatment (9 8 kg N ha ^{1}) (Table 34)

Table 34: Effect of landform and soil depth on nitrate loss through runoff in Vertic Inceptisols in black soils watershed 7 (BW7) at ICRISAT during rainy season 1998.

Treatments

	Flat			BBF			Total
	Shallow	Medium-deep	Mean	Shallow	Medium-deep	Mean	Mean
1 Runoff (mm)	283	290	287	251	200	226	257
2 Nitrogen loss (kg ha^{-1})	12 6	14 0	13 3	10 3	9 3	9 8	11 6

4.6 Nutrient balance (N, P and K) :

Nutrient (N, P and K) balance sheet was worked out taking into account the data relating to the inputs and outputs of nutrients in the soil-plant-atmosphere system, under soybean / pigeonpea and soybean + chickpea cropping systems grown on flat and BBF landforms on shallow and medium-deep Vertic Inceptisols during 1997 & 1998

4.6.1 N balance (kg ha $^{-1}$)

The nitrogen balance was estimated from the intercrop and sequential cropping systems by adding different forms of N (inputs) in the soil and outputs of N from the soil (Appendix I & II)

Inputs (kg ha $^{-1}$)

1 N added to the soil through biological nitrogen fixation by crops estimated with N-difference and ^{15}N-isotope dilution methods

2 N added to the soil through organic manures like *Glyricidia* leaves and farmyard manure applied to soil on BBF landforms only

3 N added to the soil through nitrogen recycling by fallen leaves and rootstocks

4 N added to the soil through rainfall

Outputs (kg ha $^{-1}$)

1 Nitrogen uptake by crops

2 N loss in runoff

3 N loss in deep drainage (this was calculated using simulated values)

4.6.1.1 N balance (kg ha $^{-1}$) by ^{15}N isotope dilution method (Table 35)

Table.35: Nitrogen balance for soybean+chickpea and soybean/pigeonpea croppingsystems grown on flat and BBF land forms and shallow and medium-deep Vertic Inceptisols during 1997 and 1998(**Nitrogen fixation values used as inputs estimated by ^{15}N isotope dilution and N- difference methods)**

Landform	1997													
	Shallow			Medium-deep			Total mean	Shallow			Medium-deep			Total mean
	soybean+ chickpea	soybean/ pigeonpea	Mean	soybean+ chickpea	soybean/ pigeonpea	Mean		soybean+ chickpea	soybean/ pigeonpea	Mean	soybean+ pigeonpea	soybean/ pigeonpea	Mean	
^{15}N Isotope dilution method														
Flat	-65	-40	-53	-60	51	56	-55	-92	-110	-101	-87	-101	94	-98
BBF	67	78	73	65	93	79	76	-74	-96	-85	-73	-84	-79	-82
Mean	1	19	10	3	21	12	11	-83	-103	-93	-80	-93	-87	-90
N- difference method														
Flat	-3	-5	-4	-14	-33	-24	-14	-6	-48	-27	7	-47	-20	-24
BBF	112	93	103	122	120	121	112	20	-35	-8	30	-22	4	-2
Mean	55	44	50	54	44	49	49	7	-42	-18	19	-35	-8	-13

N balance (kg ha^{-1}) = (NF+NG+NFYM+NL+NR+NRF) - (NU+NRU+ND)

N input(kg ha^{-1})		N output(kg ha^{-1})	
NF =	BNF	NU =	Crop uptake
NG =	*Glyricidia*	NRU =	Runoff
NFYM =	FYM	ND =	Deep drainage
NL =	Leaf fall		
NR =	Root stocks		
NRF =	Rainfall		

Nitrogen fixation values used as inputs for N balance were estimated with ^{15}N isotope dilution method. The nitrogen balance varied in landform, soil depth and cropping system treatments and their interaction. The higher and positive N balance (+76 kg ha^{-1}) was observed under the BBF landform compared with flat landform (-55) for the experiments conducted in 1997. However, during 1998 both landforms showed a negative N balance. A comparison of the two soil depths showed that a higher positive N balance (+12) was observed for the medium-deep soil compared to the shallow depth soil (10) during 1997. However, both soil depths resulted in a negative N balance during 1998.

In case of cropping systems, a higher positive N balance (+20) was observed under the intercropped soybean / pigeonpea system than the sequential cropping system (+2) during 1997. However, both cropping systems showed a negative N balance during 1998. The higher and positive N balance (+79) was observed under the BBF landform on the medium-deep soil compared with the other combinations during both years. The BBF landform with soybean / pigeonpea cropping systems recorded the maximum positive N balance (+86) compared with the BBF landform with soybean + chickpea system (+66). However, both the cropping systems grown on flat landform recorded a negative N balance during 1997. Both cropping systems grown on both landforms recorded the negative N balance during 1998. Maximum positive nitrogen gain (+21) was found for soybean / pigeonpea systems grown on the medium-deep soil. It was higher than the other cropping systems and soil depth combinations during 1997. A higher depletion of N (-103) was observed in case of intercropping system grown on the shallow soil compared to the other combinations during 1998. Highest positive N balance (+93) was observed in intercropping system grown on BBF landform on medium-deep soil during 1997 However during 1998, both cropping systems grown on both the landforms, on soils with two depths recorded the negative N balance

4.6.1.2 N balance (kg ha^{-1}) estimated with N-difference method (Table 35)

N-fixation values used as inputs for N balance were estimated with N-difference method Landform, soil depth, cropping system treatments and their interactions influenced the nitrogen balance for the experiments conducted in 1997 and 1998 The BBF influenced the nitrogen balance positively (+112) but flat landform resulted in a negative balance (-14) during 1999 However during 1998 both BBF and flat showed a negative N balance In case of soil depth, marginally higher positive balance (+50) was observed for the shallow soil than compared to the medium-deep soil (+49) during 1997 However, a more depletion of nitrogen (-18) was observed in the shallow depth soil as compared to the medium-deep soil (-8) for the experiments conducted in 1998 In case of cropping systems, sequential cropping system landforms resulted in a more positive N balance (+55) compared with the intercropping system (+44) during 1997 However, during 1998, the soybean + chickpea system showed a positive N balance (+13) and the soybean / pigeonpea influenced the negative N balance (-39) The BBF landform on both the shallow and medium-deep soils recorded a positive N balance during 1997 However, the BBF landform on medium-deep soil influenced the N balance positively during 1998 Both the sequential (+117) and intercropping systems (+107) grown on BBF landform showed a positive N balance compared with both the cropping systems grown on flat landform during 1997 Soybean + chickpea (sequential) system grown

BBF landform recorded a positive N balance (+25) It was higher than other cropping system and land configuration combinations during 1998 Maximum positive N balance (+55) was found for soybean+ chickpea grown on the shallow and medium-deep soil compared with the soybean / pigeonpea system grown on the shallow and medium-deep soil (+44) for the experiments conducted in 1997 The positive N gain was observed only in sequential cropping system grown on both the soil depths compared to the other intercropping and soil depth combinations Both sequential and intercropping systems grown on the BBF landform on both the soil depths recorded a positive N balance compared to the other flat landform and soil depth and cropping system combinations during 1997 However, during 1998, sequential cropping system grown on BBF landform on both soil depth showed a positive N gain compared with the other combinations

4.6.2 P balance (kg ha $^{-1}$)

The phosphorus balance was calculated from the soybean / pigeonpea and soybean + chickpea systems grown on the flat and BBF landforms on the shallow and medium-deep soil by adding different forms of P (inputs) in the soil and output of P from the soil (crop uptake) (Appendix 4)

Inputs (kg ha $^{-1}$)

1 P added to the soil through chemical fertilizer (SSP @ 20 kg ha $^{-1}$)

Tablel.36: Phosphorus balance for soybean+chickpea and soybean/pigeonpea cropping systems grown on flat and BBF landforms and shallow and medium-deep Vertic Inceptisols during 1997 and 1998

Landform	Soil depth													
	1997							1998						
	Shallow			Medium-deep			Total mean	Shallow			Medium-deep			Total mean
	soybean+ pigeonpea	soybean/ pigeonpea	Mean	soybean+ pigeonpea	soybean/ pigeonpea	Mean		soybean+ pigeonpea	soybean/ pigeonpea	Mean	soybean+ pigeonpea	soybean/ pigeonpea	Mean	
Flat	12	12	12	11	10	11	12	10	12	11	10	11	11	11
BBF	22	21	22	22	24	23	23	10	14	12	11	12	12	12
Mean	17	17	17	17	17	17	17	10	13	12	11	12	12	12

P balance (kg ha^{-1}) = (PC+PG+PFYM+PL+PR) - (PU)

P input (kg ha^{-1})

PC = chemical fertilizer
PG = *Glyricidia*
FYM = FYM
PL = Leaf fall
PR = Root stocks

P output (kg ha^{-1})

PU = Crop uptake

2 P added to the soil through organic manures like glyricidia leaves and farmyard manure (applied to soil on BBF landforms only)

3 P added to the soil through leaf fall and rootstocks

Output (kg ha $^{-1}$)

P uptake by crops.

The phosphorus balance was influenced by landform, soil depth, cropping system treatments and their interactions during 1997 and 1998 (Table 36) All the treatments and their interactions showed a positive P balance during both the years A comparison of the two landforms showed that a maximum positive P balance was observed for the BBF landform compared to the flat landform during 1997 and 1998 There were no marked difference in the balance of available P in the soil due to soil depths and cropping systems during both years The BBF landform on both soil depths showed the highest positive P balance during both the years Maximum positive P balance was observed under soybean pigeonpea system grown on BBF landform during 1997 (+23) and 1998 (+13) compared with the other cropping system and land configuration combinations Highest positive P balance (+24) was recorded under intercropping systems grown on BBF on medium-deep soil during 1997

4.6.3 K balance (kg ha $^{-1}$)

The potassium balance was estimated from the soybean / pigeonpea and soybean + chickpea systems grown on the flat and BBF landforms on the shallow and medium-deep soil by adding different forms of K (inputs) in the soil and output of K from the soil (Appendix 5)

Inputs (kg ha ^{1})

1 K added to the soil through organic manures like glyricidia leaves and farmyard manure (applied to soil on BBF landform only)

2 K added to the soil through leaf fall and rootstocks

Output (kg ha ^{1})

K uptake by crops

The available net K showed a negative balance in all the treatments (Table 37) The depletion of K was maximum under the flat landform compared to the BBF during both the years A comparison of the two soil depths showed that a higher negative K balance was observed for the medium-deep soil compared to the shallow soil during both 1997 and 1998 In case of cropping system, the sequential cropping system influenced the more depletion of K than that of intercropping system during both the years Maximum negative K balance was showed in the flat landform in the medium-deep soil compared to the other landform and soil depth combinations during 1997 and 1998 Soybean / chickpea system grown on the medium-deep soil influenced the more depletion of K compared with the other combinations during both years Highest negative K balance was recorded in sequential cropping system grown on flat on medium-deep soil compared to other combinations during both years

Table.37: Potassium balance for soybean+chickpea and soybean/pigeonpea cropping systems grown on flat and BBF landforms and shallow and medium-deep Vertic Inceptisols during 1997 and 1998

Landform	Soil depth													
	1997							1998						
	Shallow			Medium-deep			Total mean	Shallow			Medium-deep			Total mean
	soybean+ pigeonpea	soybean/ pigeonpea	Mean	soybean+ pigeonpea	soybean/ pigeonpea	Mea		soybean+ pigeonpea	soybean/ pigeonpea	Mea	soybean+ pigeonpea	soybean/ pigeonpea	Mean	
Flat	-38	-31	-35	-50	-39	-45	-40	-55	-48	-52	-68	-51	-60	-56
BBF	-27	-22	-25	-40	-25	-33	-29	-56	-52	-54	-66	-46	-56	-55
Mean	-33	-27	-30	-45	-32	-39	-35	-56	-50	-53	-67	-49	-58	-56

K balance (kg ha^{-1}) = (KG+KFYM+KL+KR) - (KU)

K input (kg ha^{-1})

KG = *Glyricidia*
KFYM = FYM
KL = Leaf fall
KR = Root stocks

K output (kg ha^{-1})

KU = Crop uptake

4.7 Total drymatter and seed yield of crops

4.7.1 Rainy Season (soybean)

4. 7.1.1 Total drymatter yield (kg ha ^{1}) during 1997 (Table 38, Fig. 15)

During 1997 rainy season soybean total drymatter yield was significantly affected by landform, cropping systems treatments and their interactions viz , landform × soil depth, landform × cropping system, soil depth x cropping system and landform × soil depth × cropping system Cropping system treatments did not significant effect drymatter yield The BBF landform resulted in a higher total drymatter yield of soybean than the flat landform (2651 vs 2413) Higher drymatter yield was observed in the case of sole soybean compared to the intercropped soybean (2952 vs 2111) The BBF landform on the shallow soil showed highest drymatter yield (2764) and the flat landform on the shallow soil recorded the lowest drymatter yield (2325) Maximum drymatter yield was observed (2833) in case of sole soybean grown on flat landform while minimum drymatter yield (1992) was recorded in intercropped soybean grown on flat landform than compared to the other cropping system and landform combinations Drymatter yield was highest in case of sole soybean grown on shallow Vertic Inceptisol and it was lowest in case of intercropped soybean grown on medium-deep soil (2965 vs 2098) Sole soybean grown on BBF landform on shallow soil showed the highest drymatter yield and the intercropped soybean grown on flat landform on shallow soil showed the lowest dry matter yield (3184 vs 1904)

4.7.1.2 Total drymatter yield (kg ha $^{-1}$) during 1998 (Table 38, Fig. 15)

In soybean, total drymatter yield varied significantly in different cropping system treatments and their interactions viz , landform × cropping system, soil depth × cropping

Table.38: Total drymatter and seed yield (kg ha $^{1)}$ of sole and intercropped soybean grown on flat and BBF landfoms and shallow and medium-deep Vertic Inceptisols during rainy season 1997 and 1998

Landform	Soil depth													
	1997							1998						
	Shallow			Medium - deep				Shallow			Medium - deep			
	Sole	Inter crop	Mean	Sole	Inter crop	Mean	Mean	Sole	Inter crop	Mean	Sole	Inter crop	Mean	Total mean
1)Total drymatter yiel														
Flat	2746	1904	2325	2920	2079	2500	2413	3535	2167	2851	3400	2410	2905	2878
BBF	3184	2343	2764	2959	2117	2538	2651	3411	2385	2898	3435	2267	2851	2875
Mean	2965	2124	2545	2940	2098	2519	2532	3473	2276	2875	3417	2339	2878	2877
	L	S	C	LS	LC	SC	LSC	L	S	C	LS	LC	SC	LSC
S Ed +	81 3	79 9	84 1	117 9	117 0	116 1	144 9	79 3	78 9	85 0	115 5	116 4	116 4	167 5
CD(0 05)	178 9	NS	185 1	259 5	257 5	255 5	318 9	NS	NS	187 0	NS	256 1	256 1	368 6
2) Seed yield														
Flat	1019	700	860	904	699	802	831	1692	982	1337	1627	1082	1355	1346
BBF	1064	818	941	1015	725	870	906	1573	992	1283	1632	1038	1335	1309
Mean	1042	759	901	960	712	836	869	1633	987	1310	1630	1060	1345	1328
S Ed +	48 8	48 1	51 8	70 6	71 2	70 7	96 6	51 9	49 3	58 8	73 3	78 5	76 8	104 6
CD(0 05)	NS	NS	114 0	NS	156 7	155 6	212 6	NS	NS	129 4	NS	172 7	169 0	230 2

1, Refer Table 1

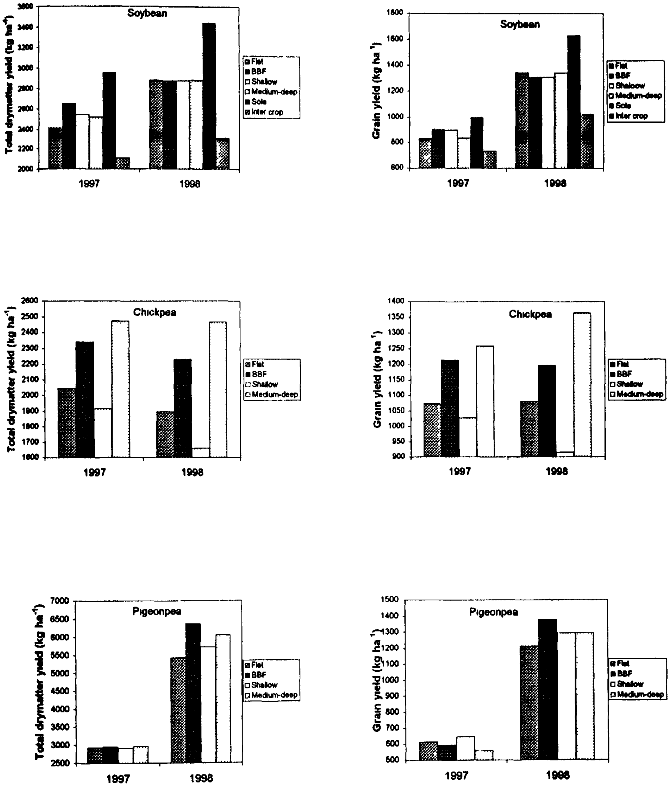


Fig.15: Total drymatter and grain yield of soybean,chickpea and pigeonpea grown on shallow and medium-deep Vertic Inceptisols with two landfoms during 1997 and 1998

system and landform × soil depth × cropping system Landform, soil depth treatments and their interaction did not show any significant effect on drymatter yield Higher drymatter yield was observed in sole soybean treatment compared to the intercropped soybean (3455 vs 2307) Highest drymatter yield (3467) was observed in case of sole soybean grown on flat landform and the lowest yield (2288) was recorded in intercropped soybean grown on flat landform Sole soybean grown on shallow depth soil showed the highest drymatter yield (3473) and the intercropped soybean grown on shallow depth soil recorded the lowest dry matter yield (2276) Maximum yield (3535) was recorded in sole soybean grown on flat landform on shallow depth soil and the minimum yield (2167) was noticed in intercropped soybean grown on flat landform on shallow depth soil than compared to the other combinations in soybean during 1998

4. 7. 1. 3 Seed yield (kg ha^{-1}) during 1997 (Table 38, Fig. 15)

During rainy season 1997 soybean seed yield was significantly changed by cropping system treatments and interactions viz , landform × cropping system, soil depth × cropping system and landform × soil depth × cropping system Soybean seed yield was not influenced significantly by landform, soil depth and their interaction In case of cropping systems, sole soybean grain yield was significantly higher (1 36 times) as compared to intercropped soybean (1001 vs 735) Highest seed yield (1039) was observed in sole soybean grown on BBF and the lowest seed yield (699) was recorded in case of intercropped soybean grown on flat landform treatment Sole soybean grown on shallow depth soil resulted in the highest seed yield (1042) and the intercropped soybean grown on medium-deep soil showed the lowest seed yield (712) Sole soybean crop grown on BBF landform on shallow depth soil resulted in the highest seed yield (1064) and the intercropped soybean crop grown on flat landform on medium-deep soil showed the lowest seed yield (699)

4.7.1.4 Seed yield (kg ha $^{-1}$) during 1998 (Table 38, Fig. 15)

Soybean grain yield during rainy season 1998, was influenced significantly by cropping system treatments and treatment interactions viz , landform × cropping system, soil depth × cropping system and landform × soil depth × cropping system There were no marked differences due to landform, soil depth and their interaction A comparison of the two cropping systems showed that a significantly higher seed yield (1 59 times more) was observed in sole soybean compared to the intercropped soybean (1634 vs 1024) Sole soybean grown on the flat landform treatment showed the highest seed yield (1660) and the intercropped soybean grown on the BBF landform resulted in the lowest seed yield (1015) Sole soybean grown on the shallow depth soil recorded the maximum seed yield (1633) while the intercropped soybean grown on the shallow depth soil observed the minimum seed yield (987) than compared to the other cropping system and soil depth combinations Highest seed yield (1692) was observed in case of sole soybean grown on flat landform on shallow depth soil and the lowest yield (982) was recorded in case of intercropped soybean grown on flat landform on the shallow depth soil

4.7.2 Post-rainy season (Pigeonpea)

4.7.2.1 Total drymatter yield (kg ha $^{-1}$) during 1997 (Table 39, Fig. 15)

Total drymatter yield of pigeon pea was not changed significantly by landform systems, soil depths and their interaction

4.7.2.2 Total drymatter yield (kg ha $^{-1}$) during 1998 (Table 39, Fig. 15)

In pigeonpea, the total drymatter yield was influenced significantly by landform treatments and landform × soil depth interaction Soil depth treatment effect on total dry matter yield was not significant A comparison of the two landforms showed that a higher total drymatter yield of pigeonpea was observed for the BBF landform compared to the flat landform treatment (6364 vs 5426) The highest total drymatter yield (6531) was evident in BBF on medium deep soil, while the lowest drymatter yield was recorded for flat landform on shallow depth soil (5258) in pigeon pea

4.7.2.3 Seed yield (kg ha $^{-1}$) during 1997 (Table 39, Fig. 15)

Landform, soil depth treatments and their interaction did not vary significantly the seed yield of pigeonpea An average higher seed yield (614) was observed in case of pigeonpea grown on the flat landform compared to the BBF landform treatment (593)

4.7.2.4 Seed yield (kg ha $^{-1}$) during 1998 (Table 39, Fig. 15)

In pigeon pea the variations in seed yield due to landform, soil depth treatments and their interaction were not significant Mean seed yield of pigeon pea was marginally higher on BBF landform than the flat landform treatment (1377 vs 1213)

Table.39: Total drymatter and seed yield(kg ha^{-1}) of chickpea and pigeonpea grown on flat and BBF landforms and shallow and medium-deep Vertic Inceptisols during post-rainy season 1997 and 1998

Landform	Soil depth					
	1997			1998		
	Shallow	Medium-deep	Mean	Shallow	Medium-deep	Mean
		Chickpea				
a) Total dry matter yield(kg ha^{-1}						
Flat	1849	2242	2046	1493	2301	1897
BBF	1981	2701	2341	1826	2633	2230
Mean	1915	2472	2194	1660	2467	2064
	L	S	LS	L	S	LS
S.Ed.+	175.7	193	268.7	189.7	207.4	289.5
CD(0.05)	NS	424.7	591.4	NS	456.4	637.1
b) Seed yield (kg ha^{-1})						
Flat	998	1149	1074	856	1304	1080
BBF	1058	1369	1214	973	1421	1197
Mean	1028	1259	1144	915	1363	1139
S.Ed.+	88.7	96.8	135.1	91.7	107.5	145.3
CD(0.05)	NS	213	297.3	NS	236.6	319.8
		Pigeonpea				
a) Total dry matter yield(kg ha^{-1}						
Flat	2889	2975	2932	5258	5593	5426
BBF	2958	2945	2952	6196	6531	6364
Mean	2924	2960	2942	5727	6062	5895
S.Ed.+	87.6	87.6	125.1	396.3	331.8	529.8
CD(0.05)	NS	NS	NS	872.2	NS	1166
b) Seed yield (kg ha^{-1})						
Flat	644	584	614	1213	1213	1213
BBF	648	538	593	1377	1377	1377
Mean	646	561	604	1295	1295	1295
S.Ed.+	32.1	46.3	57.3	94.5	3.6	94.5
CD(0.05)	NS	NS	NS	NS	NS	NS

1, Refer Table 1

4.7.3 Post-rainy season (Chickpea)

4.7.3.1 Total drymatter yield (kg ha $^{-1}$) during 1997 (Table 39, Fig. 15)

Chickpea total dry matter yield during post rainy season 1997, varied significantly due to soil depth treatment and landform × soil depth interaction Landform had no significant effect on drymatter yield A comparison of the two soil depths showed that a significantly higher drymatter yield was recorded for medium-deep soil compared to the shallow depth soil (2472 vs 1915) The BBF landform on the medium deep soil showed a maximum drymatter yield (2701) and the flat landform on the shallow Vertic Inceptisol recorded the minimum dry matter yield (1849) compared with the other landform and soil depth combinations

4.7.3.2 Total drymatter yield (kg ha ^{1}) during 1998 (Table 39, Fig. 15)

Drymatter yield of chickpea in the post-rainy cropping season 1998, was significantly influenced by the soil depth treatments and the interaction of landform × soil depth Landform did not significantly vary the drymatter yield Chickpea grown on medium-deep showed a significantly higher dry matter yield compared to shallow depth soil (2467 vs 1660) Chickpea grown on BBF on medium-deep soil showed the maximum drymatter yield (2633) and minimum yield (1493) was recorded on flat landform on medium-deep soil

4.7.3.3 Seed yield (kg ha $^{-1}$) during 1997 (Table 39, Fig. 15)

The variations in chickpea seed yield due to soil depth and landform × soil depth were significant Landform had no significant effect on grain yield A significantly more grain yield (1259) was recorded in case of medium deep soil than compared to the shallow depth soil (1028) The chickpea grown on BBF on the medium-deep soil showed the maximum seed yield (1369) while the chickpea grown on flat on shallow depth soil recorded the minimum seed yield (998) compared to the other landform and soil depth combinations 1997

4.7.3.4Seed yield (kg ha $^{-1}$) during 1998 (Table 39, Fig. 15)

Seed yield of chickpea during post rainy season 1998 was changed significantly by the soil depth treatments and the interaction of landform × soil depth Landform effect on grain yield was not significant In case of soil depth, a significantly higher (1 48 times more) grain yield was recorded for medium-deep soil compared to the shallow depth soil (1363 vs 915) The BBF landform on the medium deep soil showed the highest seed yield (1421) of chickpea and the lowest yield (856) was recorded in flat landform treatment on shallow depth Vertic Inceptisol

4.8 Total systems productivity of soybean/pigeonpea (intercrop) and soybean + chickpea (sequential crop).

4.8.1 Total systems productivity [seed yield (kg ha $^{-1}$)]during 1997 (Table 40)

The sequential and intercrop (soybean + chickpea and soybean / pigeonpea) systems total grain yield during 1997, varied significantly due to cropping system treatments and interactions viz , landform × cropping system, soil depth × cropping system and landform ×

Table.40: Total system productivity [seed yield (kg ha^{-1})] of soybean+chickpea and soybean/pigeonpea grown on flat and BB landforms and shallow and medium-deep Vertic Inceptisols during 1997 and 1998

Landform	Soil depth						
	Shallow			Medium - deep			Total mean
	Soybean + chickpea	Soybean/pigeonpea	Mean	Soybean + chickpea	Soybean/pigeonpea	Mean	
1997							
Flat	2043	1321	1682	2004	1318	1661	1672
BBF	2120	1481	1801	2410	1241	1826	1814
Mean	2082	1401	1742	2207	1280	1744	1743
	L	**S**	**C**	**LS**	**LC**	**SC**	**LSC**
S.E.d.	82.5	78.5	86.5	117.5	119.6	119.2	172.4
CD(0.05)	NS	NS	190.4	NS	263.2	262.4	379.5
1998							
Flat	2580	2128	2354	2855	2389	2622	2506
BBF	2626	2293	2460	2999	2477	2738	2608
Mean	2603	2211	2407	2927	2433	2680	2557
S.E.d.	100.6	107.4	110.4	151.2	149.3	154.0	172.4
CD(0.05)	NS	236.4	242.9	332.8	328.6	262.4	379.5

 # 1,Refer Table1

soil depth × cropping system. Landform, soil depth treatments and their interactions did not significantly influence the total systems productivity (grain yield). The productivity of soybean + chickpea was significantly higher (1. 6 times more) than that of soybean/pigeon pea (2415 vs 1341). The soybean + chickpea (sequential) system grown on the BBF landform treatment showed the highest productivity and the soybean/ pigeon pea (intercrop) system grown on the flat landform resulted in the lowest productivity (2265 vs 1320). Highest seed yield was observed in the sequential system grown on medium-deep soil while the lowest seed yield was recorded in the intercropping system grown on medium deep soil (2207 vs 1280). Maximum productivity was observed in the sequential system (soybean + chickpea) grown on BBF on medium deep soil whereas the minimum productivity was recorded in the intercropping system (soybean/pigeon pea) grown on BBF on medium deep soil (2410 vs 1241) to compared with the other combinations during 1997.

4.8.2 Total systems productivity (seed yield (kg ha $^{-1}$) during 1998(Table 40)

Total systems productivity (soybean / pigeonpea and soybean+chickpea) was significantly influenced by soil depth, cropping system treatments and interactions viz., landform × soil depth, landform × cropping system, soil depth × cropping system and landform × soil depth × cropping system. Landform effect on total systems productivity was not significant. A significantly higher productivity (seed yield) was recorded in the medium deep soil than the shallow soil. In case of cropping system, the productivity of soybean + chickpea was significantly more compared to the soybean / pigeonpea system (2765 vs 2322). The BBF landform on the medium-deep soil showed the highest productivity while the flat landform on the shallow soil recorded the lowest productivity.

Maximum productivity was observed in the intercropping system (soybean/pigeon pea) grown on the flat landform treatment whereas the lowest productivity was recorded in the sequential cropping system (soybean + chickpea) grown on BBF landform compared to the other combinations Soybean + chickpea grown on medium deep soil resulted in the highest grain yield and the soybean/pigeon pea grown on shallow soil recorded the lowest grain yield Maximum grain yield was found in the sequential system (soybean + chickpea) grown on BBF on medium deep soil where the lowest minimum grain yield was recorded in the intercropping system (soybean/pigeon pea)grown on flat landform on shallow soil compared with the other combinations during 1998

4.9 Vesicular arbuscular mycorrhizal fungi (VAMF)

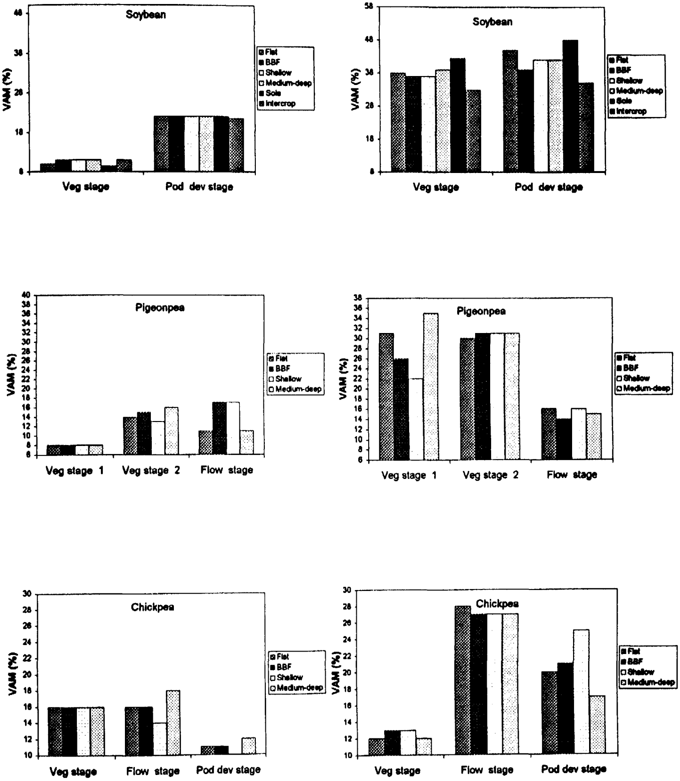
4.9.1 Soybean root colonization (%) by Vesicular arbuscular mycorrhizal fungi (VAMF) during rainy season 1997 (Table41, Fig. 16)

In soybean, root colonization by VAMF increased from vegetative to pod development stage (11 to 22) The colonization by VAMF in soybean roots increased with plant age, During vegetative stage in sole and intercrop soybean, mycorrhizal root colonization was influenced significantly by cropping system treatments and treatment interactions viz , landform × cropping system, soil depth × cropping system and landform × soil depth × cropping system The landform, soil depth treatments and their interaction did not influence significantly the mycorrhizal root colonization in soybean Higher mycorrhizal colonization (11) was observed in intercropped soybean roots than the sole soybean roots (9 5) Highest root colonization (13) by VAMF was recorded in intercropped soybean grown on the BBF landform treatment, however lowest root colonization (9) was observed

Table.41: Vesicular arbuscular mycorrhizal colonization (%) in roots of soybean grown on fla and BBF landforms and shallow and medium-deep Vertic Inceptisols during rainy season 1997 and 1998

Landform	**Soil depth**														
	Vegetative stage (36 DAS)							Pod devlopment stage (70 DAS)							
	Shallow			**Medium-deep**				**Shallow**			**Medium-deep**				
	Sole	Inter crop	Mean	Sole	Inter crop	Mean	Total mean	Sole	Inter crop	Mean	Sole	Inter crop	Mean	Total mean
1997															
Flat	10	9	10	9	10	10	10	22	21	22	22	21	22	22
BBF	9	12	11	8	13	11	11	22	21	22	22	22	22	22
Mean	10	11	11	9	12	11	11	22	21	22	22	22	22	22
	L	**S**	**C**	**LS**	**LC**	**SC**	**LSC**	**L**	**S**	**C**	**LS**	**LC**	**SC**	**LSC**
S.Ed.±	0.9	0.8	0.9	1.3	1.3	1.3	1.8	2.4	2.3	2.3	3.4	3.4	3.2	4.1
CD(0.05)	NS	NS	1.9	NS	2.8	2.8	3.9	NS	NS	NS	NS	NS	NS	NS
1998															
Flat	44	33	39	45	32	39	38	37	43	40	56	44	50	45
BBF	40	33	37	41	34	38	37	50	35	43	50	18	34	39
Mean	42	33	37	43	33	39	38	44	39	42	53	31	42	42
S.Ed.±	3.6	1.4	4.7	3.9	6	4.9	6.3	2.5	2.5	2.5	3.7	3.7	3.6	5.2
CD(0.05)	NS	NS	NS	NS	NS	NS	NS	5.5	NS	5.5	8.1	8.1	7.9	11.4

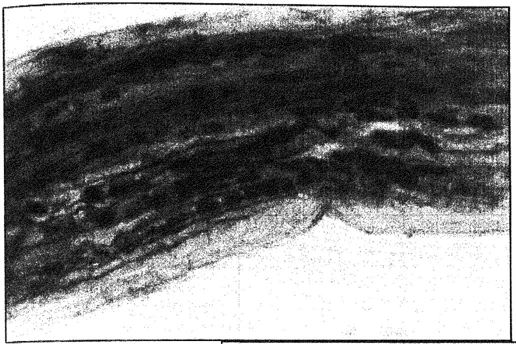
1, Refer Table 1



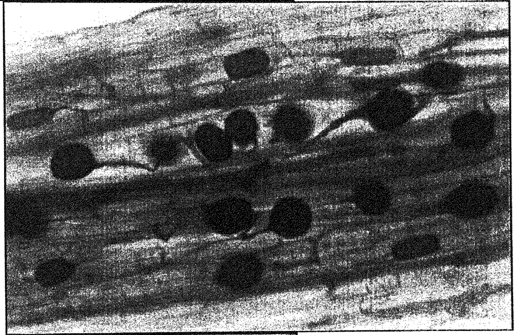
1997

1998

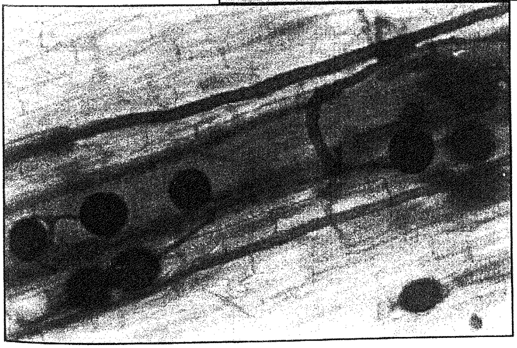
Fig.16: Effect of landfom and soil depth on Vesicular arbuscular mycorrhizal colonization (%) in soybean,pigeonpea and chickpea roots during 1997 and 1998



Arbuscules (at the vegetative stage)



Mycelia + vesicles (at the pod development stage)



Mycelia + vesicles (at the pod development stage)

Plate: 11. Vesicular arbuscular mycorrhizal colonization in soybean roots as influenced by landform and soil depth treatments during rainy season 1998.

in sole soybean grown on the BBF landform. Highest mycorrhizal colonization (12) was observed in intercropped soybean roots in the medium-deep soil, while the lowest vesicular arbuscular mycorrhizal fungi colonization (9) was recorded in sole soybean roots in the medium deep soil. Maximum root colonization (13) by VAMF was found in intercropped soybean grown on BBF on medium deep soil and it was minimum (9) in sole soybean grown on BBF on medium-deep soil compared with the other combinations during 1997.

During pod development stage, mycorrhizal fungi colonization in sole and intercropped soybean was not changed significantly by landform, soil depth and their interaction.

4.9.2 Soybean root colonization (%) by Vesicular arbuscular mycorrhizal fungi (VAMF) during rainy season 1998 (Table 41, Fig. 16)

The Vesicular arbuscular mycorrhizal fungi root colonization in soybean increased with plant age from vegetative to pod development stage (38-42). During vegetative stage in sole and intercropped soybean the variations in Vesicular arbuscular mycorrhizal fungi colonization due to landform, soil depth and their interaction were not significant. At the pod development stage root colonization by VAMF, varied significantly due to landform, cropping system treatments and interactions viz., landform × soil depth, landform × cropping system, soil depth × cropping system and landform × soil depth x cropping system. Soil depth did not influence significantly the mycorrhizal colonization. Flat landform showed a higher (45) root colonization by VAMF and it was lesser (39) in the BBF landform treatment. Higher mycorhizal colonization was found in sole soybean roots (48) than compared to intercropped soybean roots (35). Roots of soybean grown on the flat landform on the medium-deep soil had the highest (50) colonization by VAMF and it was lowest (34) in the soybean grown on BBF landform on the medium-deep Vertic Inceptisol Highest root colonization (50) by VAMF was noticed in sole soybean grown on BBF landform treatment, however, lowest (27) root colonization by VAMF was observed in intercropped soybean grown on BBF The mycorrhizal colonization was highest (53) in sole soybean grown on medium deep soil and it was lowest (31) in intercropped soybean grown on medium-deep soil Highest root colonization (56) was recorded in sole soybean grown on flat landform on medium deep soil and it was lowest (18) in intercropped soybean grown on BBF landform on medium deep soil

4.9.3 Pigeon pea root colonization (%) by Vesicular arbuscular mycorrhizal fungi during rainy and post rainy seasons 1997 (Table 42, Fig. 16)

The VAMF colonization in pigeonpea roots during vegetative stages, 36 and 70 DAS varied significantly due to landform, soil depth and their interactions During flowering stage the mycorrhizal colonization in pigeon pea roots was changed significantly by landform, soil depth and their interaction BBF landform influenced the higher mycorrhizal colonization (17) than the flat landform treatment (11) The shallow soil showed a higher (17) root colonization by VAM fungi and it was lower (11) in the medium deep soil The BBF landform on the shallow soil resulted in the highest mycorrhizal colonization (23) and lowest mycorrhizal colonization was observed (10) in the BBF landform treatment on the medium deep soil in pigeon pea roots during 1997

Table.42: Vesicular arbuscular mycorrhizal colonization (%) in roots of pigeonpea grown on flat and BBF landforms and shallow and medium-deep Vertic Inceptisols during rainy and seasons 1997 and 1998

Landform	Soil depth								
	Rainy season						Post- rainy season		
	Vegetative stage (36 DAS)			Vegetative stage(70 DAS)			Flowering stage(133 DAS)		
	Shallow	**Medium-deep**	**Mean**	**Shallow**	**Medium-deep**	**Mean**	**Shallow**	**Medium-deep**	**Mean**
					1997				
Flat	8	7	8	12	16	14	11	11	11
BBF	7	8	8	13	16	15	23	10	17
Mean	8	8	8	13	16	15	17	11	14
	L	**S**	**LS**	**L**	**S**	**LS**	**L**	**S**	**LS**
S.Ed.±	0.6	0.4	0.8	0.9	3.5	3.6	2.6	2.6	3.9
CD(0.05)	NS	NS	NS	NS	NS	NS	5.7	5.7	8.6
					1998				
Flat	16	46	31	30	30	30	16	16	16
BBF	27	24	26	31	31	31	14	14	14
Mean	22	35	29	31	31	31	16	15	15
S.Ed.±	15.9	15.9	23.1	4.0	1.5	4.3	2.8	0.8	2.9
CD(0.05)	NS	NS	NS	NS	NS	NS	NS	NS	NS

1, Refer Table 1

4.9.4 Pigeon pea root colonization (%) by Vesicular arbuscular mycorrhizal fungi during rainy and post rainy season 1998 (Table 42, Fig 16)

In pigeonpea root colonization by VAMF during vegetative (36 and 70 DAS) and flowering stages was not affected significantly by landform, soil depth and their interaction.

4.9.5 Chickpea root colonization by Vesicular arbuscular mycorrhizal fungi during post rainy season 1997 (Table 43, Fig. 16)

Landform, soil depth and their interaction did not significantly influence the mycorrhizal colonization in chickpea roots during vegetative and flowering stages. At the pod development stage the variations in the mycorrhizal colonization in chickpea roots due to soil depth and landform × soil depth were significant. Higher root colonization (25) was noticed in shallow Vertic Inceptisol than compared to the medium-deep Vertic Inceptisol (17). The chickpea grown on BBF on the shallow soil showed a maximum (26) mycorrhizal colonization and it was minimum (16) in the BBF landform on the medium-deep Vertic Inceptisol than compared with the other combinations.

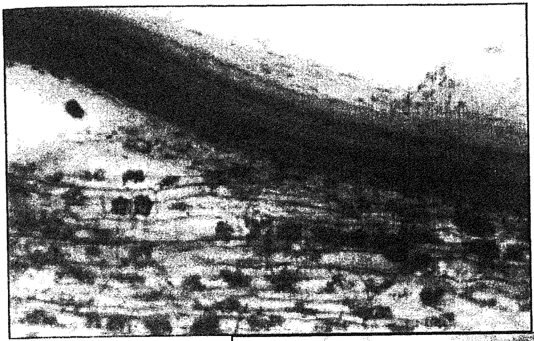
4.9.6 Chickpea root colonization by Vesicular arbuscular mycorrhizal fungi during post rainy season 1998 (Table 43, Fig. 16)

In chickpea, root colonization by VAMF was not influenced significantly by landform, soil depth and their interaction during crop growth period viz., vegetative, flowering and pod development stages.

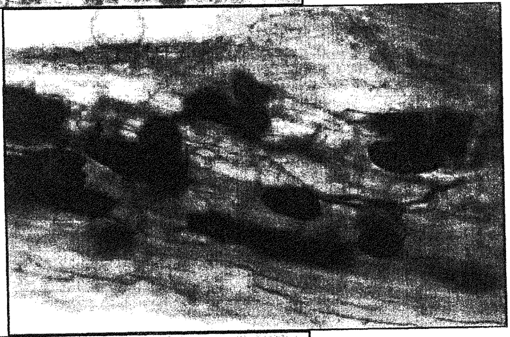
Table.43: Vesicular arbuscular mycorrhizal colonization (%) in roots of chickpea grown on flat and BBF landorms and shallow and medium-deep Vertic Inceptisols during post- rainy season 1997 and 1998

Landfor	**Soil depth**								
	Vegetative stage(38 DAS)			Flowering stage(58 DAS)			Pod development stage(73 DAS)		
	Shallow	**Medium-deep**	**Mean**	**Shallow**	**Medium-deep**	**Mean**	**Shallow**	**Medium-deep**	**Mean**
					1997				
Flat	12	11	12	29	26	28	23	17	20
BBF	13	12	13	25	28	27	26	16	21
Mean	13	12	13	27	27	27	25	17	21
	L	**S**	**LS**	**L**	**S**	**LS**	**L**	**S**	**LS**
S.Ed.±	1.8	1.9	2.7	2.7	2.7	3.9	2.4	3.6	4.4
CD(0.05)	NS	NS	NS	NS	NS	NS	NS	7.9	9.6
					1998				
Flat	16	16	16	14	18	16	10	11	11
BBF	16	16	16	14	18	16	9	12	11
Mean	16	16	16	14	18	16	10	12	11
S.Ed.±	0.9	1.0	1.4	0.1	2.8	2.8	1.0	1.6	2.0
CD(0.05)	NS	NS	NS	NS	NS	NS	NS	NS	NS

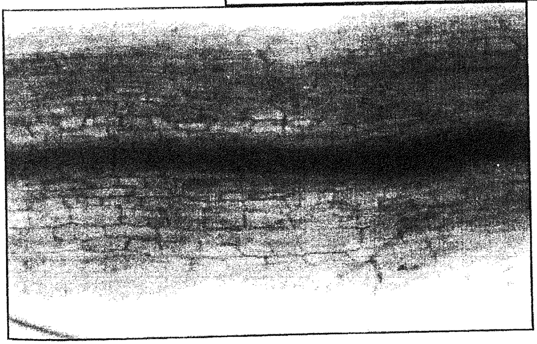
1, Refer Table 1



Arbuscules in
chickpea
(at the vegetative
stage)



Mycelia + vesicles in
pigeonpea
(at the pod
development stage)



Pigeonpea root was
not infected by VAM
(at the flowering
stage)

Plate 12 Vesicular arbuscular mycorrhizal colonization in chickpea and pigeonpea roots as influenced by landform and soil depth treatments during 1998

4.10 LAB EXPERIMENT I

4.10.1 Potentially mineralizable N

4.10.1.1 Cumulative mineral N (NH_4^++NO_3^-) (Table 44, Fig. 17)

Patterns on N mineralization in a Vertic Inceptisol amended with *Glyricidia sepium* leaves and stems and pigeonpea roots and leaves were studied *in-vitro* studies.

Mean cumulative mineral N (NH_4^++NO_3^-) content across the treatments increased significantly from 3.2 mg N kg^{-1} soil at 5 days after incubation to 105 mg kg^{-1} soil at 150 days after incubation of the soil. A higher mineralization of soil nitrogen (121 mg kg^{-1} soil) was observed when *Glyricidia* leaves surface application to the soil compared to all other treatments at 150 days of incubation (Table 44). Lowest mineralization of soil N was observed when *Glyricidia* stems were applied at surface of the soil (92 mg kg^{-1} soil).

Amongst the *Glyricidia* treatments, highest N mineralization (119 mg N kg^{-1}) occurred with the *Glyricidia* leaves compared to the G*lyricidia* stems (93 mg N kg^{-1}) during 150 days incubation. Amongst the pigeonpea treatments, a higher cumulative mineral N content was observed with pigeonpea leaves (112 mg N kg^{-1} soil) compared to the pigenopea roots (99 mg N kg^{-1} soil) at the end of a 150 day incubation period (Table 44).

4.10.1.2 Cumulative ammonial nitrogen (NH_4^+N) (Table 45, Fig. 18)

Cumulative ammonial nitrogen (NH_4^+N) content in incubated soils was influenced significantly ($P \leq 0.05$) with the addition of organic residues at surface and incorporation in the soil at 5, 10, 100 and 150 days after incubation (Table 45). The amount of ammonial nitrogen (NH_4^+N) increased from 0.7 mg kg^{-1} soil at 5 days to 5 mg kg^{-1} soil at 150 days incubation. Significantly higher amount of cumulative ammonical N (NH_4^+N) was

Table.44: Cumulative mineral N (NH_4^++NO_3^-) content (mg kg^{-1}) of Vertic Inceptisols amended with *Glyricidia* and Pigeonpea residues *in-vitro* studies during 150 days incubation

Treatment	**Incubation period (days)**							
	5	**10**	**15**	**25**	**50**	**75**	**100**	**150**
1) Control	1 6	4 4	9 4	21 1	40 8	58 5	70 3	96 8
2) GSS	3 8	7 0	11 6	19 9	35 1	53 3	65 9	92 4
3) GSI	4 7	7 3	10 8	19 3	36 5	53 2	67 2	93 7
4) GLS	7 0	16 9	24 6	40 9	59 3	76 8	92 0	121 2
5) GLI	5 9	11 6	19 4	31 7	52 7	72 6	85 6	117 0
6) PRS	0 6	2 6	5 8	16 5	36 4	54 6	66 6	96 6
7) PRI	2 3	4 3	8 1	18 1	38 2	56 4	72 4	102 2
8) PLS	2 1	5 6	12 9	28 1	48 6	68 8	85 2	117 3
9) PLI	0 8	3 6	10 3	27 0	48 1	66 4	74 7	107 3
Mean	3 2	7 0	12 6	24 7	44 0	62 0	76 0	105 0
S Ed ±	1 43	1 99	2 36	3 75	6 24	7 60	8 15	10 76
CD (0 05)	2 94	4 01	4 85	7 69	12 80	15 60	16 72	NS

1 GSS = *Glyricidia* stem on surface, GSI = *Glyricidia* stem incorporated, GLS = *Glyricidia* leaf on surface, GLI = *Glyricidia* leaf incorporated, PRS = Pigeonpea root on surface, PRI = Pigeonpea root incorporated, PLS = Pigeonpea leaf on surface, PLI = Pigeonpea leaf incorporated

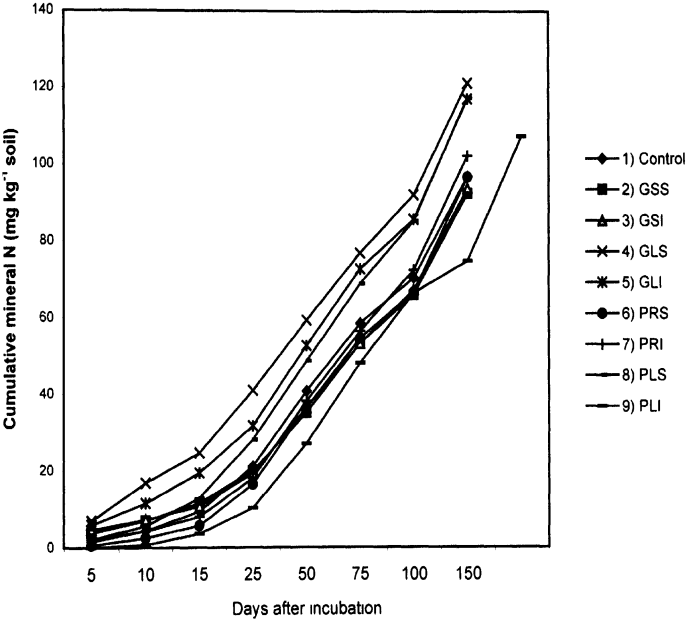


Fig 17 Cumulative mineral N (NH_4^+ + NO_3^-) content of Vertic Inceptisols amended with plant residues *in - vitro* studies

Table.45: Cumulative ammonical N (NH_4^+) content (mg kg^{-1}) of Vertic Inceptisols amended with *Glyricidia* and Pigeonpea residues *in-vitro* studies during 150 days incubation

Treatment	Incubation period (days)							
	5	**10**	**15**	**25**	**50**	**75**	**100**	**150**
1) Control	0 2	0 4	0 8	1 8	2 8	2 9	3 7	4 1
2) GSS	0 2	0 6	1 0	1 2	2 2	2 5	2 5	3 3
3) GSI	3 2	3 4	3 5	4 4	5 3	5 6	6 1	6 9
4) GLS	0 5	0 8	1 4	2 2	3 1	3 5	4 0	5 1
5) GLI	0 8	1 0	1 6	2 6	3 8	3 9	4 1	5 0
6) PRS	0 5	0 8	1 4	2 3	3 3	3 6	3 7	4 5
7) PRI	0 3	0 6	1 3	2 6	3 6	3 7	4 4	5 6
8) PLS	0 1	0 3	0 9	1 7	2 7	3 0	3 2	4 5
9) PLI	0 2	0 5	0 9	1 8	2 7	3 0	3 0	5 1
Mean	0 7	0 9	1 4	2 3	3 3	3 3	3 9	4 9
S Ed ±	0 80	0 83	0 86	0 93	0 89	0 87	0 81	0 89
CD (0 05)	1 64	1 70	NS	NS	NS	NS	1 66	1 84

1, Refer Table 44

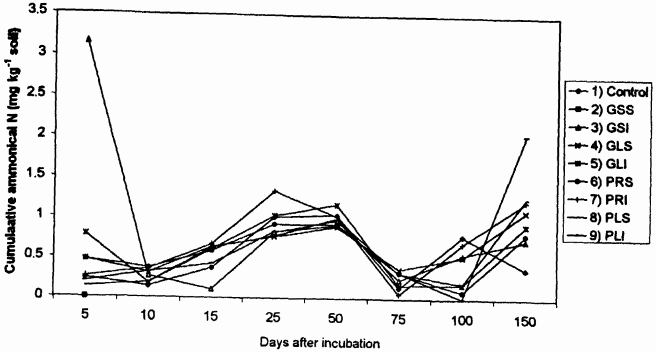


Fig.18: Cumulative NH_4^+ N content of Vertic Inceptisols amended with plant residues *in-vitro* studies

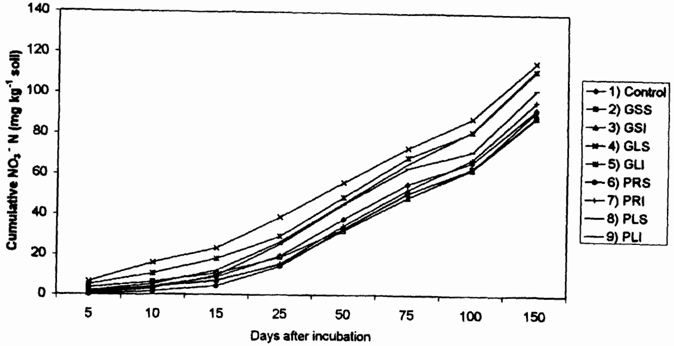


Fig.19: Cumulative nitrate N (NO_3^-) content of Vertic Inceptisols amended with plant residues *in-vitro* studies

observed (5 1 mg kg^{1} soil) with *Glyricidia* leaves amongst the surface levels treatments In case of surface application of *Glyricidia* stem produced only 3 3 mg NH_4^+N kg^{1} soil during 150 days of incubation The surface application of pigeonpea roots, initially mineralization was slow up to 15 days incubation, then it rapidly increased from 25 days after incubation, compared to other treatments Significantly more amount of cumulative NH_4^+N was observed (6 8 mg kg^{1} soil) upon the incorporation of *Glyricidia* stems into the soil amongst the organic residues incorporated A comparatively less amount of NH_4^+ N was measured when *Glyricidia* leaves were incorporated (5 mg NO_3 N kg^{1} soil) after 150 days of incubation

4.10.1.3 Cumulative nitrate nitrogen (NO_3 N) (Table 46, Fig. 19)

Cumulative nitrate nitrogen (NO_3 N) content in incubated soils increased significantly from 3 to 100 mg kg^{1} soil with progressive incubation period from 5 to 150 days with the application of organic residues at surface and incorporation in to the soil (Table 46)

Highest nitrification occurred (1 16 mg NO_3 N kg^{1} soil) when *Glyricidia* leaves were applied at surface level and the lowest nitrification was observed (89 mg NO_3 N kg^{1}) with the surface application of *Glyricidia* stems 150 days after the incubation A higher amount of cumulative NO_3 N was observed (1 12 mg NO_3 N kg^{1}soil) with the incorporation of *Glyricidia* leaves in to the soil compared to the incorporation of organic residues and a less amount N was released at 150 days of incubation (89 mg NO_3 N kg^{1}) soil) when *Glyricidia* stems were incorporated (Table 46)

Table.46: Cumulative nitrate N (NO_3^-) content (mg kg^{-1}) of Vertic Inceptisols amended with *Glyricidia* and Pigeonpea residues *in-vitro* studies during 150 days incubation

Treatment	Incubation period (days)							
	5	**10**	**15**	**25**	**50**	**75**	**100**	**150**
1) Control	1 4	4 1	8 7	19 1	38 0	55 5	66 5	92 7
2) GSS	3 6	6 5	10 6	18 7	32 9	50 8	63 4	89 1
3) GSI	1 6	3 9	7 2	15 0	32 2	48 7	62 9	88 9
4) GLS	6 6	16 1	23 2	38 7	56 2	73 3	88 0	116 1
5) GLI	5 2	10 6	17 9	29 1	49 0	68 7	81 5	111 9
6) PRS	0 1	1 7	4 3	14 2	33 1	51 0	62 9	92 1
7) PRI	2 0	3 7	6 8	15 4	34 6	52 7	68 0	96 6
8) PLS	2 0	5 3	12 0	26 3	45 9	65 7	81 9	112 8
9) PLI	0 6	3 1	9 4	25 3	45 4	63 4	71 6	102 3
Mean	2 6	6 1	11 1	22 4	40 8	58 9	71 9	100 3
S Ed ±	1 17	1 84	2 30	3 71	6 21	7 55	7 94	10 37
CD (0 05)	2 40	3 77	4 73	7 60	12 74	15 49	16 29	NS

1, Refer Table 44

4.10.1.4 N mineralization (N_o) potential of Vertic Inceptisols amended with *Glyricidia* and pigeonpea residues (Table 47).

Nitrogen mineralization potential (N_o) rate constants (K) as estimated by exponential model of the incubated (150 days) soils with organic residues were modeled. The first order exponential model yielded N_o, values ranging from 149 to 496 mg kg^{-1} soil for eight organic residue treatments. Estimated N_o values were highest (496 mg kg^{-1} soil) for pigeonpea root on surface application (PRS) followed by PRI>PLS>GSI>GSS>Control>PLI>GLI>GLS treatments. The first order rate constant of N mineralization (K) varied from 0.0015 to 0.0104 d^{-1}, and was highest in the GLS treatment

Table 47: Nitrogen mineralization potentials (N_o), rate constants (K) as estimated by exponential model of the incubated (150 days) soils amended with *Glyricidia* and pigeonpea residues.

Treatment	Linear Model		Exponential Model			
	K	SE	K	SE	N_o(mg kg^{-1} soil)	SE
1) Control	0.69	0.017	0.0042	0.0013	208	48.6
2) GSS	0.64	0.037	0.0035	0.0033	228	179.3
3) GSI	0.67	0.016	0.0033	0.0013	246	77.1
4)GLS	0.90	0.029	0.0104	0.0010	149	8.6
5) GLI	0.85	0.020	0.0071	0.0007	175	11.0
6) PRS	0.66	0.012	0.0015	0.0009	496	313.2

7) PRI	0.70	0.018	0.0017	0.0015	453	346.9
8) PLS	0.83	0.030	0.0042	0.0020	249	93.5
9) PLI	0.76	0.020	0.0051	0.0014	199	39.9

GSS : *Glyricidia* stem on surface;

GSI : *Glyricidia* stem incorporated;

GLS: *Glyricidia* leaf on surface;

GLI : *Glyricidia* leaf incorporated;

PRS: Pigeonpea root on surface;

PLI: Pigeonpea leaf incorporated.

PLS : Pigeonpea leaf on surface;

PRI : Pigeonpea root incorporated;

4.10.1.5 Time (weeks) required to mineralization of Vertic Inceptisols amended with *Glyricidia* and pigeonpea residues (Table 48)

Organic residue treatments were ranked based on the time required to mineralize a fixed quantity of N from the soil (25 and 50 mg N kg^{-1} soil), as calculated from the linear and exponential models. Time required to mineralize 25 mg N kg^{-1} soil varied from 18 to 34 weeks using the exponential model. Although the two models gave different values for this attribute, the rankings of the cropping systems remained almost the same irrespective of either of the models used. Both models showed that surface application of *Glyricidia* leaves (GLS) required less time to mineralize a fixed quantity of N than the other treatments.

Table 48: Time (weeks) required to mineralize a fixed amount of N in soil with *Glyricidia* and pigeonpea residues incubated at 30^0C using exponential and linear models

Treatment	Rank		Time (wk) required to mineralize (mg N kg^{-1})			
			25		50	
	Linear	Exponential	Linear	Exponential	Linear	Exponential
Control	6	5	36.23	30.65	72.46	65.83
GSS	9	7	38.58	33.18	77.16	70.73
GSI	7	6	37.20	32.48	74.40	68.85
GLS	1	1	27.59	17.66	55.19	39.31
GLI	2	2	29.38	21.71	58.75	47.39
PRS	8	9	37.71	34.48	75.41	70.84
PRI	5	8	35.41	33.39	70.82	68.80
PLS	3	3	30.01	25.19	60.02	53.37
PLI	4	4	32.68	26.32	65.36	56.74

4.10.1.6. Instantaneous rates of N mineralization of Vertic Inceptisols amended with *Glyricidia* and pigeonpea residues (Table 49)

Instantaneous rates of N mineralization for soils were calculated using linear and exponential models. Exponential model rates were initially higher than linear model rates, but reverse was true in the later stages of incubation (after 50 days of incubation). For the treatment where *Glyricidia* leaves were applied at surface the instantaneous rate of N mineralization was far higher than in other treatments at 50 days of incubation but it decreased substantially at 75, 100 and 150 days of incubation period. The zero order rate of N mineralization using the linear model for soil samples varied from 0.65 to 0.91 mg kg^{-1} soil wk^{-1} with a maximum rate of N mineralization for different treatment was in the order: GLS>GLI>PLS>PRI>Control>GSI>PRS>GSS.

Table 49: Instantaneous rate of N mineralization (mg N kg^{-1} soil day^{-1}) in soils from different organic residues treatments using linear and exponential models.

Treatment	Linear Model	Exponential model (days)								
		0	5	10	15	25	50	75	100	150
1) Control	0.69	0.87	0.85	0.84	0.82	0.78	0.71	0.63	0.57	0.46
2) GSS	0.64	0.80	0.78	0.77	0.76	0.73	0.67	0.62	0.56	0.47
3) GSI	0.67	0.81	0.79	0.78	0.77	0.75	0.69	0.63	0.58	0.49
4) GLS	0.90	1.55	1.47	1.40	1.33	1.20	0.92	0.71	0.55	0.33
5) GLI	0.85	1.24	1.19	1.16	1.12	1.04	0.87	0.73	0.61	0.43
6) PRS	0.66	0.74	0.73	0.73	0.72	0.71	0.69	0.66	0.64	0.59
7) PRI	0.70	0.77	0.76	0.75	0.75	0.74	0.71	0.68	0.65	0.60
8) PLS	0.83	1.05	1.04	1.01	0.99	0.95	0.85	0.77	0.69	0.56
9) PLI	0.76	1.02	0.99	0.97	0.95	0.90	0.79	0.70	0.61	0.47

4.11 LAB EXPERIMENT II :

4.11.1 Carbon mineralization (CO_2 evolution) or (Decomposition of organic residues) (Table 50, Fig. 20)

The amount of cumulative CO_2 respired from the incubated soil samples varied significantly with organic residues application, during 24 weeks of incubation in Vertic Inceptisols Mean amount of cumulative CO_2 ranged from 307 to 1466 μg C g^{-1} soil (1 to 24 weeks of incubation period) Compared to control, in all treatments a significantly higher amount of carbon was released, during 24 weeks of incubation Amongst all the treatments significantly highest amount of cumulative CO_2 (1661 μg g^{-1} soil) was respired with pigeonpea leaves when applied at surface to the soil, and lowest amount of cumulative CO_2 (1434 μg g^{-1} soil) was released with *Glyricidia* leaves when incorporated into the soil during the same incubation period Amongst the *Glyricidia* treatments, significantly higher average amount of cumulativeCO_2 was respired with *Glyricidia* stem (1517 μg CO_2 g^{-1} soil) than in *Glyricidia* leaves (1443 μg CO_2 g^{-1} soil) during the same incubation period Amongst the pigeonpea treatments, significantly higher average amount of cumulative carbon was respired with pigeonpea leaves (1592 μg CO_2 g^{-1} soil) compared to the pigeonpea roots (1493 μg CO_2 g^{-1} soil) in an incubation period of 24 weeks

Significantly more amount of cumulative CO_2 was respired (1522 μg CO_2 g^{-1} soil) with pigeonpea leaves when applied at surface of the soil compared to other surface residue applied treatments A lower amount of CO_2 was released (1451 μg CO_2 g^{-1} soil) during 24 weeks of incubation when *Glyricidia* leaves were applied at surface

Amongst the organic residue incorporation treatments, significantly ($P \leq 0.05$) higher amount of CO_2 was released (1661 μg CO_2 g^{-1} soil) due to the incorporation of

Table.50: Effect of *Glyricidia* and pigeonpea residues on cumulative CO_2 ($\mu g\ g^{-1}$ soil) released during 24 weeks incubation period in Vertic Inceptisol.

Treatment	Period of incubation (weeks)								
	1	2	4	6	8	12	16	20	24
1) Control	226	332	480	590	682	856	968	1038	1104
2) GSS	302	429	628	776	899	1109	1248	1377	1464
3) GSI	347	488	723	859	964	1175	1306	1443	1569
4) GLS	367	495	691	821	930	1113	1257	1352	1451
5) GLI	351	433	605	761	872	1055	1197	1300	1435
6) PRS	268	373	584	741	865	1094	1250	1359	1462
7) PRI	266	393	622	799	914	1144	1296	1404	1524
8) PLS	321	458	662	824	911	1124	1284	1395	1522
9) PLI	316	470	704	890	1022	1248	1412	1526	1661
Mean	307	430	633	785	895	1102	1246	1355	1466
S.Ed.±	5.1	6.1	6.7	7.4	16.0	16.4	18.6	20.9	23.8
CD (0.05)	10.5	12.6	13.7	15.2	32.9	33.6	38.2	42.9	48.8

1, Refer Table 44

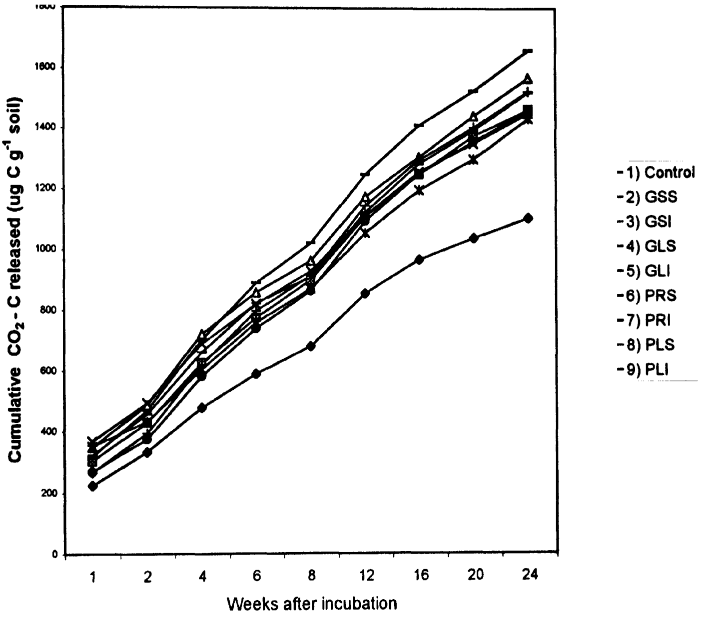


Fig.20: Effect of plant residues on cumulative carbon released during 24 weeks incubation period in Vertic Inceptisols

pigeonpea leaves and a lesser amount (1435 µg CO_2 g^{1} soil) was observed with *Glyricidia* leaves

4.11.2 Carbon mineralization (C_o) potential of Vertic Inceptisols amended with Glyricidia and pigeonpea residues (Table 51)

C mineralization potential (C_o), rate constants (k) and time (wk) required to mineralize a 50% of C_0 as estimated by exponential model of the incubated soil at 30^{0}C with different organic residues were modeled The first order exponential model yielded C_o, values ranging from 1111 to 1654 µg CO_2 g^{1} soil for different organic residue treatments (Table 51) Estimated C_0 values were highest for PL I followed by PRI, PRS, GSI > PLS, GSS > GLI > GLS > control The first order rate constant of C mineralization (k) varied from 0 114 to 0 159 wk^{1}, and was highest in the GLS treatment Time required to mineralize 50% of C_0 varied from 4 to 6 weeks as estimated by the exponential model The surface application of *Glyricidia* leaves (GLS) showed that less time was required to mineralize a 50% of C_0 than the other treatments

Table.51: Carbon mineralization potentials (C_o), rate constants (K) and time required to mineralize50% of C_o as estimated by exponential model of the incubated (24 weeks) soils amended with *Glyricidia* and pigeonpea residues

Treatment	Cumulative CO_2 released during one week	Carbon mineralisation potential (C_o)	Constant (K)	% of C_o mineralisation during one week	Time required to mineralize 50% of C_o
1) CONTROL	225 7	1111	0 133	20 32	5 21
2) GSS	302 0	1470	0 129	20 55	5 37
3) GSI	347 3	1514	0 145	22 94	4 78
4) GLS	367 2	1393	0 159	26 36	4 36
5) GLI	350 5	1397	0 136	25 09	5 10
6) PRS	268 4	1514	0 114	17 73	6 08
7) PRI	265 9	1552	0 120	17 13	5 78
8) PLS	320 9	1495	0 134	21 46	5 17
9) PLI	315 9	1654	0 130	19 10	5 33

1. GSS = *Glyricidia* stem on surface; GSI = *Glyricidia* stem incorporated; GLS = *Glyricidia* leaf on surface; GLI = *Glyricidia* leaf incorporated; PRS = Pigeonpea root on surface; PRI = Pigeonpea root incorporated; PLS = Pigeonpea leaf on surface; PLI = Pigeonpea leaf incorporated

Discussion

CHAPTER V

DISCUSSION

Soybean (*Glycine max L.)* is one of the important oilseed and legume crops largely grown in India on Vertisols and associated soils. Vertic Inceptisols are spread over 60 million ha in India and are prone to severe land degradation due to their position on a toposequence. For sustaining productivity of Vertic Inceptisols in an operational scale watershed at ICRISAT, Patancheru, India, effect of land management practices on soybean intercropped with pigeonpea and soybean + chickpea systems productivity in shallow and medium-deep soils was studied. In these experiments C and N dynamics in soil, nitrogen fixation and N, P and K uptake along with plant growth, nitrogen loss through runoff and VAMF colonization in crop roots were studied. *In vitro* studies, N release pattern from *Glyricidia sepium* and pigeonpea (*Cajanus cajan L.*) residues in Vertic Inceptisols were also studied. The results of two years field experiments (1997 and 1998) and *in vitro* studies are discussed here.

5.1 Weather during 1997 and 1998

Two cropping years (1997 and 1998) when field experiments were conducted in the watershed were distinct climatologically.

In 1997, during the rainy season a total of 523 mm and in the post–rainy season 111 mm rainfall was recorded. In 1997, sowing of rainy season crops was delayed as the rain in the month of June was not sufficient (Table 1, Fig. 3a). Further, a month long break in rainfall occurred from late July to the third week of August which created moisture deficit hence crops suffered from drought during the major part of their crop growth. However, 111 mm rainfall received during post-rainy season resulted in enough soil moisture. The year 1998 was above average in terms of rainfall when a well-distributed rainfall of 1053 mm (5% above average) during the rainy season was recorded. It sufficiently charged soil with moisture at the time of sowing of post-rainy season chickpea crop and a 20 mm rainfall during the crop growing period resulted in a good season.

5.2 Soil chemical and biological properties.

5.2.1 Available N ($NH_4^+ + NO_3^-$)

During rainy and post-rainy seasons of 1997 and 1998 observations on the soil available N in Vertic Inceptisol under soybean, pigeonpea and chickpea crops was influenced significantly by landform, soil depth, cropping systems and their interactions. In the 1997 rainy season, the landform treatments significantly influenced soil available N content measured at presowing and at vegetative stage (36-41 DAS) in sole and intercropped soybean. The flat landform showed a higher available N (13.7 and 9.8) than the BBF landform (13.0 and 8.6) at presowing and vegetative stages (36-41 DAS) respectively in sole and intercropped soybean (Table 6, Fig. 4). These results are in conformity with Saran *et al.* (1996 a) who reported that the mineral N content in a Vertisol at 28 DAS under soybean was highest (10.5) in case of flat landform treatment followed by BBF (8.7). However, during rainy season 1998 (Table 7, Fig. 4) in sole and intercropped soybean at vegetative stage (36-41 DAS), the BBF landform recorded more soil available N content (9.0) than the flat landform (7.7). This might be due to more N loss in flat landform because more rainfall was noticed in this stage during 1998 than compared to the 1997.

During rainy season 1997, in sole and intercropped soybean (at pod development and harvest stages) and in the year 1998 in sole and intercropped soybean (at presowing, pod development and harvest stages), the landform treatments did not significantly influence the available soil N content (Table 6 and 7). During post-rainy seasons 1997 and 1998 in pigeonpea (at pod development and harvest stages) and in chickpea (at presowing, vegetative and harvest stages), the landforms did not vary significantly in available N content (Table 6 and 7). Alagarswamy *et al.* (1996) had similarly reported that the mineral N content in a Vertic Inceptisol from both landform treatments (BBF and flat) was not differed significantly (7.6 to 8.1 μg N g^{-1} soil).

During 1997 rainy season in sole and intercropped soybean available N content in soil was influenced significantly by the soil depth during the crop growth period. The medium-deep soil had a higher available N content than the shallow soil because of more storage of water leads to more mineralization of N in deficit rainfall year. During rainy season of 1998, both in sole and intercropped soybean, the soil depth had no significant effect on the soil available N status. During post-rainy seasons of 1997 and 1998 in pigeonpea and in chickpea, the available N content did not vary with the soil depth. During rainy season of 1997, the sole soybean and soybean / pigeonpea cropping systems significantly influenced the soil mineral N content prior to sowing and of vegetative stages. A higher soil mineral N content was observed in soybean / pigeonpea intercropping system (13.8 and 9.4 μg N g^{-1} soil) compared to sole soybean (12.9 and 8.9 μg N g^{-1} soil) at presowing and vegetative stages respectively. However, during the rainy season 1998, available soil N content was influenced significantly by cropping system treatments during the crop growth period. Sole soybean showed higher mineral N in soil than soybean / pigeonpea intercropping system (Table 7 and Fig. 4). The differences in soil mineral N content observed between the cropping systems were mainly due to differences in rooting patterns, nutrient extraction and intensity of nutrient absorption per unit area under different moisture regimes created by difference in rainfall during 1997 and 1998. .

In pigeonpea at the harvest stage during post-rainy season 1997, landform x soil interaction effect was significant on the soil available N content. The BBF landform on the medium-deep soil recorded the highest available N status where as the flat landform on the shallow soil showed the lowest available N status (Table 16). This might be due to storage of more moisture by BBF and helps for nitrogen release from organic residues, because more quantity of leaf fall occurs at this stage.

The landform x soil depth x cropping system interaction significantly influenced the soil available N content under sole and intercropped soybean. During rainy season 1997, at the presowing, vegetative and at the pod development stages of sole and intercropped soybean, the flat landform on the medium-deep soil with soybean / pigeonpea system resulted in the highest available N content (Table 6). However, during 1998, at both the vegetative and pod development stages of sole and intercropped soybean, the BBF landform on the shallow soil with sole soybean resulted in a higher nitrogen content compared to the other combinations (Table 7). This may be due to heavy rainfall was observed during 1998 than compared to the deficit rainfall year (1997). So BBF reduced the nitrogen loss through runoff and also soybean is a good cover crop which obstructs the direct impact of raindrop so ultimately it reduces the top soil erosion. Singh *et al.* (1999) similarly reported that, soybean is a good cover crop which helps in reducing topsoil erosion and runoff.

Mineral N content in soil under sole and intercropped soybean and chickpea crop varied as the plant growth progressed. During rainy season 1997, in sole and intercropped soybean, a higher mineral N content (13.4 μg N g^{-1} soil) in soil was observed at presowing than compared to vegetative, pod development and harvest stages (Table 6, Fig. 4).

Higher mineral content in soil was noticed at presowing because upward movement of NO_3^-takes place due to capillary movement of water, resulting in increased mineral N concentrations in the top soil layer before the sowing of the rainy season crop supported by Nye and Greenland 1960; Wetselaar 1961 a and b and Wani *et al.*, 1997. Nearly similar results were reported by Wani *et al.* (1996) in legume based cropping systems, the mineral N content in the soil decreased with increasing plant age. Saran *et al.*, (1996 a) observed similarly under soybean-safflower cropping system, soil mineral N content decreased significantly with increasing plant age and highest mineral N content was observed prior to sowing. In the present experiment during the 1997 post-rainy season in chickpea, mean soil N content increased from 6.5 μg N g^{-1} soil at presowing to 12.5 μg N g^{-1} soil at the vegetative stage of the crop. Similar results were observed by Alagarswamy *et al.* (1996) in soybean. During the 1998 post-rainy season, mean mineral N content in soil under chickpea crop showed an increase from presowing (5.5 μg N g^{-1} soil) to harvesting stage (7.2 μg N g^{-1} soil) and then it decreased to 5.5 μg N g^{-1} soil at the harvest stage. These results are also in conformity with Deshmukh *et al.* (1996), who reported that mean mineral N content in soil increased up to harvesting stage of mungbean from presowing of the crop.

5.2.2 Net N mineralization

Net N mineralization in the soil under sole and intercropped soybean was changed significantly due to landform treatments at prior to sowing during 1998 (Table 9, Fig. 5). The BBF landform mineralized more net N (5.5 μg N g^{-1} soil $10d^{-1}$) compared to the flat (4.3 μg N g^{-1} soil $10d^{-1}$). In pigeonpea during harvesting stage in 1997, net N mineralized in the soil was affected by soil depth treatment (Tab 16). The medium-deep soil showed higher (5.5 μg N g^{-1} soil $10d^{-1}$) net N mineralization compared with the shallow soil (4.2 μg N g^{-1} soil $10d^{-1}$). However, during the rainy and post-rainy seasons of 1997 and 1998 under sole and intercropped soybean, pigeonpea and chickpea, the net N mineralization did not significantly differ in landform systems and soil depth treatments at different stages of crop growth period. These results are in conformity with Alagarswamy et al. (1996) and Saran et al. (1996 a), who reported that the amount of net N mineralized in Vertic Inceptisol under soybean was similar in BBF and flat landform treatments.

Landform x soil depth interaction significantly changed the net N mineralization in the soil under sole and intercropped soybean and pigeonpea. A significantly more amount of net N mineralization was observed under the BBF landform on the medium-deep soil at the vegetative stages of sole and intercropped soybean, during rainy season 1998 (Table 9) and in pigeonpea crop at the harvest stage in 1997. Landform x soil depth x cropping system interaction significantly influenced the soil net N mineralization under sole and intercropped soybean at the vegetative stages in 1998. A significantly more net

N mineralization in soil was observed under the sole soybean grown on BBF landform on the medium-deep soil. This might be due to more moisture influenced the conversion of organic form of nitrogen to inorganic form. In our present investigation during the rainy seasons, the amount of net N mineralized at the vegetative stage under sole and intercropped soybean was 8 times more during 1997 and 1.2 times more during 1998 than the amount of N mineralized in soil observed prior to the sowing of soybean. Then the amount of net N mineralized decreased from the vegetative to the harvest stages. Similar results were reported by Alagarswamy et al. (1996) in a Vertic Inceptisol under soybean.

During post-rainy season 1997 in chickpea the net N mineralization in soil was similar to that in samples collected prior to sowing and at harvesting stage, and showed a decrease at the vegetative stage. Similar results were observed by Wani *et al.* (1996) under legume based cropping systems.

5.2.3 Soil respiration (μg C g^{-1} soil $10d^{-1}$)

The amount of carbon respired from the soil under soybean, pigeonpea and chickpea was influenced significantly by landform and soil depth treatments during both the years of investigation. Flat landform resulted in significantly more soil respiration than the BBF in Vertic Inceptisol in sole and intercropped soybean (at vegetative and pod development stage during 1997 and at harvesting stage in 1998). This might be due to congenial conditions during rainy season, takes place under flat landform for activities for soil micro-organisms, so it respired the more amount of carbon.

The landform treatments did not vary significantly the soil respiration in the Vertic Inceptisol under sole and intercropped soybean (at harvesting stage, 1997 and at presowing, vegetative and pod development stages, 1998), pigeonpea (during 1997 and at pod development stage, 1998) and chickpea (during 1997 and at vegetative and harvesting stages, 1998). Alagarswamy et al. (1996), reported that the soil respiration in Vertic Inceptisol under soybean crop was not influenced significantly by the flat or BBF landform treatments.

It was observed that the medium-deep soil released more carbon than compared to the shallow soil under sole and intercropped soybean, pigeonpea and chickpea crops during both the years of investigation. This might be due to medium-deep Vertic Inceptisol (50-90 cm) stored more amount of moisture, sufficient for microbial activity (bacterial, fungal and protozoan cells) throughout rainy and post-rainy seasons.

The soil respiration was influenced by the cropping systems. Significantly, higher amount of C was respired in sole soybean (64 μg C g^{-1} soil 10 d^{-1}) than soybean / pigeonpea (50 μg C g^{-1} soil 10 d^{-1}) during rainy season 1997 (Table 10, Fig. 6). Patil *et al.* (1996) reported similar results on soil respiration as influenced by the cropping systems in Vertisols.

In 1997 and 1998 during post-rainy season, the medium-deep soil under BBF landform released the highest amount of carbon at the pod development stage of pigeonpea and at both the vegetative, harvest stages of chickpea. This might be due to more moisture which was available under BBF on the medium-deep soil during post-rainy season. This is sufficient for decomposition of organic residues and also favourable conditions taking place under this BBF for microbial activities. Landform x soil depth x cropping system interaction effect was significant on the soil respiration under sole and intercropped soybean. The soil under flat landform on the medium-deep soil with soybean / pigeonpea showed a higher soil respiration at the vegetative stage in 1997 and at the harvest stage in 1998 because of favourable moisture and aeration.

The amount of carbon respired from the soil under sole and intercropped soybean was influenced by plant growth (Tab 10). Mean soil respiration decreased from 148 μg C g^{-1} soil 10 d^{-1} for presowing samples to for the samples collected at vegetative stage (36-41 DAS) then increased to at pod development stage (71-75 DAS) and again decreased to 58 μg C g^{-1} soil $10d^{-1}$ at harvesting stage (96-112 DAS) during the rainy season of 1997. These results are in conformity with Saran *et al.* (1996 b), who reported under soybean crop mean soil respiration decreased from presowing samples to 39 DAS and then increased up to 98 DAS.

During rainy season 1998 in sole and intercropped soybean the amount of C released from the soil varied at various plant growth stages (Table 11). Highest mean amount of soil respiration (135 μg C g^{-1} soil 10 d^{-1}) was observed at pod development stage (71-75 DAS) and it was followed by maturity stage, > vegetative stage > presowing stage. Alagarswamy et al. (1996) observed similarly in Vertic Inceptisol under soybean crop at different crop growth periods with the highest amount of soil respiration at 95 DAS and it was followed by harvesting stage and presowing stage ≥ 72 DAS and ≥ 35 DAS.

During post-rainy season of 1998, under chickpea crop the soil respiration changed due to plant growth stage (Table 18). Mean soil respiration decreased with the increasing crop age up to the harvesting of the chickpea crop. This might be due to during post-rainy season soil moisture decreased with the increasing crop age and more leaf fall occurs at the harvest stage and moisture is not sufficient for decomposition of entire residues (leaf fall).

5.2.4 Microbial biomass C and N:

Landform treatments did not significantly affect the soil microbial biomass C and N under sole and intercropped soybean, pigeonpea and chickpea crops at their different crop growth stages in the two years of experimentation. Similar findings have been reported by Alagarswamy *et al.* (1996), who reported that the soil microbial biomass C and N was not influenced by the BBF and flat landform treatments. Saran et al. (1996 a) reported that the microbial biomass N was not influenced by the BBF and flat landform treatments.

Soil depth had significant effect on the soil microbial biomass C and N under sole and intercropped soybean [biomass C at harvesting stage in 1997, biomass N at pod development stage in 1997 and at presowing, pod development and harvesting stages in 1998], under pigeonpea biomass C and N at harvesting stage, 1998) and chickpea crops (biomass C at presowing in 1997 and biomass N (at presowing and harvesting stage in 1998). Significantly higher microbial biomass C and N was observed in the medium-deep Vertic Inceptisol compared to the shallow soil because of favourable moisture conditions for soil microbial proliferation.

Soil microbial biomass C and N was significantly influenced by the interaction of landform x soil depth treatments, in sole and intercropped soybean, pigeonpea and chickpea. The flat landform on the medium-deep soil showed the highest amount of microbial biomass C and N content at all the stages of sole and intercropped soybean where as the BBF landform on the shallow soil recorded the lowest amount of microbial biomass C and N at all the stages of sole and intercropped soybean. During post-rainy season 1998, at the harvest of pigeonpea and at the pod development stage of the chickpea, the BBF landform on the medium-deep soil showed the highest microbial biomass C and N content This might be due to seasonal rainfall effect, during rainy season more rainfall occurs, so flat landform on the medium-deep soil influenced favourable conditions for microbial activities However, during post-rainy season BBF on the medium-deep soil stored enough moisture for activities of soil micro-organisms

Landform x soil depth x cropping system interaction effect was significant on the soil microbial biomass C in sole and intercropped soybean The flat landform on the medium-deep soil with soybean / pigeonpea system showed a higher microbial biomass C during the different stages of the crop growth period in 1997 and 1998 because of favourable moisture and aeration conditions during rainy season

The microbial biomass C and N content in soil varied as the crop growth progressed during the two years of investigation Mean microbial biomass C and N in soil was highest (21 1 μg N g^{-1}) prior to the sowing of the crop and it then decreased as the plant aged till the harvest of the sole and intercropped soybean (15 0 μg N g^{-1} soil) during rainy season of 1997 (Table 12 and 14, Fig 7 and 8) The results are in conformity with Saran et al (1996 b) who reported that the microbial biomass C and N was highest prior to sowing of the crop and then it decreased with the plant age till the harvest of the soybean crop under deficit rainfall conditions During the rainy season of 1998 mean microbial biomass C and N in the soil under sole and intercropped soybean was higher at 55.0 μg N g^{-1} soil at pod development stage (71-75 DAS) compared to the rest of the crop growth stages (Table 13 and 15; Fig. 7 and 8). Alagarswamy *et al.* (1996) reported similarly that soil microbial biomass C and N was higher at 95 DAS than compared to the other crop growth stages in soybean. The soil microbial biomass N content increased at different stages of chickpea crop growth. It was highest at the harvest stage (105-113 DAS) of chickpea grown in the 1997 rainy season (Table 17). Wani *et al.* (1991a) also observed that the soil microbial biomass N content showed an increase at different stages of barley growth. They noted the highest biomass N at 102 days after emergence.

5.3 Biological nitrogen fixation

5.3.1 Nodulation and nitrogenase activity of crops

5.3.1.1. Nodule number

Landform treatments significantly affected the nodulation at vegetative stage (36 DAS) of soybean during the rainy season of 1998 in our experiment (Table 20, Fig. 9). Soybean grown on BBF landform showed a significantly more number of nodules (705m^{-2}) compared to the flat landform treatment (306 m^{-2}). BBF landform influenced marginally higher number of nodules (1.1 times more) than the flat landform in soybean at vegetative stage (1997) and at pod development stage (1998) during rainy season (Table 19 and 20). These results are in line with Wani *et al.* (1995 b), who reported that the nodulation in soybean grown on broadbed and furrows (BBF) on Vertisols was better than when the crops grown on a flat surface. Saran *et al.* (1996 a) reported similar results, the nodule number of soybean at 28 DAS was higher in the BBF landform system than the flat landform system in Vertisols. Alagarswamy et al. (1996) reported that the soybean nodulation was highest in the BBF landform compared to the flat landform treatment.

Landform treatments had no significant effect on the nodule number in pigeonpea during both the years of investigation. However, pigeonpea grown on BBF showed marginally more nodules than the flat landform (Table 21 and 22). Similar results were recorded by Wani *et al.* (1995 b), on the nodulation in pigeonpea grown on BBF in Vertisols than when grown on a flat surface. During the post-rainy seasons of 1997 and 1998, landform systems did not influence significantly the nodule number in chickpea. Rupela and Saxena (1987) have noted in Vertisols that chickpea grown on flat beds nodulated better than those grown on ridges with the same sowing density.

Soil depth varied the nodule number significantly in soybean (at vegetative and pod development stages in 1998) and chickpea (at flowering, pod development stages in 1997 and at vegetative stage in 1998). Medium deep soil influenced nodules number maximally compared to the shallow soil in soybean and chickpea. This might be due to favourable soil moisture conditions. Nambiar *et al.* (1988) reported that moisture plays an important role in ensuring migration of rhizobia applied to the seed coat, to the root zone, where they are required to infect the roots and form nodules.

Landform x soil depth interaction significantly changed the nodule number in sole and intercropped soybean, pigeonpea and in chickpea crops. The BBF landform on the medium-deep soil showed a significantly more nodule number at the vegetative stages of soybean and chickpea in 1998 (Table 20 and 24), and at the flowering stage of chickpea in 1997 (Table 23). The BBF landform on the shallow soil recorded more number of nodules at the flowering stages of chickpea (in 1998) and pigeonpea (in 1997) (Table 24 and 21). In soybean, the flat landform on the shallow soil showed a lesser number of nodules at the vegetative stage during rainy season 1998, and in chickpea at the vegetative, flowering stages in 1998 and at the pod development stages in 1997. This might be due to moisture differences, BBF landform drain the excess water during rainy season and stored the moisture during pos-rainy season, helps for better nodulation of the crops. Nambiar et al. (1988) reported the environmental factors could greatly influence nodule formation.

The number of soybean nodules increased with plant age during both the years of investigation. Mean nodule number increased from vegetative stage (431 and 506 m^{-2}) to pod development stage (1614 and 1865 m^{-2}) in soybean during 1997 and 1998 cropping seasons (Table 19 and 20). Algarswamy *et al.* (1996) has observed similarly that the nodule number in soybean increased with the plant age up to 70 DAS (i.e., early podding stage) and then declined marginally towards pod maturity. Van Lieu *et al.* (1996) had also similarly reported that the nodulation in soybean at pod formation stage was good.

5.3.1.2 Nodule weight

During 1998 rainy season, soybean crop grown on BBF landform has put on significantly more weight of nodules (2.2 times) than that of flat landform system during vegetative stage of the crop growth (Table20, Fig. 9). Algarswamy *et al.* (1996) and Saran *et al.* (1996 a) have also reported that the soybean nodule weight was highest in the BBF landform compared to the flat landform treatment.

Soil depth had a significant effect on the nodule weight in soybean (at vegetative and pod development stages in 1998) and in chickpea (at flowering, pod development stages in 1997 and at vegetative stage in 1998). In the medium-deep soil soybean and chickpea plants produced more nodules than in the shallow soil because of favourable moisture and nutrient availability conditions.

Cropping system treatments affected the nodule weight significantly in soybean crop. Sole soybean crop showed a significantly more nodule weight (2703 mg m^{-2}) than the intercropped soybean (1878 mg m^{-2}) during pod development stage (Table 19). This might be due to more competition for nutrients and moisture between the two crops in intercropping system than the sole cropping system.

In chickpea crop, the BBF landform on the medium-deep Vertic Inceptisol had the maximum nodule weight during the flowering and pod development stages in 1997 and at the vegetative stage in 1998 (Table 23 and 24) during post-rainy season because of optimum moisture conditions.

In soybean nodule weight increased from vegetative to pod development stage by eight times during 1997 (Table 19) and by 13 times during 1998 (Table 20). Similar findings have been reported by Algarswamy et al. (1996). They observed that the nodule mass in soybean increased with plant age upto early podding stage. Van Lieu et al. (1996) had also observed that the nodule mass in soybean at pod formation stage was good.

The nodule number and nodule weight in pigeonpea at vegetative stage (70 DAS) were highest during both the years of the experiment (Table 21 and 22). In chickpea, the nodule number and nodule weight were highest at flowering stage during 1997 and at vegetative stage during 1998 and decrease at harvest because of decrease in moisture content in post-rainy season.

5.3.1.3. Nitrogenase activity:

Landform treatments did not significantly vary the nitrogenase activity in soybean, pigeonpea and chickpea during two years of investigations. However, marginally higher nitrogenase activity was recorded in BBF landform than flat landform. These results are in conformity with Saran *et al.* (1996 a), who reported highest nitrogenase activity in soybean under BBF landform compared to the flat landform treatment in a Vertisol. Alagarswamy *et al.* (1996) also observed that the effect of land configuration on nitrogenase activity of soybean was not significant.

Soil depth had a significant effect on nitrogenase activity of soybean (during 1998) and chickpea (at vegetative stage in 1998) during crop growth periods. Significantly higher nitrogenase activity was recorded when the crop was grown on medium-deep soil compared to the shallow soil.

Cropping system treatments significantly varied the nitrogenase activity of soybean at pod development stage (70 DAS) during 1997 (Table 1). Sole soybean had higher nitrogenase activity (195.0 μmol $C_2 H_4 m^{-2} h^{-1}$) compared to the intercropped soybean (84.3 μmol $C_2 H_4 m^{-2} h^{-1}$). This might be due to more number of nodules under sole soybean compared to intercropped soybean.

Landform x soil depth interaction effect was significant on nitrogenase activity of sole and intercropped soybean, pigeonpea and chickpea crops. At both the vegetative and pod development stages of sole and intercropped soybean (Table 1) and at both the vegetative and flowering stages of pigeonpea (Fig.2b), the BBF landform on the shallow soil recorded more nitrogenase activity during 1997. However, during rainy season 1998, in sole and intercropped soybean at both the vegetative and pod development stages, the

BBF landform on the medium-deep soil showed the highest nitrogenase activity (Table 2) because of variability in rainfall pattern in 1997 and 1998

Nitrogenase activity was influenced by plant growth in soybean, pigeonpea and chickpea crops. In soybean mean nitrogenase activity increased 17 times during 1997 and 5 times during 1998 from vegetative to pod development stage (Table 1 and 2). Similarly Nambiar and Dart (1983) reported nitrogen fixation peaked during the pod filling stage and declined at maturity In pigeonpea, highest mean nitrogenase activity was observed at vegetative stage (70 DAS) during both the years of investigations compared to flowering stage (data not included) Similarly Kumar Rao and Dart (1987) reported that soil moisture deficit might be one of the reasons for the cessation of nitrogenase activity by 100 DAS of pigeonpea In chickpea crop mean nitrogenase activity increased 19 times from vegetative stage to flowering stage and then decreased at pod development stage during 1997 (data not included) However, during 1998 in chickpea crop mean nitrogenase activity decreased to 184 times from vegetative to pod development stage of the crop The differences in nitrogenase activity trend during the crop growing period between two years, mainly due to soil moisture differences. Similarly Nambiar *et al* (1988) reported crops grown on residual moisture, the differences in nitrogenase activity might be due to moisture difference during the crop growth period

During rainy season of 1998, in soybean crop specific nitrogenase activity was influenced significantly by soil depth (Table 2) Medium-deep soil showed a significantly more specific nitrogenase activity (40 9 μmol $C_2 H_4$ g^{-1} nodule h^{-1})

compared to the shallow depth soil (22.1 μmol C_2H_4 g^{-1} nodule h^{-1}) because of favourable moisture conditions in rainy season.

5.3.2 N-difference and ^{15}N isotope dilution methods

5.3.2.1 Nitrogen fixed

N fixed by soybean and chickpea as estimated by N-difference and ^{15}N isotope dilution methods using sorghum as non fixing plant, was not affected significantly by landforms (e.g., flat and BBF) during both the years of investigation (Table 25 and 26, Fig. 11). However, the effects of land configuration on N fixed by pigeonpea as estimated with ^{15}N-difference and N isotope dilution methods, were significant during 1998 (Table 26). Pigeonpea grown on BBF landform fixed higher amount of N (73 kg ha^{-1} and 97 kg ha^{-1}) when compared to N fixed on flat landform (49 kg ha^{-1} and 73 kg ha^{-1}) as estimated with ^{15}N difference and N isotope dilution methods respectively (Table 26). Alagarswamy *et al.* (1996) observed the BBF landform fixed a marginally higher amount of N (185 kg ha^{-1}) than the flat landform treatment (172 kg N ha^{-1}).

Soil depth had a significant effect on the amount of N fixed by soybean (during 1998) and chickpea (during both years) as estimated with N-difference method, soybean crop in the medium-deep soil fixed more amount of N than on the shallow soil during 1998 (1.85 times more). Similarly chickpea fixed N during 1997 and 1998 (1.40 and 1.53 times more) in medium-deep soils. Alagarswamy *et al.* (1996), reported that soybean grown on medium-deep soil fixed higher amount of N compared to the soil with a shallow depth.

Cropping system treatments significantly affected the amount of N fixed by soybean as estimated by N-difference and ^{15}N isotope dilution methods (Table 25, Fig.

11). Sole soybean fixed more nitrogen (58 and 22 kg ha^{-1}) than the intercropped soybean (16 and 15 kg ha^{-1}) as estimated by N-difference method during 1997 and 1998 respectively. Similarly, sole soybean fixed higher nitrogen (35 kg ha^{-1}) than the intercropped soybean (14 kg ha^{-1}) as estimated with ^{15}N isotope dilution method during 1997.

Landform x soil depth interaction effect was significant on nitrogen fixed by soybean and by chickpea (in 1997 and 1998) as estimated by N-difference method. The BBF landform on the medium-deep soil showed the highest nitrogen fixed by soybean and by chickpea (Table 25 and 26). In pigeonpea crop also the BBF landform on the medium-deep soil recorded the highest N-fixed as estimated by both the N-difference and ^{15}N isotope dilution methods during 1998 (Table 26). This might be due to the BBF landform increasing infiltration of water into the soil and increased soil water content of the medium-deep soil.

The nitrogen fixation rates as estimated with N-difference methods were 38 and 19 kg ha^{-1}; in soybean 76 and 61 kg ha^{-1} in pigeonpea and 28 and 19 kg ha^{-1} in chickpea during 1997 and 1998 respectively. The nitrogen fixation rates as estimated with ^{15}N isotope dilution method were 40 and 45 kg ha^{-1} in soybean; 75 and 85 kg ha^{-1} in pigeonpea; 15 and 11 kg ha^{-1} in chickpea during 1997 and 1998 respectively.

Gibson *et al.* (1982) reported that the amount of nitrogen fixed by soybean in India was 102 kg ha^{-1}. Schroder (1990) estimated the biological nitrogen fixation in soybean was 88 kg N ha^{-1}, in pigeonpea 224 kg N ha^{-1} and in chickpea 104 kg N ha^{-1}. Wani et al. (1995a) reported that the amount N fixed by soybean (128-312 kg N ha^{-1} season^{-1}), pigeonpea (4-53 kg N ha^{-1} season^{-1}) and chickpea (23-40 kg N ha^{-1} season^{-1}).

Alagarswamy *et al.* (1996) observed that soybean crop fixed (179 kg N ha^{-1}) through BNF as estimated by N-difference method.

5.3.2.2 Percent N derived from atmosphere (%Ndfa)

The proportion of N fixed by soybean, pigeonpea and chickpea using N-difference method was not influenced significantly by landform treatments during both the years of investigation. In soybean the N-fixation changed significantly in response to soil depth treatment during rainy season 1998 (Table 25, Fig. 11). The medium-deep soil had a higher proportion of N fixation (21%) than the shallow soil (12%). However, the proportion of N fixed by soybean varied due to cropping system treatment during rainy season 1997, higher nitrogen fixation (35%) was found in sole soybean crop than compared to the intercropped soybean (15%). The proportion of N-fixation using N-difference method, was influenced significantly by landform x soil depth interaction in soybean (during 1998) and in chickpea (during 1997). The BBF landform on the medium-deep soil influenced the highest proportion of nitrogen fixation. The interaction of landform x soil depth x cropping system significantly changed the proportion of N fixed by soybean using N-difference method during both the years of investigation (Table 26, Fig. 11). Highest proportion of N fixation was observed in sole soybean grown on BBF landform on medium-deep soil. The relative nitrogen derived from atmosphere (% Ndfa) by soybean were 24% and 17%, by pigeonpea were 79% and 66% and by chickpea were 54% and 54% during 1997 and 1998 respectively in our experiments. Peoples and Herridge (1990) reported the percent nitrogen derived from atmosphere (% Ndfa) ranged from 0 to 95 for soybean, 10 to 88 for pigeonpea and 17 to 85 for chickpea under sole cropping system and the % Ndfa in intercropped pigeonpea ranged from 65 to 96.

5.4 Nutrient (N, P and K) uptake of crops

The uptake of N, P and K by soybean, pigeonpea and chickpea were significantly influenced by landform, soil depth and cropping system treatments at different stages of the crop growth period during rainy and post-rainy seasons 1997 and 1998.

5.4.1. N Uptake

BBF landform significantly showed more N uptake than the flat landform at the harvest stage of soybean (1997), in pigeonpea at flowering and harvest stages (1998) and in chickpea at the vegetative stage (1997). This might be due to the increased moisture storage which in turn facilitated more root proliferation and higher drymatter production. Veerabadran (1989) observed similarly in Vertisols, when crops grown on BBF system recorded higher N uptake than flat landform.

N uptake by crops was significantly influenced by soil depth. Significantly the medium-deep soil showed more N uptake than shallow soil in soybean, pigeonpea at both the vegetative and flowering stage in 1997 and in chickpea at the pod development stage (1997). This might be due to the increased moisture storage which in turn facilitated for more root proliferation and drymatter production.

Cropping system treatment had a significant effect on the uptake of N by soybean. More N uptake was recorded in sole soybean than intercropped soybean at the harvest stage during 1997 and 1998. This might be due to more drymatter production in sole soybean than intercropping system.

5.4.2. P Uptake

The uptake of P by soybean, pigeonpea and chickpea crops varied significantly due to landform, soil depth and cropping system treatments. Maximum P uptake was observed in case of BBF landform compared to the flat landform in soybean crop at harvest stage during 1997 and in pigeonpea at pod development stage during 1997 and at flowering, pod development, harvesting stages during 1998. This might be due to high moisture regime coupled with drymatter production than in flat. Similarly Veerabadran (1989) and Selvaraju (1994) reported that crops grown in BBF system recorded higher P uptake.

Soil depth had a significant effect on the uptake of P by soybean, pigeonpea and chickpea crops. During rainy season in soybean, shallow soil depth increased P uptake (at harvest stage, 1997 and at pod development stage, 1998) compared to medium-deep Vertic Inceptisol. However, pigeonpea grown in medium-deep soil recorded significantly higher P uptake [at vegetative stage 36-42 DAS, 1997]. In chickpea at pod development and harvesting stages, 1997 and at harvesting stage, 1998 similarly a higher P uptake was recorded in medium-deep soil compared to the crop grown in soil having a shallow depth. These differences in P uptake by crops between the two seasons might be due to moisture fluctuations in soil. Significantly more P uptake was found in sole soybean than the intercropped soybean at harvest stages during the experiments conducted in 1997 and 1998. This might be due to the more drymatter production in sole soybean.

5.4.3 K uptake:

The uptake of K by soybean, pigeonpea and chickpea at harvest stage, was significantly influenced by landforms, soil depths and cropping systems. BBF landform resulted in a significantly higher uptake of K by soybean during 1997 and by pigeonpea during 1998, compared to the crops grown on flat landform. This might be due to BBF influenced more K uptake. Similarly Veerabadran (1989) and Selvaraju (1994) reported, BBF system recorded higher K uptake. K uptake of pigeonpea in the medium-deep Vertic Inceptisol during 1997 and by chickpea during 1997 and 1998 was higher than the crops grown in the shallow soil. This might be due to the increased moisture storage which in turn facilitated for more root proliferation and drymatter production.

Inclusion of soybean, cropping systems had a significant effect on K uptake. Maximum K uptake was observed in case of sole soybean compared to intercropped soybean during both the years of investigation.

Based on the studies of nutrient uptake, it was noted that landforms, soil depth and cropping systems significantly affected uptake of nutrients by soybean, pigeonpea and chickpea crops only at a few stages of their growth and development. Alagarswamy et al (1996) reported the uptake N, P and K by soybean were not influenced significantly by the landform treatments (BBF and flat).

Landform x soil depth interaction significantly influence the nutrient uptake by soybean, pigeonpea and chickpea. The BBF landform on the medium-deep recorded the maximum N, P and K uptake by chickpea at the harvest stage during both the years, N uptake by pigeonpea at the harvest stage (in 1998) and K uptake by soybean at the harvest stage (in 1997). This might be due to the availability of more moisture under

BBF landform on the medium-deep soil, so this favours the higher drymatter production ultimately more N, P and K by the crops.

During the two years of investigation, the uptake of N and P by soybean, pigeonpea and chickpea showed a linear increase with crop growth and development up to the pod development stage and then decreased at the harvest. Similar results were reported by Alagarswamy *et al.* (1996) on the uptake of N and P which showed a linear increase up to 70 DAS of crop growth in soybean.

5.5 Runoff

The 1998 rainy season was characterized by a large number of medium-intensity long-duration rain storms and therefore a relatively high runoff was recorded in all the land management systems. Total seasonal runoff from the BBF system was considerably lower when compared with flat landform system on both the shallow and medium-deep Vertic Inceptisols (Table 34). Average runoff observed on flat was higher (33% of seasonal rainfall) compared to the BBF landform treatment (26% of seasonal rainfall). Average NO_3^- loss observed on flat landform treatment was higher (13.5 kg N ha^{-1}) compared to the BBF landform treatment (9.8 kg N ha-1). These results are in conformity with the results reported by Piara Singh *et al.* (1999) that total runoff was higher on flat (28% of seasonal rainfall) compared to BBF (21% seasonal rainfall) on Vertic soil. Pathak *et al.* (1983) Srivastava and Jangawad (1988), Gupta and Sharma (1994), Alagarswamy *et al.* (1996) and Sharma and Parmar (1997) have also reported that the surface runoff from the BBF landform system was lower when compared with flat landform system, because the BBF landform increased rainfall infiltration into the soil.

5.6 Nutrient balance (N, P and K)

The N, P and K balance was estimated by taking into account all the available data relating to the inputs and outputs of nutrients in the soil-plant atmosphere system, under soybean/pigeonpea and soybean+chickpea cropping systems grown on flat and BBF landforms on shallow and medium-deep Vertic Inceptisols during 1997 and 1998. (Appendix I and II)

5.6.1 N balance (kg ha^{-1}) by ^{15}N isotope dilution method (Table 35)

Nitrogen fixation values used as inputs for N balance were estimated with ^{15}N isotope dilution method. The nitrogen balance varied due to landform, soil depth and cropping system treatments and their interactions. Averaged over the two years, a lower negative N balance (-6 kg ha^{-1}) was observed under the BBF landform than the flat bed system (-77 kg ha^{-1}). This may be ascribed to lower loss of nitrogen through runoff and deep drainage in BBF and also nitrogen was added in to the soil through *Glyricidia* and FYM applied in the BBF landforms only. Negative nitrogen balance on both landforms is due to a higher nitrogen uptake by crops. In case of soil depth, average values for the two years showed a lower negative nitrogen balance for the medium-deep soil (-75 kg ha^{-1}) than the shallow soil (-83 kg ha^{-1}). In case of cropping systems, average values for the two years showed negative nitrogen balance (-39 kg ha^{-1}) under the intercropping (soybean / pigeonpea) system than the sequential (soybean + chickpea) cropping system. Similarly Kundu *et al.* (1996) reported a negative N balance in soybean on Vertisols. It may be concluded that cultivation of soybean apparently leaves a negative N balance in the soil.

5.6.2 N balance (kg ha^{-1}) by N-difference method (Table 35)

Nitrogen fixation values used as inputs for N balance, estimated with N-difference method, showed that the nitrogen balance varied due to landform, soil depth and cropping system treatments and their interactions. Averaged over the two years, the BBF system increased the nitrogen balance (+55 kg ha^{-1}) but flat landform had the negative N balance (-19 kg ha^{-1}). This may be attributed to lower loss of nitrogen through runoff and deep drainage in BBF plus additional nitrogen was added in to the soil through applications of *Glyricidia* and FYM. Average values for the two years, on the effect of soil depth showed a higher positive N balance for the medium-deep soil (+21 kg ha^{-1}) than the shallow soil (+16 kg ha^{-1}). In case of cropping systems, average values of the two years for the soybean and chickpea (sequential) cropping system a higher positive nitrogen balance (+34 kg ha^{-1}) was noted than the soybean / pigeonpea (intercrop) system (+3 kg ha^{-1}). This might be due to the more amount nitrogen fixed by soybean and chickpea crop in sequential system through biological nitrogen fixation.

5.6.3 P balance

The phosphorus balance was calculated under soybean + chickpea and soybean / pigeonpea systems grown on flat and BBF landforms on the shallow and medium-deep soils by adding different sources of P (inputs) into the soil and crop removal of P from the soil (Appendix 4) Averaged values for the two years showed that BBF landform had a maximum positive P balance (+18 kg ha^{1}) compared with flat landform (+12 kg ha^{-1}) There was no marked difference in the balance of available P in the soil due to soil depth (+ 15 kg ha^{1} for both soils) In case of intercropping system (soybean / pigeonpea) marginally higher positive N balance (+15 kg ha^{1}) was recorded than the soybean + chickpea system (+14 kg ha^{1}) In our results, a positive phosphorus balance was observed in all the treatments this could be mainly attributed to the phosphorus solubilization from native soil sources due to VAM fungi Similar findings were reported by Bolan (1991), who found that mycorrhizae influence the solubilization of soil P through the release of organic acids and phosphate enzymes

5.6.4 K balance

The potassium balance was estimated for soybean / pigeonpea and soybean + chickpea systems grown on flat and BBF landforms on shallow and medium-deep soils by adding different sources of K (inputs) in the soil and output of K from the soil (Appendix 5) The available net K showed negative balance in all the treatments (Table 37) According to averaged values for the 1997 and 1998, the depletion of K was more (-48 kg ha^{1}) in case of flat landform than the BBF (-42 kg ha^{1}) Higher negative K balance was recorded in the medium-deep soil (-49 kg ha^{1}) compared to the shallow soil (-42 kg ha^{1}) In case of cropping system, soybean + chickpea depleted the higher K (-51 0 kg ha^{1}) than that of intercropping system (-50 0 kg ha^{1}) This negative balance could be mainly attributed to more removal of K from soil by the crop Similar findings were reported by Dubey (1999) in soybean on Vertisols

5.7 Crop yields

5.7.1 Soybean

During 1997 rainy season total dry matter yield of soybean was significantly influenced by landforms but seed yield remained unaffected Highest total dry matter (2651 kg ha^{1}) and seed (906 kg ha^{1}) yields of soybean were observed under the BBF landform on the Vertic Inceptisols The lowest dry matter (2413 kg ha^{1}) and seed yields (831 kg ha^{1}) were recorded when the crop was grown on the flat landform Saran et al (1996b) had similarly obtained higher soybean grain yields in BBF landform in a Vertisol compared to the flat landform during rainy season of 1994, in Indore Klaij et al (1996) also recorded increased grain and straw yields of wheat under BBF landform and lowest yields under flat landform in the Vertisols of Ethiopian highlands Ingle *et al* (1999) reported higher seed yield of soybean on the BBF landform system than on the flatbeds

In the present investigations during the rainy season of 1998 the seed and drymatter yields of soybean did not vary significantly in the two landform treatments (Table 38, Fig 15) Alagarswamy et al (1996) had also observed that soybean seed yield did not change significantly in Vertic Inceptisol due to landform treatments under sufficient rainfall conditions

Soil depth did not result in a significant effect on total drymatter and seed yield of soybean in both the years of investigations (Table 38) However, the medium-deep soil recorded marginally higher yield (drymatter and seed) when compared to the shallow soil

During 1997 rainy season, landform x soil depth interaction were significant on the drymatter yield, but not on the seed yield of soybean. This is due to the BBF landform increasing infiltration of water into the soil, and increased soil water content of the medium-deep soil. Several workers reported increased crop yields due to broadbed and furrows in Vertisols (CRIDA, 1982; UAS, 1983; Thiagarajan and Ramaiah, 1984; Bhatawadekar, 1985, CRIDA, 1990). The BBF landform on the shallow soil recorded the highest drymatter (2764 kg ha^{-1}) and seed yield (941 kg ha^{-1}) of soybean.

Cropping system treatment had a significant effect on total drymatter and seed yield of soybean during both the years of investigation (Table 38, Fig. 15). Higher drymatter and seed yield was observed in case of sole soybean than intercropped soybean. This is due to the low light intensity through shading of intercropped pigeonpea, caused reduced yield of intercropped soybean. Similarly Selvaraju (1994) reported in pearl millet / cowpea intercropping system, cowpea yield was reduced due to the low light intensity through shading of base crop.

Landform x soil depth x cropping system interaction significantly changed the dry matter and seed yield of soybean. During rainy season 1997, maximum drymatter and seed yield was observed in case of sole soybean grown on BBF landform on shallow depth soil. However, during rainy season 1998, maximum drymatter and seed yield was recorded in case of sole soybean grown on the flat landform on the shallow depth soil. The yield differences between the two years, mainly due to the rainfall differences. In deficit rainfall 1997, BBF stored more moisture, helps for increasing the yield of soybean. However, during rainy season 1998, heavy rainfall was noticed (more than the average rainfall), flat bed system might have fecilated the more available light to the crop than BBF Similarly Selvaraju (1994) reported the higher light availability under flat bed configuration might be the cause for higher growth and yield of cowpea Piara Singh *et al* (1999) also similarly reported that the soybean seed was greater on the flat landform for the shallow soil than BBF shallow soils during both the years (1995 and 1996)

5.7.2 Pigeonpea

The pigeonpea drymatter yield was significantly influenced by landform treatments and the interaction of landform x soil depth (during 1997) Higher drymatter yield was recorded in BBF landform than flat bed (6364 vs 5426 kg ha^{-1}) during 1998 Pigeonpea grown on BBF landform on a medium-deep soil yielded maximum drymatter (6531 kg ha^{-1}) This is due to the stored moisture in BBF useful for increase the drymatter Landforms, soil depth treatments and landform x soil depth interaction effects on seed yield of pigeonpea was not significant during both the years of investigations

5.7.3 Chickpea

Total drymatter and seed yield of chickpea crop was not significantly influenced by landforms during both the years of investigation Soil depth had a significant effect on total drymatter and grain yield of chickpea during both the years of investigation (Table 39, Fig 15) Significantly, higher drymatter and grain yields were observed in medium-deep soil than soil with shallow depth because of more soil water storage in the medium-deep soil These results are in conformity with those of Piara Singh *et al* (1999) who reported that the total drymatter and seed yield of chickpea was significantly higher on the medium-deep soil than on shallow soil

During 1997 and 1998, the interaction effect of landform x soil depth was significant on drymatter and seed yield of chickpea The BBF landform on the medium-deep soil showed the higher drymatter and grain yields of chickpea and the lowest yield was recorded in flat landform treatment on the shallow Vertic soil This is due to the BBF landform increasing infiltration of water into the soil, and increased soil water content of the medium-deep soil Similar results were reported by Abebe *et al* (1994) who found that the higher chickpea seed yield in BBF landform than the flat bed in Vertisols Mamo *et al* (1994) found chickpea grown on the BBF gave significantly higher seed and straw yields than when grown on flat beds in Vertisols

5.8 Total system productivity of soybean + chickpea (sequential crop) and soybean/ pigeonpea (intercrop)

The total system productivity (seed yield) of soybean + chickpea was significantly higher (1 6 and 1 2 times) than that of soybean / pigeonpea during 1997 (2415 vs 1341 kg ha^{-1}) and in 1998 (2765 vs 2322 kg ha^{-1}) respectively (Table 40) Bhaskar *et al.* (1992) reported that the soybean-chickpea were promising and economic sequences in Vertisols Jadhao *et al* (1994) found the soybean-chickpea crop sequence recorded significantly higher seed production than all the other crop sequence in Vertic Inceptisols of Maharastra Joshi *et al* (1997) observed the soybean / pigeonpea intercropping system gave the highest soybean-seed equivalent gross and net monetary returns Dwivedi *et al* (1998) also reported the maximum net returns were obtained in soybean-chickpea sequence Marger and Deshmsukh (1999) similarly reported that soybean – chickpea was the most remunerative crop sequence

The soybean+chickpea (sequential) system grown on the medium-deep soil showed the highest productivity (sum of soybean and chickpea seed yields) during 1997 (2207 kg ha^{-1}) and 1998 (2927 kg ha^{-1}) in the present investigation. Singh *et al.* (1999) reported similarly, total system productivity for seed yield (sum of soybean and chickpea seed yields) was significantly higher on the medium-deep soil than on the shallow soil. In the present two year experiments, maximum system productivity (seed yield) was found in the soybean + chickpea grown on BBF on medium-deep soil during 1997 (2410 kg ha^{-1}) and 1998 (2999 kg ha^{-1}). This might be due to the BBF landform increasing infiltration and water in to the soil and increased soil water content of the medium-deep soil.

5.9 Vesicular arbuscular mycorrhizal fungi (VAMF)

In soybean and pigeonpea, root colonization by vesicular arbuscular mycorrhizal fungi (VAMF) varied significantly due to landform treatments (Table 41 and 42, Fig. 16). Flat landform system showed a higher (45%) root colonization by VAMF than the BBF landform treatment in soybean at pod development stage during 1998. However, BBF landform increased mycorrhizal colonization to 17% than the flat landform system (11%) in pigeonpea roots at flowering during 1997. Similar results were reported by Saran et al. (1996b), who reported that flat landform increased mycorrhizal colonization by VAM fungi in sorghum roots compared to the BBF landform system.

Soil depth treatments significantly influenced mycorrhizal colonization by VAM fungi in pigeonpea at flowering stage (Table 42, Fig. 16) and in chickpea at pod development stage (Table 43, Fig. 16) during 1997. In the shallow soil, highest root colonization in pigeonpea was recorded 17% and in chickpea (25%). In the medium-deep soil lowest root colonization found in pigeonpea was 11% and in chickpea (17%). Ellis *et al.* (1992) found the root colonization by VAMF ranged from 93% at 15 cm to 15% at the 120 cm soil depth under sorghum-soybean rotation.

Cropping system treatments had a significant effect on the mycorrhizae colonization in soybean roots. The sole soybean had more mycorrhizal colonization (48%) in its roots than the intercropped soybean (35%) at the pod development stage in 1998 (Table 41, Fig. 16)

5.10 Potentially mineralizable N (N_o)

Effect of application of organic residues to the soil (*Glyricidia*: stems leaves and pigeonpea: roots and leaves) on the net mineralization of soil nitrogen (N) were studied in Vertic Inceptisol in incubation experiment. A higher mineralization of soil nitrogen (121 mg N kg^{-1}) was observed for surface applied *Glyricidia* leaves compared to the other treatments at 150 days of incubation (Table 44, Fig. 17). Handayanto *et al.* (1994) had also observed higher nitrogen release rate from the *Glyricidia* amended treatment in a red-yellow padzolic soil

Nitrogen mineralization potential (N_o) value was higher at (496 mg kg^{-1} soil) for surface applied pigeonpea roots than the other application of organic residues to the soil (Table 47). Wani *et al.* (1995) observed similar results in pigeonpea based cropping systems in Vertisols. The quality of pigeonpea dry matter was observed to effect nitrogen mineralization potential (N_o) in the soil. The lowest nitrogen mineralization potential (N_o) value (149 mg kg^{-1} soil) was observed for the surface application of *Glyricidia* leaves in our experiment. Islam *et al.* (1998) reported lower N_o values in peavine application because of a greater immobilization of N than in rice straw treatments.

The values for the nitrogen mineralization rate constant (K) varied between 0.0015 and 0.0104 d^{-1} (Table 47). The K values were observed higher for the surface application of *Glyricidia* leaves in the soil as compared to other treatments. This is probably due to the succulent nature of *Glyricidia* leaves. Similar results were reported by Wani *et al.* (1995) for the nitrogen mineralization rate constant values were higher in soil from cowpea / pigeonpea plots.

Organic residue treatments were ranked on the basis of time required to mineralize a fixed quantity of N (25 and 50 mg N kg^{-1} soil) as calculated from the linear and exponential models (Table 48). Both models showed that surface application of *Glyricidia* leaves (GLS) required less time to mineralize a fixed quantity of N in the soil compared to the other treatments. Wani *et al.* (1995) reported similar results for both models (linear and exponential) for cropping systems which contained pigeonpea. They also found that in comparison less time was required to mineralize a fixed quantity of N than the chickpea-based systems.

Instantaneous rates of N mineralization for soils were calculated using linear and exponential models. For the treatment where *Glyricidia* leaves were applied at surface the instantaneous rate of N mineralization was far higher than in other treatments at 50 days of incubation but it decreased substantially at 75, 100 and 150 days of incubation. This could be due to the fact that instantaneous rate of N mineralization is based on quantity of mineral N leached in the treatment where surface application of *Glyricidia* leaves was made. It was far lower than in other soils at later stages of incubation. Wani *et al.* (1995)

similarly observed for the cowpea intercropped with pigeonpea in the first year followed by sorghum in the next rainy season and safflower in the post-rainy season that the instantaneous rate of N mineralization was far higher at 8 weeks of incubation, but it decreased drastically at 16 and 20 weeks of incubation

5.11 Carbon mineralization (CO_2 evolution)

The amount of cumulative CO_2 respired from the incubated soil samples varied significantly with organic residues application during 24 weeks of incubation in Vertic Inceptisols Amongst all the treatments significantly highest amount of cumulative CO_2 (1592 $\mu g\ g^{-1}$ soil) was respired with pigeonpea leaves and lowest amount of cumulative CO_2 (1443 $\mu g\ g^{-1}$ soil) was released with *Glyricidia* leaves (Table 50, Fig 20) during 24 weeks of incubation in our experiment (values are averages for both surface and incorporation levels) Jothimani *et al* (1997) reported that *Glyricidia* evolved a more amount of CO_2 than the coirpith treatments during 180 days incubation Sarmah and Bordoloi (1994) reported the highest amount of CO_2 was released with sesbania rostrata followed by rice straw and farmyard manure Overall the treatments, higher amount of cumulative CO_2 (1547 $\mu g\ g^{-1}$ soil) released due to the incorporation of organic residues into the soil than the surface application of organic residues on to the soil (1475 $\mu g\ CO_2\ g^{-1}$ soil) [values are average for all treatments] Similar results were reported by Curtin *et al.* (1998), a higher amount of CO_2 released (73 $\mu\ m^{-2}$) due to the incorporation of wheat straw into the soil than the surface application to the soil (41 $g\ m^{-2}$)

CONCLUSIONS

Based on the above results and discussion, the following conclusions are drawn

1 Soil available N, net N mineralization, soil respiration and soil microbial biomass C and N under soybean, pigeonpea and chickpea crops at different stages were significantly influenced by landform, soil depth and cropping system treatments and their interactions Mean available N, net N mineralization soil respiration and microbial biomass C and N contents in soil varied at different stages of the crop growth period

2 In soybean and in chickpea crops, the BBF landform on the medium-deep soil showed a significantly more number of nodules Highest nodule number, nodule weight and nitrogenase activity were observed in case of medium-deep soil than compared to shallow soil in both the soybean and chickpea crops In soybean, pigeonpea and in chickpea, the lowest nitrogenase activity was observed under the flat landform treatment on the shallow soil Nodule number, nodule weight and nitrogenase activity and specific nitrogenase activity were changed by the age of the crops viz , soybean, pigeonpea and chickpea

3 Nitrogen fixed by soybean and chickpea was not affected significantly by landform systems However, the significant effect was observed due to landforms on nitrogen fixed by pigeonpea Soybean and chickpea grown on medium-deep soil fixed a significantly more amount of N than compared to the shallow soil In soybean, pigeonpea and in chickpea crops, the BBF landform on the medium-deep soil showed the highest nitrogen fixed and the percentage of nitrogen

derived from atmosphere Sole soybean crop fixed a more nitrogen compared to the intercropped soybean

4 N, P and K uptake by soybean, pigeonpea and chickpea were significantly influenced by landforms, soil depths and cropping system treatments The uptake of N and P by soybean, pigeonpea and chickpea showed a linear increase with crop growth and development up to the pod development stage and then increased at the harvest stage of the crops The uptake of K by soybean, pigeonpea and chickpea crops at harvest stage was significantly influenced by landform, soil depth and cropping system treatments

5 Total seasonal runoff and the amount of NO_3 lost through runoff from the Vertic Inceptisol under BBF system was lower when compared with the flat landform on both the shallow and medium-deep soils

6 In soybean and chickpea the BBF landform on the shallow soil resulted in the highest drymatter and seed yield during 1997

7 In soybean and pigeonpea root colonization by VAM fungi varied significantly due to the landform treatments

8 The soybean + chickpea (sequential cropping system) grown on BBF landform on the medium-deep soil showed the highest productivity

9 BBF landform showed a less negative nitrogen balance (-6 kg ha^{1}) and positive N balance (+55 kg ha^{1}) than compared with flat bed system as estimated by ^{15}N isotope dilution method and N-difference methods respectively Medium-deep soil influenced a less negative N balance (-75 kg ha^{1}) and higher positive N balance than the shallow soil as estimated by ^{15}N isotope dilution and N-

difference methods respectively. BBF landform resulted in a maximum positive P balance (+18 kg ha^{-1}) compared with the flat landform (+12 kg ha^{-1}). The BBF influenced a less depletion of K in soil than compared to the flat landform.

10. *In vitro* studies showed that, a higher mineralization of soil nitrogen was observed when *Glyricidia* leaves were surface application to the soil compared to all other treatments at 150 days incubation.
11. *In vitro* studies showed that, the amount of cumulation CO_2 respired from the incubated soil samples varied significantly with organic residues application during 24 weeks of incubation.

Future line of work

- The effect of landform management systems may be studied on different cropping systems viz., maize-based cropping systems, sorghum-based cropping systems etc for nutrient budgeting and crop yields in rainfed agriculture.
- The different landform management systems may be evaluated under different cropping systems for soil chemical and biological properties in different rainfall seasons in different locations.
- Nitrogen and carbon mineralization studies have to be continued by addition of different plant residues and green leaf manures in rainfed agriculture.

Biological nitrogen fixation studies have to be conducted in different leguminous cropping systems under different landform management systems.

Summary

CHAPTER VI

SUMMARY

In India, out of 72 m ha black soils, Vertic Inceptisols cover 60 m ha. These soils are often located on lands exceeding 2% - 5% slope, are shallow in depth and are prone to soil erosion. The productivity of the cropping systems in Vertisols and associated soils is threatened because of loss of surface soil and severe depletion of nutrients and beneficial organisms resulting in the degradation of soil. In order to sustain the productivity of these soils, there is an urgent need to identify suitable cropping systems and land management practices. Soybean-based systems are the most promising for sustaining the productivity and for improving the economic status of farmers in rainfed areas. Keeping these aspects in view, the present investigation entitled "Evaluation of land management practices for nutrient budgeting and dynamics in soybean-based cropping systems in Vertic Inceptisols' was undertaken during the rainy and post-rainy cropping seasons of 1997 and 1998 in an operational-scale watershed (BW7) at the ICRISAT Center, Patancheru, A.P., India.

Black watershed 7 represents a natural occurring toposequence of variable soil depths. The watershed has been divided into shallow (<50cm) and medium-deep (50-90 cm) and deep soil >90 cm blocks. For this study only shallow and medium soil depths were selected. Each soil depth has been further divided into two parts with two land management systems – broadbed and furrow (BBF) with vegetative bund (*Glyricidia* planted) and flat landform on contour sowing. Thus whole watershed consists of four hydrological units: these are (1) Flat landform management system on shallow soil, (2) BBF landform management system on shallow soil, (3) Flat land management system on medium-deep soil

and (4) BBF land management system on medium-deep soil. Two cropping systems (soybean / pigeonpea; soybean + chickpea) were grown to these four units. These hydrological units were not replicated. Each hydrological unit was further partitioned into 6 to 8 sub units, and treated as replications. Soils and crops in each sub-unit within each hydrological unit were sampled for detailed observations.

The soil of the experimental site is a member of the fine, montmorillonitic, isohyperthermic family of paralithic Vertic Ustropepts. It contains10% coarse sand, 20% fine sand, 20% silt and 50% clay. The pH was 8.1, the electrical conductivity was 0.24 d s m^{-1}, organic carbon in 0-15 cm was 0.8%. The water retention was -3.3 and -18.9 M pa at 1/3 and 15 bars. The fixed experimental findings of the investigation are briefly summarized as under:

- In the 1997 rainy cropping season, the landform treatments significantly modified soil available N at presowing and at vegetative stage (36-41 DAS) in sole and intercropped soybean. The flat landform showed a higher available N content (14 and 10 µg N g^{-1} soil) than the BBF landform (13 and 9 µg N g^{-1} soil) at presowing and vegetative stages respectively. However, during the rainy cropping season in 1998 the BBF landform recorded more soil available N content (9 µg N g^{-1} soil) than the flat landform (8 µg N g^{-1}) in both sole and intercropped soybean at vegetative stage (36-41DAS).
- During the 1997 rainy season in sole and intercropped soybean soil available N content was influenced significantly by the soil depth measured during the cropping period. The medium-deep soil had a higher available N content compared to the shallow Vertic Inceptisol.

- During the rainy season of 1997, the sole soybean and soybean / pigeonpea cropping systems significantly affected the soil mineral N content both prior to its sowing and at its vegetative stage. A higher soil mineral N content was observed in soybean / pigeonpea intercropping system (14 and 9 µg N g^{-1} soil) compared to the sole soybean (13 and 9 µg N g^{-1} soil) at presowing and vegetative stages of the crop respectively. During the 1998 rainy season, the soil under sole soybean crop showed a higher available N status than the soil under intercropped soybean during the crop growing period.

- Landform x soil depth interaction effect was significant for available N content under sole and intercropped soybean. The flat landform on the medium-deep soil recorded the highest available N content during the crop growth period in 1997. However, the BBF landform on the shallow soil resulted in the highest available N status at both the vegetative and pod development stages, in sole and intercropped soybean during 1998.

- Landform, soil depth and their interaction had no significant effect on available N content under pigeonpea (except at harvesting stage in 1997) and chickpea during post-rainy seasons of both the years.

- During rainy season 1997, at the presowing, vegetative and at the pod development stages of sole and intercropped soybean, the flat landform on the medium-deep soil with intercropped soybean resulted in the highest available N content. However, during rainy season 1998 at both the vegetative and pod development stages of sole and intercropped soybean, the BBF landform on the shallow soil with sole soybean resulted in a higher nitrogen content.

- Available soil N content varied at different stages of the crop growth during both rainy and post-rainy cropping seasons in the years 1997 and 1998.

- Net N mineralized in the sole under sole and intercropped soybean was significantly different in the two landform treatments when measured prior to sowing of the crop in 1998 The BBF landform had more net N mineralized (5 μg N g^{1} soil 10 d^{1}) compared to the flat landform (4 μg N g^{1} soil 10 d^{1}) In pigeonpea crop at its harvest in 1997, net N mineralized in the soil was significantly higher in the medium-deep (6 μg N g^{1} soil 10 d^{1} net N mineralization) compared with the shallow soil (4 μg N g^{1} soil 10 d^{1})
- Landform x soil depth x cropping system interaction significantly influenced the soil net N mineralization under sole and intercropped soybean at both the presowing and vegetative stages in 1998 A significantly lesser net N mineralization in soil was observed under the soybean / pigeonpea intercrop grown on the flat landform on the medium-deep soil
- Net N soil mineralized under sole and intercropped soybean showed that chickpea influenced it at its different plant growth stages during both the years of investigation In sole and intercropped soybean the amount of net N mineralized at vegetative stage was 8 times more during 1997 and 1 2 times more during 1998 than the amount of N mineralized prior to the sowing of soybean
- The amount of carbon respired from the soil under soybean pigeonpea and chickpea was significantly influenced by the landform treatment and soil depth during both the years of investigation In the medium-deep soil, more amount of carbon was released compared to the shallow soil under sole and intercropped soybean, pigeonpea and chickpea crops during both the years of study Significantly higher amount of C was respired in sole soybean (64 μg C g^{1} soil 10d^{1}) compared to the intercropped soybean (50 μg C g^{1} soil 10d^{-1}) during the rainy cropping season of 1997

- The medium-deep soil under flat landform treatment released the highest amount of carbon during at different stages of sole and intercropped soybean (in 1997 and 1998). In chickpea crop, the lowest amount of C was released from the shallow soil under BBF landform treatment during the crop growth period in 1997 and 1998.
- In sole and intercropped soybean, the soil under flat landform on the medium-deep soil with soybean / pigeonpea showed a more soil respiration at the vegetative stage in 1997 and at the harvest stage in 1998. The flat landform on the medium-deep soil with sole soybean resulted in the highest soil respiration during both the pod development and harvest stages in 1997, and at the presowing in 1998.
- The amount of C released from the soil under sole and intercropped soybean, pigeonpea and chickpea varied at different plant growth stages during both the years of investigation.
- Microbial biomass C and N contents in the surface soil samples under sole and intercropped soybean, pigeonpea and under chickpea crops was not changed significantly by landform treatments during two years of our experiments.
- Soil microbial biomass C content under sole and intercropped soybean (at harvesting stage, 1997), under pigeonpea (at harvesting stage, 1998) and under chickpea (at presowing 1997 and at presowing and harvesting stages, 1998) varied significantly due to soil depth treatments. Higher microbial biomass C was recorded in medium-deep Vertic Inceptisol than compared to the shallow soil.
- Significantly higher microbial biomass N was observed in the medium-deep Vertic Inceptisol than compared to the shallow soil under sole and intercropped soybean (at pod development stage, 1997 and at presowing, pod development and harvesting stages, 1998),

under pigeonpea (at harvesting stage, 1998) and under chickpea (at presowing and harvesting stage, 1998).

- Mean microbial biomass C and N content in soil varied at different stages of the crop growth during the two years of investigation.

- Microbial soil biomass N content was significantly influenced by cropping systems in sole and intercropped soybean during the rainy cropping season in 1997. Intercropped soybean increased biomass N content in soil over the sole soybean.

- In soybean and chickpea crops, highest soil microbial biomass C and N was observed under the flat landform on the medium-deep soil whereas the lowest soil microbial biomass C and N was recorded under the BBF landform system on the shallow soil.

- In sole and intercropped soybean, the flat landform on the medium-deep soil with soybean / pigeonpea system showed a significantly higher microbial biomass C and N.

- Soybean grown on BBF landform system showed a significantly higher number of nodules (705 m^{-2}) compared to the flat landform treatment (306 m^{-2}) at vegetative stage of the crop (36 DAS) during 1998. The soybean crop in the medium-deep soil produced maximum number of nodules, significantly more than in the shallow soil (at vegetative and pod development stages in 1998) and in the chickpea crop (at flowering, pod development stages in 1997 and at vegetative stages in 1998).

- The number of nodules in the soybean crop increased with plant age (up to pod development stage) during both the years of investigation.

- In soybean and chickpea crops, the BBF landform on the medium-deep soil showed a significantly more number of nodules whereas the flat landform on the shallow soil recorded a lesser number of nodules.

- In soybean (during 1998), at the vegetative stage, more number of nodules were observed in intercropped soybean grown on BBF on the medium-deep Vertic Inceptisol, however, at the pod development stage higher nodule number was recorded in the sole soybean grown on the BBF landform on the medium-deep soil.
- During the rainy season of 1998, soybean crop grown on BBF landform showed significantly higher (2.2 times) nodule weight compared with the flat landform at the vegetative stage of the crop.
- The soybean and chickpea crops grown in the medium-deep soil resulted in significantly more weight of nodules compared to the crops grown in the shallow soil.
- Sole soybean crop showed a significantly more nodule weight (2703 mg m^{-2}) than intercropped soybean (1878 mg m^{-2}) during its pod development stage in 1997. However, in the year 1998, intercropped soybean showed a higher nodule weight (302 mg m^{-2}) compared to the sole soybean (186 mg m^{-2}) crop at its vegetative stage of growth.
- In chickpea crop, the maximum nodule weight was observed in the BBF landform on the medium-deep soil and the minimum nodule weight was recorded in the BBF landform on the shallow soil.
- During rainy season 1998, in soybean at the pod development stage, the flat landform on the medium-deep soil with sole soybean showed the highest nodule weight and the lowest nodule weight was recorded in intercropped soybean in the BBF landform system on the medium-deep soil.
- In soybean crop, the nodule weight increased from vegetative to pod development stages by eight times during 1997 and by 13 times during 1998.

- Landform treatments did not significantly affect the nitrogenase activity in sole and intercropped soybean, pigeonpea and chickpea during the two years of investigations.
- Significantly higher nitrogenase activity was recorded in medium-deep soil compared to the shallow soil in soybean and in chickpea (at vegetative stage) in 1998.
- Sole soybean had maximum nitrogenase activity of 195 µmol C_2H_4 m^{-2} h^{-1} compared to 84 µmol C_2H_4 m^{-2} h^{-1} observed in the intercropped soybean at pod development stage (70 DAS) during 1997.
- In soybean and in pigeonpea, more nitrogenase activity was observed in the BBF landform on the shallow soil during 1997.
- In soybean during 1997, the highest nitrogenase activity was observed in sole soybean grown on the BBF landform on the shallow soil. However, during 1998, the lowest nitrogenase activity was recorded in sole soybean grown on the flat landform on the shallow soil during both the vegetative and pod development stages.
- In soybean mean nitrogenase activity increased by 17 times during 1997 and 5 times during 1998 from vegetative stage to pod development stage.
- In pigeonpea, highest mean nitrogenase activity was observed at vegetative stage (70 DAS) during both the years of investigations.
- In chickpea, mean nitrogenase activity was increased to 19 times from vegetative stage to flowering stage and then decreased at the pod development stage during 1997. However, during 1998, mean nitrogenase activity was decreased to 184 times from vegetative to pod development stage.
- Soybean crop grown during the rainy cropping season, 1998, the specific nitrogenase activity was significantly affected by sol depth treatment. In medium-deep soil,

the crop showed more specific nitrogenase activity (40.9 µmol C_2H_4 g^{-1} nodule h^{-1}) compared to the shallow soil (22.1 µmol C_2H_4 g^{-1} nodule h^{-1}).

- In soybean, highest specific nitrogenase activity was observed on the BBF landform on the shallow soil with sole soybean during 1997. However, during 1998, the BBF landform on the medium-deep soil with sole soybean showed the highest specific nitrogenase activity.
- The nitrogen fixation rates as estimated with N-difference method in soybean were 38 and 19 kg ha^{-1} in pigeonpea were 76 and 61 kg ha^{-1} and in chickpea were 28 and 19 kg ha^{-1} during 1997 and 1998 respectively.
- The nitrogen fixation rates as estimated with ^{15}N isotope dilution method in soybean were 40 and 45 kg ha^{-1}, in pigeonpea were 75 and 85 kg ha^{-1} and in chickpea were 15 and 11 kg ha^{-1} during 1997 and 1998 respectively.
- Pigeonpea grown on BBF landform fixed a significantly higher amount of N (73 kg ha^{-1} and 97 kg ha^{-1}) compared to the N fixed by the crop when grown on flat landform (49 kg ha^{-1} and 73 kg ha^{-1}) as estimated with N difference and ^{15}N isotope dilution methods respectively during 1998.
- The soybean crop grown in the medium-deep soil fixed more amount of N compared to the shallow soil during 1998 (1.85 times more). In the chickpea crop, this increase was 1.4 & 1.5 times more during 1997 and 1998.
- Sole soybean crop fixed higher nitrogen compared to the intercropped soybean as estimated with N-difference and ^{15}N isotope dilution methods.

- The percent nitrogen derived from atmosphere (% N dfa) by soybean were 24% and 17%, by pigoenpea were 79% and 66% and by chickpea were 54% and 54% during 1997 and 1998 respectively.
- Sole soybean grown on BBF landform on medium-deep soil fixed a higher amount of nitrogen as estimated by both the N-difference (in 1998) and ^{15}N isotope dilution methods (in 1997).
- In the medium-deep soil the soybean crop resulted in a higher proportion of N fixation (21%) than in the shallow soil (12%) during 1998. Sole soybean crop resulted in a higher proportion of N fixation (35%) than the intercropped soybean (15%) during 1997.
- In soybean, highest proportion of N fixation was observed in sole soybean grown on BBF landform on medium-deep soil.
- Landform, soil depth and cropping system treatments significantly influenced N and P uptake by the sole and intercropped soybean, pigeonpea and chickpea crops at a few stages of crop growth and development only.
- The uptake of N and P by soybean, pigeonpea and chickpea showed a linear increase with crop growth and development upto the pod development stage and then decreased at the harvest stage of the crops.
- In soybean, the highest N uptake was observed insole soybean grown on flat landform on shallow depth soil.
- Highest P uptake by soybean was observed in sole soybean grown on BBF landform system during 1997.
- The uptake of K by soybean, pigeonpea and chickpea crops at harvest stage was significantly influenced by landform, soil depth and cropping system treatments.

- The BBF landform on the medium-deep soil recorded the maximum K uptake by soybean (in 1997) and by chickpea (in 1997 and 1998).
- A significantly maximum uptake of K by soybean was observed in case of sole soybean grown on BBF landform system during both the years of investigation.
- The runoff observed on flat landform treatment was higher [287 mm, 33% of seasonal rainfall] compared to the BBF landform treatment [225 mm, 26% seasonal rainfall].
- Total seasonal runoff from the Vertic Inceptisol under BBF system was considerably lower when compared with the flat landform on both the shallow and medium-deep soils.
- The amount of NO_3-N lost in runoff was higher in the flat (13 kg N ha^{-1}) compared to the BBF landform (10 kg N ha^{-1})
- In soybean crop grown on two landform, the total drymatter yield varied significantly , but not the grain yield during rainy season 1997. However, the highest total drymatter (2651 kg ha^{-1}) and grain (906 kg ha^{-1}) yields of soybean were observed on the BBF landform system on a Vertic Inceptisols. The lowest drymatter (2413 kg ha^{-1}) and grain yields (831 kg ha^{-1}) were recorded on the flat landform during this 1997 rainy season.
- The seed and drymatter yields of soybean did not vary significantly due to landforms during rainy season 1998.
- Soil depth had no significant effect on total drymatter and grain yield of soybean in both the years of investigation.
- The BBF landform on the shallow soil resulted in highest drymatter (2764 kg ha^{-1}) and grain yield (941 kg ha^{-1}) of soybean during 1997.

- Significantly higher drymatter and grain yield was observed in case of sole soybean compared to the intercropped soybean.

- Sole soybean grown on flat landform treatment showed the highest drymatter yield and grain yield (1998). However, sole soybean grown on shallow depth soil showed the highest drymatter and grain yield

- In soybean during rainy season 1997, maximum drymatter and grain yield was observed in case of sole soybean grown on the BBF landform on the shallow depth soil. However, during 1998, maximum drymatter and grain yield was recorded in case of sole soybean grown on the flat landform on the shallow depth soil.

- In pigeonpea, a significantly higher drymatter yield was recorded in BBF landform treatments compared to the flat bed (6364 vs 5426 kg ha^{-1}) during 1998.

- In pigeonpea, soil depth did not show any significant effect on drymatter and grain yield in both the years of investigation.

- Landform treatments and landform x soil depth interaction effects on grain yield of pigeonpea were not significant during both the years of investigation.

- Total drymatter and grain yield of chickpea was not significantly influenced by landform treatments during both the years of investigation.

- Soil depth and landform x soil depth interaction effects on total drymatter and grain yield of chickpea during two years investigation were significant. The crop yield in medium-deep soil showed higher drymatter and grain yields than the shallow soil. The BBF landform on the medium-deep soil showed the highest drymatter and grain yield of chickpea, lowest yield was recorded in flat landform treatment on the shallow depth Vertic Inceptisol.

- The total system productivity (grain yield) of soybean + chickpea was significantly higher (1.6 and 1.2 times more) than that of soybean / pigeonpea during 1997 and 1998.
- The soybean + chickpea (sequential cropping system) grown on the medium-deep soil showed the highest productivity (sum of soybean and chickpea grain yields) during both the years.
- In soybean and pigeonpea root colonization by VAM fungi varied significantly due to the landform treatments.
- Flat landform system showed the higher (45%) root colonization by VAM in soybean at pod development stage during 1998. However, BBF landform influenced the higher mycorrhizal colonization (17%) in pigeonpea roots at flowering stage during 1997.
- Shallow soil recorded the highest root colonization by VAM fungi in pigeonpea (17%) and in chickpea (25%) crops during 1997.
- During 1998, the sole soybean roots had more VA mycorrhizal colonization (48%) compared to the intercropped soybean roots (35%) at the pod development stage.
- Landform x soil depth x cropping system interaction was significant on mycorrhizal colonization by VAM fungi in soybean roots at both the vegetative and pod development stages. Highest mycorrhizal colonization was recorded in intercropped soybean grown on BBF landform on medium-deep soil at the vegetative stage in 1997, but during 1998, at the pod development stage, lowest mycorrhizal colonization was observed in intercropped soybean grown on the BBF landform on the medium-deep soil.
- Average of the two years, results showed that by using ^{15}N isotope dilution method showed a less negative nitrogen balance (-6 kg ha^{-1}) under the BBF landform than compared with flat bed system (-77 kg ha^{-1}). Less negative N balance was recorded for the medium-

deep soil (-75 kg ha^{-1}) the shallow soil (-83 kg ha^{-1}). Less negative N balance was observed under the intercropping (soybean / pigeonpea) system than the sequential (soybean + chickpea) cropping system.

- Average of the two years results showed that by using N-difference method, the BBF system influenced the nitrogen balance positively (+55 kg ha^{-1}) but flat had the negative balance (-19 kg ha^{-1}). Significantly higher positive N balance was recorded for the medium-deep soil (+21 kg ha^{-1}) than the shallow soil (+16 kg ha^{-1}). Sequential cropping system resulted in a higher positive N balance (+34 kg ha^{-1}) than the intercropping system (+3 kg ha^{-1}).
- Average values of the two years showed that the BBF landform resulted in a maximum positive P balance (+18 kg ha^{-1}) compared with the flat landform (+12 kg ha^{-1}).
- The available net K showed a negative balance in all the treatments. The depletion of K was more (-48 kg ha^{-1}) in case of flat landform than the BBF system (-42 kg ha^{-1}).

In the lab experiment on Potentially mineralizable N (N_o),

- The cumulative mineral N (NH_4^+ + NO_3^-) content increased significantly from 3.2 mg N kg^{-1} soil at 5 days after incubation to 105 mg kg^{-1} soil at 150 days after incubation of the soils.
- Higher mineralization of soil nitrogen (121 mg kg^{-1} soil) was observed when *Glyricidia* leaves were applied on surface as compared to all other treatments at 150 days of incubation. Lowest mineralization of soil N was observed when *Glyricidia* stems were applied at surface of the soil (92 mg kg^{-1} soil).

- Cumulative ammonial nitrogen (NH_4^+N) content in incubated soils increased from 0.7 mg kg^{-1} soil at 5 days to 5 mg kg^{-1} soil at 150 days incubation
- Cumulative nitrate nitrogen (NO_3^-N) content in incubated soils increased significantly from 3 to 100 mg kg^{-1} soil with progressive incubation period of 5 to 150 days with the application of organic residues at surface and incorporation into the soil
- The first order exponential model yielded nitrogen mineralization potential (Ng) values ranging from 149 to 496 mg kg^{-1} incubated soil for eight organic residue treatments Estimated N_o values were highest (496 mg kg^{-1}) for pigeonpea root surface application (PRS) followed by PRI>PLS>GSI>GSS>control>PLI>GLI>GLS treatments
- The first order rate constant of N mineralization (K) varied from 0 0015 to 0 0071 d^{-1}, and was highest in the GLS treatment (0 0104)
- Time required to mineralize 25 mg N kg^{-1} soil varied from 18 to 34 weeks using the exponential model Both exponential and linear models showed that surface application of *Glyricidia* leaves (GLS) required less time to mineralize a fixed quantity of N than the other treatments
- For the treatment where *Glyricidia* leaves were applied at surface the instantaneous rate of N mineralization was far higher than in other treatments at 50 days of incubation but it decreased substantially at 75, 100 and 150 days of incubation period

In the lab experiment on Carbon mineralization (CO_2 evolution),

- The amount of cumulative CO_2 respired from the incubated soil samples varied significantly with organic residues application during 24 weeks of incubation, it was ranged from 307 to 1466 µg C g^{-1} soil

- Amongst all the treatments significantly highest amount of cumulative CO_2 (1661 μg g^{-1} soil) was respired with pigeonpea leaves when incorporated in to the soil, and the lowest amount of cumulative CO_2 (1103 μg g^{-1} soil) was observed in control during 24 weeks of incubation.
- The first order exponential model yielded carbon mineralization potential (C_O) values ranged from 1111 (control) to 1654 μg CO_2 g^{-1} soil (pigeonpea leaves incorporated into soil) for different organic residue treatment
- The first order rate constant of C mineralization (K) varied from 0.114 to 0.159 wk^{-1}.
- Time required to mineralize 50% of C_O varied from 4 to 6 weeks as estimated by the exponential model.

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Appendices

Appendix.1: Effect of landform treatments on seasonal runoff and nitrate loss on shallow and medium-deep Vertic Inceptisols in BW7 waters during rainy season 1998

		Flat medium-deep			**Flat shallow**			**BBF medium-deep**			**BBF shallow**		
DAS	Rainfall (mm)	Runoff (mm)	N conc. mg L^{-1}	N loss kg $plot^{-1}$	Runoff (mm)	N conc. mg L^{-1}	N loss kg $plot^{-1}$	Runoff (mm)	N conc. mg L^{-1}	N loss kg $plot^{-1}$	Runoff (mm)	N conc. mg L^{-1}	N loss kg $plot^{-1}$
5	28.0	1.39	3.21	0.06	1.64	2.81	0.04	0.02	2.81	0.00	1.07	2.41	0.03
32	62.2	7.24	3.23	0.30	9.98	2.95	0.28	3.53	2.84	0.12	7.13	2.34	0.19
33	17.6	8.06	5.89	0.61	7.71	3.84	0.29	3.75	4.54	0.20	8.06	3.90	0.36
38	39.5	14.17	4.53	0.83	16.26	3.22	0.50	14.73	3.62	0.63	13.21	3.10	0.47
41	40.6	15.14	4.91	0.96	21.62	3.11	0.65	6.53	3.71	0.29	14.13	3.10	0.50
42	45.8	28.36	4.03	1.48	25.82	3.78	0.94	14.83	3.64	0.64	23.29	3.10	0.83
43	63.3	45.69	4.27	2.53	43.74	3.88	1.64	28.38	3.90	1.31	42.69	3.56	1.74
48	34.2	6.29	5.39	0.44	5.85	3.12	0.18	6.26	4.07	0.30	3.90	3.69	0.17
49	17.0	2.23	2.94	0.08	3.09	3.47	0.10	2.59	3.07	0.09	1.27	2.79	0.04
50	17.0	8.14	3.69	0.39	10.05	4.24	0.41	6.12	3.57	0.26	9.04	2.79	0.29
51	15.6	2.86	6.09	0.23	3.27	4.72	0.15	2.66	5.14	0.16	2.08	4.60	0.11
52	10.2	2.00	4.79	0.12	2.15	4.66	0.10	1.40	4.38	0.07	1.26	3.69	0.05
53	45.2	30.46	4.58	1.81	26.83	4.04	1.05	20.27	4.10	0.99	31.72	3.69	1.34
55	25.4	14.72	7.11	1.36	2.62	5.77	0.15	5.90	6.43	0.45	10.50	6.40	0.77
62	11.0	0.00	0.00	0.00	0.72	0.00	0.00	0.25	0.00	0.00	0.00	0.00	0.00
64	56.4	17.71	9.59	2.20	16.00	9.20	1.42	16.24	9.02	1.74	16.71	8.26	1.58
71	12.8	0.92	7.98	0.09	0.72	7.48	0.05	0.85	7.60	0.08	0.40	7.33	0.03
72	24.2	3.60	8.16	0.38	2.85	8.34	0.23	2.21	8.10	0.21	2.29	7.80	0.20
80	35.6	0.32	5.11	0.02	0.69	4.75	0.03	0.15	4.71	0.01	0.00	4.27	0.00
85	29.0	7.21	5.11	0.48	9.74	4.75	0.45	5.73	4.71	0.32	6.04	4.27	0.30
102	68.2	22.27	5.11	1.47	19.35	4.75	0.89	16.86	4.71	0.94	18.19	4.27	0.89
104	7.9	0.86	5.11	0.06	0.98	4.75	0.04	0.56	4.71	0.03	0.18	4.27	0.01
105	4.5	0.22	5.11	0.01	0.00	4.75	0.00	0.00	4.71	0.00	0.15	4.27	0.01
109	12.0	0.73	5.11	0.05	0.63	4.75	0.03	0.41	4.71	0.02	0.00	4.27	0.00
115	22.4	0.72	5.11	0.05	3.21	4.75	0.15	0.91	4.71	0.05	0.24	4.27	0.01
118	11.0	0.00	0.00	0.00	0.00	0.00	0.00	0.45	0.00	0.00	0.00	0.00	0.00
123	14.8	0.28	4.21	0.02	1.34	5.29	0.07	0.54	4.60	0.03	0.04	4.29	0.00
125	42.8	19.09	4.21	1.04	16.68	5.08	0.82	16.89	4.53	0.91	13.98	4.29	0.69
126	25.4	13.39	4.21	0.73	12.45	5.29	0.63	12.20	4.60	0.67	11.86	4.29	0.58
127	22.4	16.10	4.21	0.88	17.20	5.49	0.91	8.60	4.66	0.48	11.20	4.29	0.55
	862.0	290.20		14.42	283.20		12.64	199.8		9.27	250.60		10.25

Appendix.2: Nitrogen balance under sobean/pigeonpea and soybean+chickpea systems grown on BBF and flat landforms and shallow and medium- deep vertic inceptisols during 1997 and 1998 (Nitrogen fixation values used as inputs estimated with ^{15}N isotope dilution method)

Landform	N input (kg ha^{-1})							N output (Kg ha^{-1})				N balance
	BNF (Amount of N fixed)	Organic manure		N recycling		Rainfall	Total N (B)	Crop removal (N uptake)	Runoff	Deep - drainage	Total N (A)	(kg ha^{-1}) (A-B)
		Glyricidia	FYM	Leaf fall	Root stocks							
Soybean/pigeonpea (^{15}N isotope dilution method)												
1997												
Flat shallow	95	0.0	0.0	45	4.05	6.4	150.5	153	0.0	0.9	153.9	-3
BBF shallow	108	59.5	76.3	53	4.73	6.4	307.9	194	0.0	1.5	195.5	112
Flat medium - deep	109	0.0	0.0	50	4.53	6.4	169.9	184	0.0	0.0	184.0	-14
BBF medium - deep	95	59.5	76.3	55	4.98	6.4	297.2	175	0.0	0.0	175.0	122
1998												
Flat shallow	102	0.0	0.0	58	6.49	11.2	177.7	164	12.6	7.2	183.8	-6
BBF shallow	131	12.2	0.0	43	7.16	11.2	204.6	195	10.3	8.8	214.1	20
Flat medium - deep	124	0.0	0.0	67	7.42	11.2	209.6	182	14.4	6.1	202.5	7
BBF medium - deep	148	12.2	0.0	78	7.73	11.2	257.1	208	9.3	10.0	227.3	30
Soybean + chickpea (^{15}N isotope dilution method)												
1997												
Flat shallow	61	0.0	0.0	26	3.02	6.4	96.4	160	0.0	0.9	160.9	-65
BBF shallow	64	63.7	76.3	30	3.36	6.4	243.8	175	0.0	1.5	176.5	67
Flat medium - deep	71	0.0	0.0	28	3.34	6.4	108.7	169	0.0	0.0	169.0	-60
BBF medium - deep	71	63.7	76.3	30	3.82	6.4	251.2	186	0.0	0.0	186.0	65
1998												
Flat shallow	54	0.0	0.0	30	3.48	11.2	98.7	171	12.6	7.2	190.8	-92
BBF shallow	49	13.4	0.0	29	3.53	11.2	106.1	161	10.3	8.8	180.1	-74
Flat medium - deep	63	0.0	0.0	31	3.77	11.2	109.0	175	14.4	6.1	195.5	-87
BBF medium - deep	62	13.4	0.0	32	4.13	11.2	122.7	176	9.3	10.0	195.3	-73

Appendix.3: Nitrogen balance under sobean/pigeonpea and soybean+chickpea systems grown on BBF and flat landfoms and shallow and medium to deep vertic inceptisols during 1997 and 1998 **(Nitrogen fixation values used as inputs estimated with N difference method)**

Landform	N input (Kg ha-1)							N output (Kg ha^{-1})				N balance
	BNF (Amount o N fixed)	Organic manures		N recycling		Rainfall	Total N (B)	Crop remo (N uptake)	Runoff	Deep - drainage	Total N (A)	(kg ha^{-1}) (A-B)
		Glyricidia	FYM	Leaf fall	Root stocks							
Soybean /pigeonpea (N - difference method)												
1997												
Flat shallow	93	0.0	0.0	45	4.05	6.4	148.5	153	0.0	0.9	153.9	-5
BBF shallow	89	59.5	76.3	53	4.73	6.4	288.9	194	0.0	1.5	195.5	93
Flat medium - deep	90	0.0	0.0	50	4.53	6.4	150.9	184	0.0	0.0	184.0	-33
BBF medium - deep	93	59.5	76.3	55	4.98	6.4	295.2	175	0.0	0.0	175.0	120
1998												
Flat shallow	60	0.0	0.0	58	6.49	11.2	135.7	164	12.6	7.2	183.8	-48
BBF shallow	76	12.2	0.0	73	7.16	11.2	179.6	195	10.3	8.8	214.1	-35
Flat medium - deep	70	0.0	0.0	67	7.42	11.2	155.6	182	14.4	6.1	202.5	-47
BBF medium - deep	96	12.2	0.0	78	7.73	11.2	205.1	208	9.3	10.0	227.3	-22
Soybean + chickpea (N - difference method)												
1997												
Flat shallow	86	0.0	0.0	26	3.02	6.4	121.4	160	0.0	0.9	160.9	-40
BBF shallow	75	63.7	76.3	30	3.36	6.4	254.8	175	0.0	1.5	176.5	78
Flat medium - deep	80	0.0	0.0	28	3.34	6.4	117.7	169	0.0	0.0	169.0	-51
BBF medium - deep	99	63.7	76.3	30	3.82	6.4	279.2	186	0.0	0.0	186.0	93
1998												
Flat shallow	36	0.0	0.0	30	3.48	11.2	80.7	171	12.6	7.2	190.8	-110
BBF shallow	27	13.4	0.0	29	3.53	11.2	84.1	161	10.3	8.8	180.1	-96
Flat medium - deep	49	0.0	0.0	31	3.77	11.2	95.0	175	14.4	6.1	195.5	-101
BBF medium - deep	51	13.4	0.0	32	4.13	11.2	111.7	176	9.3	0.0	185.3	-84

Appendix.4: Phosphorus balance under sobean/pigeonpea and soybean+chickpea systems grown on BBF and flat landforms and shallow and medium-deep Vertic Inceptisols during 1997 and 1998.

Landform	P input (kg ha-^{1})						P output (kg ha^{-1})		P balance
	Chemical fertilizer (SSP)	Organic manures		P recycling		Total P (B)	Crop removal (P uptake)	Total P (A)	(kg ha^{-1}) A-B
		Glyricidia	FYM	Leaf fall	Root stocks				
				Soybean/pigeonpea					
1997									
Flat shallow	20	0.00	0.00	2.5	0.6	23.1	10.7	10.7	12
BBF shallow	20	3.49	8.63	3.0	0.7	35.8	15.1	15.1	21
Flat medium - deep	20	0.00	0.00	2.8	0.6	23.4	13.0	13.0	10
BBF medium - deep	20	3.49	8.63	3.1	0.6	35.8	11.5	11.5	24
1998									
Flat shallow	20	0.00	0.00	3.3	0.8	24.1	11.8	11.8	12
BBF shallow	20	0.73	0.00	4.0	1.0	25.7	12.1	12.1	14
Flat medium - deep	20	0.00	0.00	3.6	0.9	24.5	14.0	14.0	11
BBF medium - deep	20	0.73	0.00	4.2	1.0	25.9	13.5	13.5	12
				Soybean + chickpea					
1997									
Flat shallow	20	0.00	0.00	1.8	0.6	22.4	10.8	10.8	12
BBF shallow	20	3.77	8.63	2.0	0.6	35.0	13.2	13.2	22
Flat medium - deep	20	0.0	0.00	1.9	0.6	22.5	12.0	12.0	11
BBF medium - deep	20	3.77	8.63	2.0	0.7	35.1	12.8	12.8	22
1998									
Flat shallow	20	0.00	0.00	2.2	0.7	22.9	12.9	12.9	10
BBF shallow	20	0.77	0.00	2.1	0.7	23.6	13.5	13.5	10
Flat medium - deep	20	0.00	0.00	2.2	0.8	23.0	13.1	13.1	10
BBF medium - deep	20	0.77	0.00	2.2	0.7	23.7	13.0	13.0	11

Appendix.5: Potassium balance under soybean/pigeonpea and soybean+chickpea systems grown on BBF and flat landforms and shallow and medium - deep Vertic inceptisols during 1997 and 1998

Landform	K input (kg ha^{-1})						K output (Kg ha^{-1})		K balance
	Chemical fertilizer	Organic manures		K recycling		Total K (B)	Crop removal (K uptake)	Total K (A)	(kg ha^{-1}) (A-B)
		Glyricidia	FYM	Leaf fall	Root stocks				
Soybean/pigeonpea									
1997									
Flat shallow	0.0	0.00	0.00	19	1.9	20.9	52	52	-31
BBF shallow	0.0	3.49	8.63	23	2.2	37.3	59	59	-22
Flat medium - deep	0.0	0.00	0.00	21	2.2	23.2	62	62	-39
BBF medium - deep	0.0	3.49	8.63	23	2.1	37.2	62	62	-25
1998									
Flat shallow	0.0	0.00	0.00	25	3.3	28.3	76	76	-48
BBF shallow	0.0	0.73	0.00	30	4.1	34.8	87	87	-52
Flat medium - deep	0.0	0.00	0.00	28	3.8	31.8	83	83	-51
BBF medium - deep	0.0	0.73	0.00	32	4.3	37.0	83	83	-46
Soybean + chickpea									
1997									
Flat shallow	0.0	0.00	0.00	19	1.7	20.7	59	59	-38
BBF shallow	0.0	3.77	8.63	21	1.9	35.3	62	62	-27
Flat medium - deep	0.0	0.00	0.00	21	2.0	23.0	73	73	-50
BBF medium - deep	0.0	3.77	8.63	25	2.5	39.9	80	80	-40
1998									
Flat shallow	0.0	0.00	0.00	21	1.7	22.7	78	78	-55
BBF shallow	0.0	0.77	0.00	21	1.9	23.7	80	80	-56
Flat medium - deep	0.0	0.00	0.00	23	2.2	25.2	93	93	-68
BBF medium - deep	0.0	0.77	0.00	25	2.4	28.2	94	94	-66