

9

**MAIZE BASED CROPPING SYSTEMS AND INTEGRATED
NUTRIENT MANAGEMENT PRACTICES ON SOIL
QUALITY AND CROP PRODUCTIVITY**

Thesis submitted in part fulfillment of the requirement for the degree of
DOCTOR OF PHILOSOPHY (AGRICULTURE) IN AGRONOMY
to the Tamil Nadu Agricultural University,
Coimbatore

By

C. UMA MAHESWARI, M.Sc. (Ag.)
(I.D. No. 99-806-014)


DEPARTMENT OF AGRONOMY
Centre for Soil and Crop Management Studies
Agricultural College and Research Institute
Tamil Nadu Agricultural University
Coimbatore – 641 003

2002

CERTIFICATE

This is to certify that the thesis entitled **Maize Based Cropping Systems and Integrated Nutrient Management Practices on Soil Quality and Crop Productivity** submitted in part fulfillment on the requirements for the award of the degree of **DOCTOR OF PHILOSOPHY IN AGRONOMY** to the Tamil Nadu Agricultural University, Coimbatore is a record of bona fide research work carried out by **Ms. C. UMA MAHESWARI** under my supervision and guidance and that no part of the thesis has been submitted for the award of any degree, diploma, fellowship or other similar titles and that the work has not been published in part or full in any scientific or popular journal or magazine.

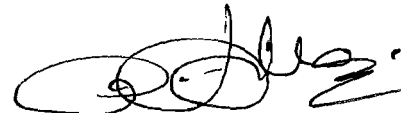
Place : Coimbatore
Date : 09/09/2002



(Dr. P. SUBBIAN)

Approved By

Chairman




(Dr. P. SUBBIAN)

Members



(Dr.A. BALASUBRAMANIAN)



(Dr.C. KAILASAM)



(Dr.A. SARAVANAN)

Date :



EXTERNAL EXAMINER

ACKNOWLEDGEMENT

I would like to express my deep sense of gratitude to **Dr. P. SUBBIAN**, Professor, Department of Agronomy, Tamil Nadu Agricultural University and Chairman of the Advisory Committee for his excellent counseling, steadfast inspiration, consistent encouragement, surpassing guidance with love and affection throughout the course of this study.

I am very thankful to the members of the Advisory Committee, **Dr.A.BALASUBRAMANIAN**, Professor, Department of Agronomy, **Dr.C.KAILASAM**, Professor of Mathematics, and **Dr. A. SARAVANAN**, Professor, Department of Soil Science and Agricultural Chemistry for their valuable suggestions and contributions to this study as Advisory Committee members.

I am very grateful to **Dr. N. SANKARAN**, Professor and Head, Department of Agronomy, and **Dr. T.N. BALASUBRAMANIAN**, Professor and Head, Department of Agricultural Meteorology for their guidance and encouragement throughout the study.

My sincere thanks are due to **Dr.R.SELVARAJU**, and **Dr.C.R.CHINNAMUTHU**, Assistant Professors of Agronomy, and all the staff members of the Department of Agronomy and Department of Soil Science and Agricultural Chemistry for their help during the course of this study.

I wish to express my sincere thanks to **Dr.C.CHINNUSAMY** and **Dr.S.PANNEERSELVAM**, Associate Professors of Agronomy and **Thiru.E.SOMASUNDARAM**, Assistant Professor of Agronomy for their help as Farm Managers for the successful completion of this study.

My sincere thanks are due to **Dr.K.K.CHANDRAGIRI** and **Dr.P.DEVASENAPATHY**, Professors of Agronomy for their help and encouragement as PG Coordinators.

My sincere thanks are due to **Thiru.S.MARIMUTHU**, **Ms.K.M.S.SUMATHI**, and **Ms.K.SATHYABAMA**, Ph.D. Scholars and all my classmates and friends who have in one way or other contributed to the successful completion of this thesis.

I greatly thank M/s Soumiya Communications and **Thiru.S.Lakshmi Narasimhan**, for their timely help and neat and prompt execution of thesis typing.

My sincere thanks are due to my husband, parents, brothers and sister for their constant encouragement and help throughout the study period.


(C. UMA MAHESWARI)

ABSTRACT

MAIZE BASED CROPPING SYSTEMS AND INTEGRATED NUTRIENT MANAGEMENT PRACTICES ON SOIL QUALITY AND CROP PRODUCTIVITY

BY

C. UMA MAHESWARI

Degree : **DOCTOR OF PHILOSOPHY (AGRICULTURE) IN
AGRONOMY**

Chairman : **Dr. P. SUBBIAN**
Professor (Agronomy)
Department of Agronomy
Tamil Nadu Agricultural University
Coimbatore – 641 003.

Year : **2002**

Field experiments were conducted at Tamil Nadu Agricultural University for two years covering seven seasons (from Summer 2000 – Summer 2002) to study the effect of maize based cropping systems and integrated nutrient management practices on soil physical, chemical and biological properties, growth and yield of the component crops and soil available nutrient balance. The experiment was laid out in split plot design with three replications. The cropping systems, viz., maize-fallow-fallow, maize-fallow-cowpea, maize-sunflower-cowpea were the main plot treatments and the integrated nutrient management practices, viz., 100% recommended NPK + FYM, 150% recommended NPK + FYM, 100% recommended NPK + FYM + Zn + Fe and 150%

recommended NPK + FYM + Zn + Fe formed the sub-plot treatments. The maize, sunflower and cowpea crops were raised in the summer (December to April), kharif (June to August) and rabi (September to November) seasons, respectively. The FYM was applied @ 12.5 t ha⁻¹ and zinc sulphate @ 25 kg ha⁻¹ as basal. The ferrous sulphate was applied as 1% foliar spray.

The dry matter production and root dry weight at harvest, grain yield, straw yield and nutrient uptake by the component crops were recorded. The crop residues were added to soil after the harvest of the grain. Post harvest soil samples were analysed for the determination of bulk density, hydraulic conductivity, porosity, percentage of water stable aggregates, available soil moisture, organic carbon, available nitrogen, phosphorus and potassium and population of bacteria, fungi and actinomycetes. The results revealed that the maize-sunflower-cowpea system increased dry matter production, root dry weight, grain and stover yield of the component crops in all the seasons followed by maize-fallow-cowpea system. The maize-fallow-fallow system was inferior to other two systems in increasing the growth and yield of maize. The maize-sunflower-cowpea and maize-fallow-cowpea systems had no significant influence on the growth and yield of cowpea. The growth and yield of the maize, sunflower and cowpea were significantly increased by the application of 150% NPK + FYM compared to 100% NPK + FYM. There was a marginal increase in the growth and yield of the maize, sunflower and cowpea due to application of micronutrients. The maize-sunflower-cowpea system with 150% NPK + FYM and 150% NPK + FYM + Zn + Fe significantly increased the growth and yield of all the three crops.

Significant decrease in bulk density was noticed under maize-sunflower-cowpea system followed by maize-fallow-cowpea system in the last three seasons (Kharif 2001, rabi 2001 and summer 2002). During the previous seasons, there was no significant

decrease in bulk density under the different cropping systems. The non-capillary porosity, total porosity, hydraulic conductivity, percentage of water stable aggregates, moisture content at field capacity, permanent wilting point and available soil moisture content significantly increased under the maize-sunflower-cowpea system followed by the maize-fallow-cowpea system in all the seasons. The corresponding improvement in soil physical properties was less under maize-fallow-fallow system. There was no significant influence of different cropping systems on capillary porosity. The bulk density was lower and capillary porosity, total porosity, hydraulic conductivity, percentage of water stable aggregates, moisture content at field capacity and permanent wilting point and available soil moisture were higher with 150% NPK + FYM when compared to 100% NPK + FYM, but in general, the increase was not significant.

The build up in soil organic carbon, available nitrogen and phosphorus contents was significantly higher under maize-sunflower-cowpea and maize-fallow-cowpea systems than under maize-fallow-fallow system. Cropping systems did not significantly influence the available potassium content of soil in all the seasons. The organic carbon content was significantly higher with 150% NPK + FYM than with 100% NPK + FYM. Available nitrogen, phosphorus and potassium were not significantly influenced by integrated nutrient management practices. The maize-sunflower-cowpea system with 150% NPK + FYM + Zn + Fe and 150% NPK + FYM recorded higher values of organic carbon, available nitrogen, phosphorus and potassium in all the seasons.

The population of bacteria, fungi and actinomycetes was higher under maize-sunflower-cowpea system followed by maize-fallow-cowpea system. The influence of integrated nutrient management practices on microbial population was not consistent in all the seasons. The microbial population was invariably higher at 150% NPK + FYM than with 100% NPK + FYM treatment.

The nitrogen, phosphorus and potassium uptake values by component crops of maize, sunflower and cowpea were higher under maize-sunflower-cowpea system followed by maize-fallow-cowpea system. The nutrient uptake was significantly higher at 150% NPK + FYM than the 100% NPK + FYM. Micronutrients had no significant influence on nutrient uptake by maize, sunflower and cowpea.

The available nitrogen, phosphorus and potassium status increased considerably under maize-sunflower-cowpea system at the end of the cropping cycle III closely followed by the maize-fallow-cowpea system.

Among the integrated nutrient management practices, 150% NPK + FYM + Zn + Fe (F₄) and 100% NPK + FYM (F₁) behaved similarly in increasing the soil available nitrogen and phosphorus status at the end of cropping cycle III. With respect to soil available potassium the 150% NPK + FYM + Zn + Fe (F₄), 150% NPK + FYM (F₂) and 100% NPK + FYM (F₁) behaved similarly with higher values of soil available potassium.

The maize-sunflower-cowpea system with 150% NPK + FYM + Zn + Fe produced higher net return; however, the B/C ratio was higher under maize-fallow-fallow system with 150% NPK + FYM + Zn + Fe in both the crop cycles.

CONTENTS

Chapter No.	<i>Title</i>	Page No.
I	INTRODUCTION	1
II	REVIEW OF LITERATURE	5
III	MATERIALS AND METHODS	33
IV	RESULTS	50
V	DISCUSSION	112
VI	SUMMARY AND CONCLUSION	149
	REFERENCES	
	APPENDIX	

LIST OF TABLES

Table No.	Title	Page No.
1	Characteristics of crop varieties and seasons	34
2a	Soil characteristics of the experimental field at the inception of the experiment in January 1999	38
2b	Soil physical and chemical properties at the end of <i>rabi</i> 1999 cropping season	39
3	Dry matter production of crops at harvest (kg ha ⁻¹)	51
4	Root dry weight of crops at harvest (kg ha ⁻¹)	54
5	Grain yield of crops (kg ha ⁻¹)	57
6	Stover, stalk and haulm yield of maize, sunflower and cowpea, respectively (kg ha ⁻¹)	60
7	Crop residue addition (kg ha ⁻¹)	63
8	Bulk density (Mg m ⁻³)	65
9	Non capillary porosity (%)	67
10	Capillary porosity (%)	69
11	Total porosity (%)	70
12	Hydraulic conductivity (cm hr ⁻¹)	72
13	Water stable aggregates (>25 mm) (%)	74
14	Field capacity (%)	76
15	Permanent wilting point (%)	78

Table No.	Title	Page No.
16.	Available soil moisture (cm m ⁻¹)	80
17.	Organic carbon (%)	81
18.	Available nitrogen (kg ha ⁻¹)	84
19.	Available phosphorus (kg ha ⁻¹)	86
20.	Available potassium (kg ha ⁻¹)	87
21.	Population of bacteria	89
22.	Population of fungi	92
23.	Population of actinomycetes	95
24.	Nutrient uptake by maize (kg ha ⁻¹)	98
25.	Nutrient uptake by sunflower (kg ha ⁻¹)	101
26.	Nutrient uptake by cowpea (kg ha ⁻¹)	103
27.	Available nitrogen balance (kg ha ⁻¹)	105
28.	Available phosphorus balance (kg ha ⁻¹)	107
29.	Available potassium balance (kg ha ⁻¹)	108
30.	Economics (Cropping cycle I)	110
31.	Economics (Cropping cycle II)	111

LIST OF FIGURES

Figure No.	Title	Page No.
1.	Weather prevailed during cropping cycle I (Jan. 2000 to Dec. 2001)	35
2.	Weather prevailed during cropping cycle II (Dec. 2000 to Nov. 2001)	36
3.	Weather prevailed during summer (Dec. 2001 to April 2002) cropping season	37
4.	Layout of the treatments in the experimental field	42
5.	Dry matter production of the component crops under different cropping systems and integrated nutrient management practices	113
6.	Grain yield of the component crops under different cropping systems and integrated nutrient management practices	115
7.	Bulk density under different cropping systems and integrated nutrient management practices	123
8.	Water stable aggregates under different cropping systems and integrated nutrient management practices	125
9.	Available soil moisture under different cropping systems and integrated nutrient management practices	127
10.	Organic carbon under different cropping systems and integrated nutrient management practices	129
11.	Available nitrogen content under different cropping systems and integrated nutrient management practices	131
12.	Available phosphorus content under different cropping systems and integrated nutrient management practices	135
13.	Available potassium content under different cropping systems and integrated nutrient management practices	136
14.	Net returns under different cropping systems and integrated nutrient management practices	146
15.	Benefit cost ratio under different cropping systems and integrated nutrient management practices	147

INTRODUCTION

*“A farmer should live as though he were going to die tomorrow,
but he should farm as though he were going to live forever”*

- George Ewart Evans

In only half a century, the world population will touch 10 billion mark. Of the additional 4.3 billion expected by 2050, 95 per cent will live in developing countries where over three-fourth of the global population already resides. Food demand in developing countries would more than double by the year 2025, and could triple by 2050. Cereal grain yields would then have to increase from the 1992 global average of 2.8 metric tons per hectare to 4.2 metric tons per hectare simply to maintain the 1992 status quo on a per capita basis, since there is little likelihood of increasing the area under cultivation.

It is estimated that India's population by 2010 will be 1.2 billions and the total food demand by that time will be around 245 MT from the present production of 206 MT. Though increase in food grain production to feed the burgeoning population is technically achievable, the question remains whether the targets in food grain production can be achieved with economically viable, environmentally sustainable systems, without causing degradation and pollution of soil, air and water.

Sustainable development has been accepted as a concept that must be central to all future human endeavours. Development of new agricultural technologies and a better appreciation of the existing but underutilised knowledge of resource management will be crucial in meeting the ecological needs and in achieving the anticipated food demands of the growing population in the future. Experience over the past three decades has shown

that mismatch between crop production methods and resource characteristics has led to decline in soil fertility, increased soil losses, disturbed ecological balance and a build up of pests and diseases. The expanded food needs of the future must be met without great expansion in the area of land under cultivation. The added production must come primarily from increase in yields per unit area and time. In this context, system approach of crop production and the role of effective plant nutrient management in increasing and sustaining productivity of cropping systems need no emphasis.

Maize is the third largest food grain crop next to wheat and rice, occupying 6.3 million hectares in India with a total annual production of 10.13 million tones and productivity of 1716 kg ha⁻¹. In Tamil Nadu, maize occupies an area of 0.082 million ha with a production of 0.132 million tones and productivity of 1625 kg ha⁻¹. Even though maize has got a great potential, its productivity is often limited due to moisture stress, poor soil fertility and inefficient agronomic management. As the importance and demand of maize is gaining momentum due to its diversified use, it is essential to enhance the productivity of maize by improving the soil quality through efficient cropping systems and nutrient management practices.

The deficiency of micronutrients and secondary nutrients that occurs due to imbalanced and non-integrated use of fertilizers limits the crop yields after a period of time and their application becomes necessary to sustain high yield potential. The integrated use of optimal dose of NPK and FYM gives better and sustainable yields and it can also correct some of the micronutrient and secondary nutrient deficiencies.

Soils of India, in spite of being cultivated from time immemorial, could maintain productivity mainly due to inclusion of legume component invariably in the cropping systems. Legumes enrich the soil by adding N through fixation or organic matter through

leaf fall and root residues. Incorporation of haulms having narrow C:N ratio also adds to soil fertility build up, besides saving energy input and N equivalent of 20 to 30 kg ha⁻¹.

In most of the Indian soils, intensive cropping under tropical irrigated conditions depletes the organic matter and results in the deficiency of major and micro nutrients, unless it is replenished by substances comprising inorganic fertilizer, organic manures and crop residues. The average amount of crop residues added through roots and stubbles left in the soil, after the harvest of crops accounted to 3 t ha⁻¹ each year (Subbian and Palaniappan, 1992). Inclusion of legumes in intensive cropping systems increased the organic carbon, available N, P and K contents of soil from their initial status (Lekha Sreekantan and Palaniappan, 1989).

Soil organic carbon plays a major role on the productivity of agricultural crops in tropics and sub tropics. It has been estimated that 15-17 per cent of the carbon transferred to atmosphere from terrestrial ecosystems comes from the decomposition of soil organic carbon (Houghton and Hackler, 1994). The loss of soil organic carbon leads to deterioration of soil quality and green house effect (Velayutham *et al.*, 2000). Hence, restoration of soil and environmental quality through soil organic carbon management is a major concern for tropical soils. For maintaining and improving soil organic carbon content, suitable cropping systems and integrated nutrient management practices are to be evolved.

Maintaining innate soil fertility through judicious crop residue management is an urgent priority in tropical cropping systems, since it is not possible to apply adequate bulky organic manures. In highly productive fields, the soil nutrient supply matches the crop nutrient uptake pattern. The yield benefits from high native soil fertility are indeed difficult to replace with fertilizers. The most conservative estimates show that hardly

270-300 MT of organic manures of different kinds contributing around 4 to 6 million tonnes of NPK are available in the country.

Summer fallowing without any crop residues addition is being traditionally followed by the farmers to allow the land to conserve moisture. Leaving the land as fallow for one or two seasons in the crop rotations is reported to improve the soil quality. However, studies on the influence of fallowing on soil quality in crop rotations are very limited.

In this context, the present investigation was designed to study the influence of fallowing with crop residue additions and integrated nutrient management practices on soil quality and productivity of maize based cropping systems with the following objectives:

- i. to study the influence of maize-based cropping system and integrated nutrient management practices on soil properties.
- ii. to enhance the productivity of maize and maize-based cropping systems by improving soil properties.
- iii. to study the effect of fallowing on the soil properties and maize yield.
- iv. to work out the nutrient balance and economics for maize-based cropping systems and integrated nutrient management practices.

CHAPTER II

REVIEW OF LITERATURE

Nutrient management in intensive cropping systems is crucial for sustainable use of soils with low inherent fertility. (Nutrient recycling through crop residues reduces nutrient losses and minimizes the requirement for chemical fertilizers.) Most of the prevalent land uses and predominant agricultural systems are characterised, with few notable exceptions, by low crop and animal productivity, rapid decline in productivity with continuous use and high rates of soil and environmental degradation. The impact of soil and crop management in various cropping systems with reference to fallowing and integrated nutrient management on soil properties and crop productivity are reviewed and presented in this chapter.

2.1. Soil quality

Soil quality is the capacity of a specific kind of soil to function, within natural or managed ecosystem boundaries, to sustain plant and animal productivity, maintain or enhance water and air quality, and support human health and habitation (Karlen *et al.*, 1995). Soil quality depends on a range of soil properties and processes. The important properties related to soil quality are soil structure, soil organic carbon content, available water, nutrient reserves, aeration, rate and magnitude of nutrient cycling and transformations; the important processes are accelerated erosion, leaching, depletion of soil organic matter and soil fertility leading to nutrient deficiencies and toxicities and anaerobiosis (Lal and Muller, 1993). Warkentin (1995) reported that the concept of soil quality has changed from 'suitability to chosen uses' to the 'range of possible uses' of the

soil to finally the 'intrinsic value' of the soil in the biosphere. The criteria suggested for the parameter 'intrinsic value' was irreplaceable and uniqueness.

Sustainability is intimately linked to soil quality. The principal objective of a sustainable land use system is to maintain a high level of productivity, maintain or improve environmental and aesthetic attributes and enhance soil quality (CGIAR, 1990). Soil quality enhancement requires improvement of soil physical, chemical and biological properties through improvement in soil structure, available nutrient status, soil organic matter content and soil biodiversity (Subbian *et al.*, 2000).

2.1.1. Cropping systems and integrated nutrient management on soil quality

The effect of crop rotations on soil quality is due to the interaction of many factors including soil structure (Roder *et al.*, 1989). Inclusion of suitable species in the cropping systems, especially legumes, has beneficial effects in enhancing aggregate stability and other physical properties of the soil. The soil organic carbon and total N content were found to increase under - legume based cropping systems in comparison to monoculture (Subbian and Palaniappan, 1992). Although cereal crops benefit from biological N fixation and the soil N conserving effect of the preceding legume - *Rhizobium* symbiosis, several reports suggest non - N rotational effects on soil properties and successive crops (Cook, 1988; Fyson and Oaks, 1990; Wani *et al.*, 1991).

Crop rotations, which include legumes, improve soil physical characteristics to a greater extent compared to those, which do not include legumes (Misra *et al.*, 1999). Legumes in rotation improve soil fertility especially mineralisable N content in the soil (Campbell *et al.*, 1991). The active fraction (the ratio of potentially mineralisable N to the total N) is affected by the cropping history of the soil and increases under diverse

cropping systems compared to monoculture (Peterson and Varvel, 1989; Mc Gill *et al.*, 1998).

Legumes stimulate microbial activity in the rhizosphere more than cereals (Hoflich *et al.*, 2000). Many authors reported higher soil microbial biomass and diversity in rotations compared to monoculture (Franzluebbers *et al.*, 1995; Weigand *et al.*, 1995; Lupwayi *et al.*, 1999). The rotations modify the relationship between soil organic carbon and microbial biomass (Anderson and Domsch, 1989). With increased crop diversity, there is a reduction in pathogenic and non-pathogenic deleterious microorganisms and proliferation of beneficial organisms including mycorrhizae (Jawson *et al.*, 1983; Cook, 1984; Turco *et al.*, 1990).

Nutrient management is crucial to sustained crop production. Highly weathered soils, being inherently low in nutrient reserves, need a regular and supplemental nutrient supply to facilitate intensive cropping (Lal, 1994). Intensive land use and high yields on soils of low inherent fertility can be achieved only by raising the nutrient levels through the use of inorganic fertilizers, organic manures and nutrient recycling through crop residues (Nambiar and Abrol, 1989; Hegde, 1996). In this regard, agricultural intensification implies adoption of high yielding varieties, and applying appropriate type and rate of chemical fertilizers and organic manures to sustain productivity (Dick, 1992; Caporali and Onnis, 1992; Reeves, 1994).

2.2. Fallowing

In less intensive systems, the land is left as fallow for one or two seasons. Fallowing intensifies loss of organic carbon from the soil. The detrimental effect of fallowing on soil organic carbon is two fold. Fallow systems produce no above or below ground residue since they are kept weed and crop free and biological

oxidation of existing soil organic carbon increases substantially. All the more, labile attributes decrease considerably by fallowing (Wani *et al.*, 1995; Campbell *et al.*, 1999). Soil microbial biomass is an important agent in nutrient transformations and is a crucial factor in soil fertility and ecosystem functioning (Smith and Paul, 1990). Soil microbial biomass and diversity are low in fallow systems because a regular and sizable addition of manures and crop residues is absent to maintain a favourable level of soil organic matter content (Campbell *et al.*, 1991).

2.2.1. Fallowing on soil physical properties and available nutrients

Favourable effect of fallowing on soil physical and chemical properties is reported by several authors. Fallowing had a favourable effect on water stable aggregation, hydraulic conductivity and infiltration of a silty clay loam soil at Pantnagar compared to rice-wheat-cowpea rotation (Kurual and Tripathi, 1990). The organic matter, bulk density and water content of a Mollisol at Pantnagar improved due to fallowing compared to the unfertilized rice-wheat plots which were continuously cropped for 9 years (Bharadwaj and Omanwar, 1992). Fallowing increased the nitrate content of a black soil at Hyderabad compared to cropped plots on which sorghum was grown (Das and Rao, 1986) and available nutrient status of a Mollisol at Pantnagar compared to an unfertilized rice-wheat-cowpea rotation (Tyagi and Venkatesh Bharadwaj, 1994).

The negative effect of fallowing on soil fertility is also reported. Available nutrients decreased under fallow – pearl millet sequence on a loamy sand soil compared to legume- pearl millet rotation (Rao *et al.*, 1995). The mineralisable N content of a Vertisol at Patancheru, Hyderabad decreased under fallow-sorghum rotation compared to cropping systems with pigeonpea as a component crop (Wani *et al.*, 1995). The labile

fractions of soil organic matter in silt loam soil decreased with the practice of fallowing every two years, compared to continuous wheat after a period of 29 years (Campbell *et al.*, 1999).

2.2.2. Fallowing on microbial population

The microbial biomass is supplied with carbon mainly from active fractions of soil organic matter and the passive fractions supply only a small proportion (Paustian *et al.*, 1992). The microbial biomass is very sensitive to management practices and any change in management is reflected on the biomass faster than that on the soil organic matter (Powlson *et al.*, 1987). Agricultural soils vary widely in their microbial biomass as a result of crop management practices and inherent properties (Campbell *et al.*, 1991).

Few reports reveal a favourable effect of fallowing on microbial population. Fallowing had a positive effect on microbial biomass, compared to a rice-lentil sequence at Varanasi (Ghoshal and Singh, 1995). Bharadwaj and Omanwar (1992) recorded a favourable effect of fallowing on microbial biomass in a Mollisol at Pantnagar compared to a rice-wheat-cowpea sequence.

A decline in microbial population due to fallowing was also reported by a few authors. Fallowing had a detrimental effect on microbial population compared to legume – wheat rotation (Sawasha and Patil, 1985) and on VAM fungi in a P-deficient sandy loam soil at New Delhi compared to soils cropped with wheat and chickpeas (Mohan Singh and Tilak, 1992).

2.2.3. Fallowing effects on yield

Increase in yield of crops grown after a fallow period is reported by a few authors. The yield of safflower grown after a season of fallowing on a Vertisol at Jalgaon

increased compared to groundnut as the preceding crop (Mahajan and Nikam, 1992). The yield of mustard was higher in a fallow-mustard sequence compared to cereal – mustard and sorghum-mustard sequences (Sharma *et al.*, 1992; 1995).

Many experiments revealed a decline in yield of the crops that were grown after a fallow period. The yield of mustard and safflower declined when they were preceded by a fallow period compared to greengram as the preceding crop (Sachan and Bhas, 1986). The yield of wheat was reduced when it was preceded by a fallow period compared to mungbeans and urbeans as the previous crops; the yields of wheat with 90 kg N ha⁻¹ after the legumes were similar to those with 120 kg N ha⁻¹ after fallow (Yadav, 1990). The yield of wheat that followed a fallow period declined compared to pigeonpea as the previous crop (Mishra, 1994). The grain yield of wheat and barley (Singh and Uttam, 1994) and mustard (Tomar *et al.*, 1994) decreased when they were preceded by a fallow period compared to blackgram as the previous crop in a clay loam soil at Tikamgarh, Madhya Pradesh.

Under few situations a high response to added nutrients was recorded in systems which included a fallow period compared to others. The response of wheat to added N at rates ranging from 0-150 kg ha⁻¹ was 19.5 kg grain kg⁻¹ N in fallow plots in an Inceptisol at Ludhiana compared to 14.8 kg in plots where cowpea was grown in the previous season (Sidhu *et al.*, 1992). The grain yield of wheat increased with N upto 120 kg ha⁻¹ when it was grown after a fallow period in a sandy loam soil at Ranchi, but the grain yield increased with only upto 80 kg N ha⁻¹ when it was preceded by groundnut and blackgram (Srivastava and Srivastava, 1993). Sinha and Rai (1994) reported that wheat grain yield was increased due to fertilization when grown after fallowing but there was no response to fertilization when grown after cowpea.

2.3. Integrated nutrient management in cropping systems

In the cereal-based cropping systems, about 25-50 per cent of fertilizer dose could be curtailed with the use of organics such as FYM and crop residues. High crop yields can be achieved with application of adequate quantities of inorganic nutrients in conjunction with organic manures (Subramanian and Kumaraswamy, 1989; Lal and Stewart, 1995).

2.3.1. Role of crop residues, FYM and inorganic fertilizers in cropping systems

The effect of cropping frequency is reflected on the amount of organic carbon and N because of the differences in crop residue addition (Campbell *et al.*, 1999). With higher rate of fertilizer application, not only the organic carbon content of the soil increases but its mineralizable potential also increases (Paustian *et al.*, 1997; Dormaar and Carefoot, 1998). An increase in soil organic carbon due to fertilization is often attributed to improved crop nutrition and dry matter production which in turn increased the crop residues added to the soil (Gregorich *et al.*, 1996). Balubane (1996) reported that the contribution of maize root-derived carbon to soil organic carbon was 1.5 times that of stover carbon and the decay rate of root-derived organic carbon was slower.

The FYM application increases the total N under diverse cropping systems. When FYM is applied, the N is better preserved in macroaggregates due to greater microbial activity and immobilisation (Wani *et al.*, 1994). Christensen and Olesen (1998) reported that long-term annual additions of crop residues contribute mainly to the accumulation of soil N with a slow turnover and the increase in N mineralisation with 4 t ha⁻¹ of crop residues corresponded to 11 kg N ha⁻¹. The residual effect of crop residues is prolonged (half life of 10 years) and probably result from changes in soil properties that enhance the nutrient availability (Prasad and Power, 1991).

2.3.2. Decomposition and nutrient supply from crop residues and FYM

The biodegradation of crop residues involves different fungal species at different stages of decomposition (Robinson *et al.*, 1994). Rasmussen and Collins (1991) reported that the Q_{10} value (the change in the rate of reaction for every 10°C change in temperature) of crop residue decomposition averages about 2.6 for temperatures from 12.5 to 40°C and decomposition occurs rapidly at water potential of about -0.3 bars. Decomposition rate of crop residue decreases as the soluble carbon and total nitrogen in the residue decreases and C/N ratio and lignin content increases. Franzluebbers *et al.* (1995) reported that low levels of soil microbial biomass result in an initially slower rate of decomposition of soil incorporated organic materials.

After the incorporation of chopped rice straw (C/N ratio 72) and rock phosphate, the C/N ratio decreased to 11 and N content increased upto 60 days and became relatively stable after 90 days (Singh and Yadav, 1986). When sugarcane trash was incorporated (chopped to 1-2 cm) at 20 t ha⁻¹ with 150 kg N ha⁻¹ in four types of sugarcane growing soils at Lucknow, the decomposition was fast up to 60 days and stabilized after 90 days. The available N decreased over the control up to 30 days upon application of trash alone and thereafter increased. Addition of N helped in releasing more nutrients from the trash and overcoming immobilisation of soil N (Yadav *et al.*, 1987).

Application of wheat crop residues to various soils at Ludhiana accelerated the decomposition of native soil organic matter by 0.20 to 22 per cent and the decomposition was high in soils having low soil organic matter (Raina and Goswami, 1988).

Application of FYM to a sandy loam soil at Ludhiana resulted in a net immobilisation of soil N which lasted up to 4 weeks and by the end of 16th week only 19 per cent of the added N was mineralized (Singh *et al.*, 1988.) It is also reported

that when rice and wheat straw were incorporated at 60 per cent water holding capacity of the soil, 25 to 43 per cent of the applied carbon was decomposed in 60 days period. When maize stover and paddy straw were added to a red sandy soil at Bangalore, the dehydrogenase activity had increased over a period of 60 days; however, during the initial 20 days, immobilisation of N resulted in very low available N (Shivaramu *et al.*, 1994).

At 50 per cent water holding capacity of the soil, sunflower residues decomposed rapidly and wheat straw decomposition rates declined slowly over time. The decomposition of FYM was slower and uniform. Application of FYM increased the soil organic matter, available N and P to a greater extent and the increase in available K was maximum with crop residue addition (Patil *et al.*, 1993). Addition of sorghum residues (C/N ratio 72) at field capacity and 50 per cent field capacity resulted in N immobilisation upto 90 days. The N release was always greater at field capacity and the critical C/N ratios below which N release and above which N immobilisation would occur were 46 and 39 at field capacity and permanent wilting point, respectively (Das *et al.*, 1993).

2.3.3. Integrated nutrient management on soil physical properties

Soil variables respond to management practices in different time scales (Dormaar and Carefoot, 1998). Among the soil physical properties, texture is an important factor that affects soil organic carbon through chemical and physical protection of recent carbon inputs (Hassink and Whitmore, 1997). Soils with fine textures retain more of the residue carbon returned to the soil and the turnover of this carbon is slower than in soils with coarser textures. Hence coarse textured soils need to be carefully managed in order to maintain soil organic matter levels under continuous cultivation (Liang *et al.*, 1998).

Many authors reported that integrated nutrient management practices favourably influenced the physical properties of the soil such as bulk density, porosity, aggregate stability, hydraulic conductivity, available soil moisture and infiltration rate. (Favourable effect on soil physical properties was reported due to application of FYM to a maize + soybean – wheat sequence on an acid soil at Palampur over 3 years (Dinesh Badiyala and Verma, 1990). Application of FYM to sorghum + pigeonpea and sorghum + cowpea systems improved the physical properties of the soil (Lomte *et al.*, 1993). The FYM applied to a black soil at Indore under wheat–fodder maize–soybean sequence had favourable effect on soil physical properties (Kesavan *et al.*, 1995). The FYM applied once in every year for 20 years to maize in maize – wheat – cowpea rotation on a loamy soil improved the soil physical properties (Benbi *et al.*, 1998; Aoyama *et al.*, 1999). Continuous application of FYM + NPK to an acidic red loam soil at Ranchi over a period of 20 years (Prasad and Singh, 1980) and to a deep black soil at Navsari under rice–wheat – green gram sequence for a period of 6 years (Patel *et al.*, 1993) resulted in significant improvement in soil physical properties.)

Bhagat and Verma (1991) reported that application of FYM + rice straw to a clay soil at Palampur over a 5 year period improved the soil physical properties. Application of crop residues to a loamy sand and sandy loam soil at Telengana under a pearl millet–cowpea sequence over an 8 year period was found to improve the soil physical properties (Venkateswarlu, 1987). Incorporation of sorghum stubbles and safflower stalks each at 5 t ha⁻¹ to a Vertisol at Bijapur (Badanur *et al.*, 1990), addition of sorghum stubbles to a Vertisol at Dharwad (Bellaki and Badanur, 1994) and incorporation of *Lantana camara* at 10–30 t ha⁻¹ to a silty clay loam soil at Palampur under a rice – wheat sequence (Sharma *et al.*, 1995) influenced the soil physical properties favourably.

Non-significant effect of integrated nutrient management practices on soil physical properties was also reported. Darwish *et al.* (1995) found that manure-induced physical changes in the soil were small and evidently did not accumulate over time. Rapid microbial decomposition of the manure could be responsible for the lack of marked changes in the soil physical properties. Soon (1998) reported that removal or incorporation of barley straw over 10 years from adequately fertilized continuous cropping systems did not significantly influence soil aggregate stability. Aoyoma *et al.* (1999) found that long term application of NPK fertilizers to a loamy soil had no impact on soil organic carbon content and aggregate stability.

2.3.4. Integrated nutrient management on organic carbon and available nutrients

The organic carbon content of the soils is highly correlated with their potential productivity. Although the amount of soil organic matter in most semiarid dryland soils is relatively low ranging from 0.5 to 3.0 per cent and typically less than 1.0 per cent, its influence on soil properties is of major significance. Even at low concentrations, soil organic carbon is the major substance facilitating aggregation and structural stability (Smith and Elliot, 1990). Belanger *et al.* (1999) reported that the response of soil organic carbon to increased crop residue addition is dependent on soil texture and its organic carbon content.

(An increase in organic carbon and available N, P and K in the soil was noticed due to application of FYM + NPK to an acidic red loam soil at Ranchi (Prasad and Singh, 1980) and incorporation of chopped wheat straw at 4 t ha⁻¹ to a maize-wheat rotation at Ludhiana (Sidhu and Beri, 1989) (Application of FYM + NPK to an Alfisol at Palampur (Deepak Kher, 1991) and greengram residues + NPK to a sandy loam soil at Ludhiana under a greengram – maize – wheat sequence (Sidhu and Sur, 1993) resulted in an

increase in organic carbon and available nutrients. Application of 100 per cent NPK + FYM to an Inceptisol at Coimbatore (Sreeramachandrasekaran *et al.*, 1995) and incorporation of rice straw and FYM each at 5 t ha⁻¹ to a wheat-rice rotation at Palampur (Verma and Bhagat, 1992) improved the soil organic carbon and available nutrients.)

(A non-significant impact was observed due to increasing doses of fertilization on organic carbon and available P and K content of an Inceptisol at Coimbatore under pearl millet – wheat sequence; but significant positive effect was observed on available N (Gupta *et al.*, 1992). Darwish *et al.* (1995) reported that addition of FYM for 15 years to sandy loam, silt loam and clay loam soils increased the soil organic carbon by 3 per cent in the sandy loam and by 25 per cent in silt loam and clay loam and about 95 per cent of the added manure had been degraded over the 15 years.

Incorporation of maize residues in a red sandy clay soil at Bangalore resulted in a non significant change in available N and P; but significant increase in soil organic matter and available K was noticed (Hegde *et al.*, 1982). Gregorich *et al.* (1996) found that even with more than 30 years of fertilization to maize, the increase in organic carbon was not significant but the amount of maize-derived carbon in the soil increased. When adequate N fertilizers were used, straw removal or incorporation had no effect on total N content of the soil (Soon, 1998).

(Even with integrated nutrient management, a decline in organic carbon and available nutrients was also reported. Mandal *et al.* (1984) reported a decline in organic carbon and total N in a new Gangetic alluvial soil at Barrackpore with 8 years of continuous manuring to a jute-rice-wheat rotation, while increase in available N and P was noticed. Decline in available N was observed in an Inceptisol at Hisar with NPK + FYM application to a pearl millet – wheat sequence. Increasing doses of fertilizer N had

very little effect on soil organic carbon, available P and K but had significant positive effect on available N (Gupta *et al.*, 1992). Soil available K status was found declining in a red soil at Coimbatore with FYM + NPK + crop residues application (Sundara, 1993). A decrease in soil available N with manure application and soil organic carbon with straw incorporation was observed by Nuttal *et al.* (1986) and Weill *et al.* (1990). Thompson (1992) and Dormaar and Carefoot (1998) noticed an increase in nitrate release and total soil organic carbon with straw removal.

Some problems were also reported that encountered with straw incorporation. Adding more straw diminishes mineralisation and promotes immobilisation if the C/N and C/P ratios of the straw are high (Christensen and Olesen, 1998; Soon, 1998). The reduced nitrate mineralisation and movement down the profile could lead to inadequate nitrate for crop growth after several years (Standly *et al.*, 1990). Although total N got lowered after straw incorporation, in reality it is advantageous in terms of slow release of N during straw decomposition (Dormaar and Carefoot, 1998).

2.3.5. Integrated nutrient management on microbial population

The determination of microbial biomass size and turnover helps to assess the nutrient fluxes through this organic pool. These fluxes have been shown to be equivalent to plant nutrient uptake under various climates (Paul and Clark, 1989). Changes in microbial biomass indicate the early changes in total soil organic matter due to crop residue management. Crop residues and organic amendments are incorporated into soil organic matter only or partly via the microbial biomass (Sabine Houot and Chaussod, 1995). Soils with greater level of microbial biomass may be able to release nutrients more rapidly from the applied plant material (Franzluebbers *et al.*, 1995).

Among the microbes, fungi can grow at much lower water potential than bacteria (Stott *et al.*, 1986) and fungi comprise a large proportion of the active residue-borne microbial community on surface applied residues. Following residue incorporation, fungi dominates the microbial community during the early decomposition period and a shift occurs to a more bacterial dominated community in the later stages. The composition and activity of microbial community are influenced by the previous history of crop residue management.

Many reports revealed that integrated nutrient management practices increase the microbial biomass in the soil and it varies throughout the crop growing period. In an Entisol at Akola, the population of bacteria, fungi and actinomycetes was maximum at 30 days after sowing greengram but it decreased at harvest. The nitrogen fixed by greengram offset the initial immobilisation of soil N due to application of wheat straw (Jaya Niranjane *et al.* 1993).

Microbes use the FYM and crop residues as a source of carbon and hence their population increases due to application of FYM and crop residues. Gaonkar *et al.* (1993) reported an increase in microbial population due to application of FYM + sorghum residues. Combined application of crop residues + fertilizers to wheat (Hema Singh, 1995) and application of FYM to a rice-lentil sequence at Varanasi (Nandita Ghoshal and Singh, 1994) enhanced the microbial population. Application of crop residues to a rice-wheat sequence at Ludhiana resulted in increased microbial population (Walia *et al.*, 1995).

The increase in microbial biomass was higher (81 per cent) when FYM and fertilizers were applied together than FYM alone (51 per cent) compared to control

(Ghoshal and Singh, 1995). During microbial decomposition of crop residues, growth promoting substances were released. Ocio *et al.* (1991) reported that after few weeks of residue incorporation, microbial biomass increased and then decreased slowly back to the initial value. Since crop rotation systems add greater amount of residues to the soil, they support higher microbial biomass (Hoflich *et al.*, 2000). Crop residues serve as a substrate for microbes and their population increases with higher rate of straw application (Das and Mukherjee, 1990).

The impact of management practices on microbial biomass may also be small. Rochette and Gregorich (1998) found that application of 200 kg N ha⁻¹ in the form of ammonium nitrate annually over three years to maize grown on a loamy soil had little effect on microbial biomass.

The availability of N to the crop is reduced if the residues contain readily oxidizable carbon and low N because of immobilisation of soil N (Smith and Elliot, 1990); addition of fertilizer N is essential to offset this adverse effect on crop growth (Jaya Niranjane *et al.*, 1993).

2.3.6. Integrated nutrient management on dry matter production and nutrient uptake by crops

Soil nitrogen uptake by the plants increases with decrease in fertilizer N levels and in the absence of fertilizer addition, plants utilize N mineralised from the labile soil organic matter pool (Morel *et al.*, 1984). Nutrient uptake is related to the microbial biomass size since microbes regulate nutrient cycling via mineralization and immobilisation.

Crop residues with low C/N ratio increase the nutrient uptake by the following crops. Fertilizer application increases the available form of mineral nutrients.

Viswanathan and Doddamani (1994) found that applied P to maize on a Vertisol increased all forms of soil P with increases in Al-P being the greatest. From stepwise regression analysis it was found that Al-P was the main source of P contributing to P uptake by maize.

Response of crops to applied N depends on soil organic carbon content. The response of field pea grown on various soil types at Gurdaspur to applied N decreased with increasing soil organic carbon content (Azad *et al.*, 1992).

(An increase in DMP and N, P and K uptake was reported due to application of cowpea residues + fertilizers to maize on a sandy soil at Ludhiana (Hundal *et al.*, 1990). The contribution of cowpea residues in pure stand and intercropped stand to total N uptake by the following wheat was 39 and 32 per cent respectively (Patra *et al.*, 1990). ✓

An increase in DMP and N, P and K uptake by maize was observed when it was grown after cowpea on a sandy loam soil at New Delhi (Velayutham and Seth, 1987).

(Application of 60 kg N ha⁻¹ as urea + 60 kg N ha⁻¹ as FYM to sorghum on a Vertisol at Akola (Guldekar *et al.*, 1992), incorporation of wheat residues to mung (Sekhon *et al.*, 1992) and application of 5 t ha⁻¹ of chopped sugarcane trash to wheat in a wheat – maize sequence at Palampur (Dev and Bharadwaj, 1995) increased the nutrient uptake by the crops. ✓)

(The dry matter production and nutrient uptake were higher at higher rate of fertilizer application compared to lower rates as reported by many workers (Chandrasekara *et al.*, 1995; Ghosh and Singh, 1995; Raju and Iruthayaraj, 1995; Soon, 1999).)

The contribution of N from crop residues in rotations to the N uptake by the following crops is low if the residues contain organic N that offers resistance to

decomposition (Omay *et al.*, 1998). Thomson and Jensen (1994) found that the uptake of straw N by three successive spring barley crops was 5, 3 and 1 per cent respectively, most of the N was retained in the soil. Non significant effect of integrated nutrient management practices on nutrient uptake by the crops was also reported by many other workers (Annadurai and Palaniappan, 1994; Singaram and Kothandaraman, 1994).

2.3.7. Integrated nutrient management on crop yield

Crop yield has a significant correlation with soil inorganic N content, rate of N mineralization and light fraction N at 0-15 cm depth (Barrios *et al.*, 1996). Crop yield is immediately increased by application of commercial fertilizers, but in over-fertilized systems the yield is less stable (Susanne Aref and Wander, 1998).

The effect of residue application on crop yield was greater in the presence of fertilizer (Bahl and Pasricha, 2000), but grain yields are seldom greatly affected by residue management practices under conditions of favourable precipitation, adequate soil moisture, good drainage and adequate available N. Incorporation of residues with high C/N and C/P ratios has detrimental effects on yield because of immobilisation of some N and P and hence recommended rates of fertilizer application is essential to reverse this trend (Soon, 1998).

Many authors reported increased yield of the crops due to application of FYM, crop residues and fertilizers. Application of maize residues to a red sandy clay soil at Bangalore increased the grain yield of maize (Hegde *et al.*, 1982). Chopped wheat residues applied to maize at 4 t ha⁻¹ in a maize-wheat sequence at Ludhiana increased the yield of maize. The yield of maize with application of 80 kg N ha⁻¹ + 4 t ha⁻¹ of chopped wheat residues was identical to that with 120 kg N ha⁻¹ alone (Sidhu and Beri, 1989). Application of 60 kg N ha⁻¹ as wheat straw + 60 kg N ha⁻¹ as urea to sorghum on a

Vertisol at Akola (Guldekar *et al.*, 1992) and application of wheat residues + fertilizers to wheat (Telang *et al.*, 1992) had favourable influence on the yield of the crops.

Higher rate of fertilizer application helps to offset the adverse effects of immobilisation of N on crop yields when residues with high C/N ratio are incorporated into the soil (Malhi *et al.*, 1989). Many workers reported higher grain yields with higher rate of fertilization (Khokhani *et al.*, 1993; Poonguzhalan *et al.*, 1996; Soon, 1999).

No measurable effect of higher rates of nutrient addition on crop yields was also reported. In a 10 year study, additional N and P above soil test recommendation applied to a silty clay loam soil had no effect on barley yield (Soon, 1998).

Reduced grain yields with crop residue incorporation are common in areas with adequate to excessive precipitation, low temperatures, poor drainage, poor weed control and low fertility levels (Prasad and Power, 1991). In a rice-wheat rotation at Ludhiana, the effect of crop residue removal and incorporation was measured for 11 years and it was found that residue removal resulted in greater yields than residue incorporation. However, after the discontinuation of residue management practices after 13 years, wheat and maize grown in sequence recorded significantly greater yields on plots where the residues had been previously incorporated (Beri *et al.*, 1995).

2.3.8. Micronutrients in cropping systems

Nutrient balance among the trace elements is as essential as macronutrient balance, but is even more difficult to maintain. Foliar sprays of dilute inorganic salts or organic chelates are more effective than soil treatments where high soil pH or other factors render the soil applied nutrients unavailable (Gupta, 1995). Marked differences in crop needs for micronutrients make fertilization a problem in crop rotations.

2.3.8.1. Integrated nutrient management on soil available micronutrients

The available information on zinc status of soils, role of zinc, uptake and removal of zinc by crops and crop rotations and Zn management in cropping systems were reviewed by Gupta (1995). An increase in available Zn and Fe status of the soil was recorded due to the application of crop residues in a rice-wheat rotation at Ludhiana over a period of 10 years (Beri *et al.*, 1992). Application of ferrous sulphate + zinc sulphate to groundnut on a calcareous soil at Junagadh increased the availability of iron and zinc (Singh *et al.*, 1990).

Conversely, a depletion was recorded in available zinc even with the cumulative effect of application of NPK + FYM to a sorghum – wheat sequence on a Vertisol at Akola (Rao and Dakhore, 1994) and available micronutrient cations with FYM + wheat straw + NPK application to a sodic soil at Faizabad (Alok Kumar and Yadav, 1995).

2.3.8.2. Micronutrients on dry matter production and nutrient uptake by crops

An increase in dry matter production and nutrient uptake by crops was noticed due to micronutrient application. The DMP and uptake of Zn and Fe increased due to application of Zn to maize on a loamy sand soil at Ludhiana (Singh and Nayyar, 1993). Application of 20 kg ZnSO₄ ha⁻¹ or 1 or 2 foliar sprays of 0.5 per cent ZnSO₄ to lentil (Gangwar and Singh, 1991) and application of NPK + ZnSO₄ to maize on a sandy loam soil at Hisar (Chaudhary and Kumar, 1992) increased the DMP and micronutrient uptake. However, Gupta and Potalia (1991) reported a decrease in DMP and Fe uptake by maize on a sandy soil at Hisar with increasing Zn rates.

2.3.8.3. Micronutrients on crop yield

Many studies revealed an increase in yield of crops due to micronutrient application. Three foliar sprays of 2 per cent FeSO_4 to sorghum on a calcareous soil at Coimbatore increased the grain yield (4.71 t ha^{-1}) compared to application of NPK alone (2.83 t ha^{-1}). In the absence of FYM, soil application of FeSO_4 had no significant effect on sorghum grain yield (Nagasundaram *et al.*, 1986). Application of NPK + $25 \text{ kg ZnSO}_4 \text{ ha}^{-1}$ or three foliar sprays of 0.5 per cent FeSO_4 on 30, 40 and 50 days after sowing increased the yield of maize on a red sandy loam soil at Coimbatore (Devarajan *et al.*, 1989). Soil application of $20 \text{ kg ZnSO}_4 \text{ ha}^{-1}$ to pea on a zinc deficient soil (Singh *et al.*, 1988) increased the crop yields.

Application of NPK + 25 kg ZnSO_4 or three foliar sprays of 1 per cent FeSO_4 to wheat on a sandy loam soil at Chiplima, Orissa (Mishra *et al.*, 1989) and $15 \text{ kg ZnSO}_4 + 50 \text{ kg P ha}^{-1}$ to sorghum on a medium black soil at Akola (Pandurangi *et al.*, 1989) enhanced the crop yields. Application of 25 kg N as basal + 25 kg N and 0.5 per cent ZnSO_4 spray at 30 days after sowing to groundnut on a deep black soil at Siruguppa, Karnataka (Channabasavanna and Setty, 1993) and 1.0 per cent $\text{FeSO}_4 + 0.1$ per cent citric acid spray to groundnut on a calcareous soil at Junagadh (Patel *et al.*, 1993b) increased the yield of crops. Sudarsan and Ramaswami (1993) reported higher yields with application of $20 \text{ kg ZnSO}_4 + 0.5$ per cent ZnSO_4 spray 40 DAS + 0.25 per cent borax spray 50 DAS to groundnut on a sandy clay soil at Coimbatore.

A non-significant impact of micronutrient application on yield of crops was also reported. Application of 0.5 per cent FeSO_4 or ZnSO_4 spray to mustard grown on a sulphur deficient soil at Jobner (Rathore and Maliwal, 1990) and soil application of

ZnSO₄ to wheat in a rice-wheat rotation (Prasad and Umar, 1993) had no significant impact on the yield of the crops.

2.3.9. Residual effects of integrated nutrient management practices on crop yields

Residual effect is more pronounced with the integrated use of organic and inorganic sources of plant nutrients and it reflects on the yield of the succeeding crops (Mahapatra and Sharma, 1988). In some situations, the residual effect is equally effective as that of direct nutrient application.

In a finger millet-maize rotation at Coimbatore, maize grain yield was slightly lower with residual P compared with direct P application (Singaram and Kothandaraman, 1994). Residual effect on the yield of succeeding wheat was noticed due to application of 25 kg P ha⁻¹ to rice on a loamy sand soil at Ludhiana (Gill and Meelu, 1982).

The cumulative effect of application of FYM to a maize-wheat sequence at New Delhi over a four-year period was noticed by Sharma *et al.* (1987). Gurung and Sherchan (1993) found that the residual effect of application of compost at 15 t ha⁻¹ + 60 : 30 : 30 kg NPK ha⁻¹ was manifested only in the fourth year.

The residual effect of cowpea residues on the grain yield of succeeding maize was noticed (Kler *et al.*, 1993). Incorporation of greengram residues seven days before sowing of maize had residual effect on the following wheat on a sandy loam soil at Ludhiana (Sidhu and Sur, 1993).

The residual effect of application of K to sunflower resulted in increased yield of the succeeding soybean. The yield of soybean which was given 40 kg K₂O ha⁻¹ was not significantly different from that obtained from the residual effect of 40 kg K₂O ha⁻¹ (Annadurai *et al.*, 1994).

The residual effect of application of FYM at 20 t ha⁻¹ to maize on a black calcareous soil increased the yield of succeeding wheat. Application of sugarcane trash or mustard straw at 5 t ha⁻¹ + N to wheat enhanced the yield of the succeeding maize. The residual effect was higher with higher rate of N application (Dev and Bharadwaj, 1995).

Relatively low residual effect due to fertilizer application was also noticed. In a corn-soybean rotation on a silt loam soil, the maximum amount of residual fertilizer ¹⁵N removed in the maize grain was 4 kg N ha⁻¹ after one year. The amount of fertilizer ¹⁵N taken up by corn during the second year after fertilizer application was relatively low (Omay *et al.*, 1998).

2.3.10. Legume effects

Legumes contribute to long-term soil fertility more than fertilizers through N effect as well as rotation effects (Jansen, *et al.*, 1990).

Legume N contributes to soil fertility in the long run through build up of organic N reserves rather than as an immediate source (Harris and Hasterman, 1990). The improvement in soil fertility due to legumes in rotation depends on the total biomass produced, amount of N fixed and amount of N added to the soil through above ground and root residues (Wani *et al.*, 1995). Even with the removal of above ground plant materials, mineralisable N content in the soil can be increased with legume based rotations (Wani *et al.*, 1995).

The organic matter and total N in the soil not only increased after legumes but also remained at a higher level throughout the crop sequence (Yadav and Verma, 1995). The N contributed to sorghum by cowpea was equivalent to 109 kg fertilizer N (Nagre and Chandrasekar, 1988) and summer legumes added about 15 kg N ha⁻¹ to the soil (Srinivasan *et al.*, 1991). Mungbean residues applied to rice substituted for 30 kg N ha⁻¹

and subsequently had a residual effect on spring wheat equivalent to the residual effect of 112 kg N ha⁻¹ applied to rice (Sharma *et al.*, 1985). Greengram and blackgram residues incorporated into a red sandy soil at Lucknow added the equivalent of 94 and 115 kg urea N ha⁻¹ respectively to wheat (Sharma *et al.*, 1996).

Legumes stimulate microbial activity in the rhizosphere more than cereals and the growth of plants is positively correlated with the microbial activity (Hoflich *et al.*, 2000). In contrast, Rego and Burford (1992) reported no significant increase in total N content under legume-based systems.

2.3.11. Response of crops to integrated nutrient management

The response of crops to added nutrients depends on soil fertility (Azad *et al.*, 1992; Thind *et al.*, 1993).

Addition of fertilizer N to the rotation is less effective because rotations are not as N deficient and fertilizer N represents a much smaller portion of the available N pool. However results based on isotopic method showed lower recovery in the monoculture indicating that fertilizer N applied to monoculture systems underwent greater losses and immobilisation (Omay *et al.*, 1997).

In maize-wheat cropping sequence at Ludhiana, higher response to applied P was noticed with wheat than with maize. The utilization of applied P was 30 and 20 per cent at low and high fertilizer application respectively and the maximum amount of applied P was retained as Ca-P and Fe-P during the first 8 years. However, the rate of change was maximum in Al-P and it was found that P associated with Fe and Al was more vital for maize and wheat nutrition. The residual effect of applied P was studied when its build up in the soil was 16 ppm and it revealed that there was no response to residual P in all the maize crops and one wheat crop.

At Hebbal, Bangalore, maize responded up to 100 and 200 kg N ha⁻¹, respectively in summer and *Kharif* seasons (Venugopal and Shivashankar, 1989). Maize grown after fallow on a loamy sand soil at Ludhinana responded upto 120 kg N ha⁻¹ while the maize grown on cowpea green manured plots did not respond to N rates from 60 to 120 kg ha⁻¹ (Grewal *et al.*, 1992).

In a wheat- maize sequence at Solan, wheat responded only to direct application of P whereas, maize responded to directly applied as well as residual P. In an Inceptisol low in organic carbon and N at Ludhiana, the N fertilizer required to produce maximum wheat yield was highest (198 kg N ha⁻¹) in pearl millet + clusterbean plots. The response of wheat to fertilizer N was maximum (19.5 kg grain kg⁻¹ N added) in fallow plots compared to 14.8 kg in cowpea residual plots (Sidhu *et al.*, 1992).

In different legume based cropping systems at Sehore, Madhya Pradesh, a linear response was observed to applied P in various *kharif* legumes; the yield of legumes increased linearly with P application while the succeeding *rabi* wheat responded only upto 30 kg P₂O₅ ha⁻¹ (Vyas *et al.*, 1995). It is also reported that wheat did not respond to P application irrespective of the preceding crops to which P was applied indicating that P application was not needed if the previous crop had received recommended rates of P fertilizer.

2.3.12. Nutrient balance in cropping systems

Under intensive cropping, the most productive systems remove high N, P and K from the soil (Ram Newaj and Yadav, 1994). In a soybean – rainfed rice – autumn rice rotation at Mymensingh, Bangladesh, the maximum net gain in total N was 50 kg ha⁻¹ followed by wheat – mungbean – autumn rice (38 kg ha⁻¹). A deficit balance in N to the extent of 41 and 19 kg ha⁻¹ respectively was noticed in fallow-jute-autumn rice and

wheat-fallow-autumn rice rotation. Total N removed by the crops was higher than the total fertilizer N added under the rotations with legume crops; the available N pool increased by 32 and 40 kg ha⁻¹ after chickpea and lentil respectively compared to wheat (Patwary *et al.*, 1989).

In a long term fertilizer trial with soybean-wheat-fodder maize sequence on a vertisol at Gwalior, net depletion of soil K over 5 year period ranged from 490 kg ha⁻¹ in control plots to 179 kg with 100 per cent NPK + FYM application (Bansal, 1992). In a grain legume-wheat sequence on a sandy loam soil at Ranchi, after three cropping cycles, available N was positive and increased with increase in N rate from 0 to 120 kg ha⁻¹ N to wheat. Whereas, soil P level, though positive, decreased with increase in N rate and soil K was negative at all N rates. The least drain of available N, P and K was recorded in the groundnut-wheat rotation (Srivastava and Srivastava, 1993).

In an experiment at Faizabad with different intensive cropping systems, after two years, the balance of N and K was negative and that of P was positive in all the systems after two years. The maize-potato + Indian mustard – blackgram system which was given 346:78:388 kg NPK ha⁻¹ recorded greater depletion of N and K (111 and 268 kg ha⁻¹ yr⁻¹) and greater build up of P (10.2 kg ha⁻¹ yr⁻¹) in the surface layer (Ram Newaj and Yadav, 1994).

In a legume-sorghum cropping sequence at Pune in which sorghum was given N ranging from 0 to 90 kg N ha⁻¹, the N and K balance was positive under groundnut-sorghum rotation because groundnut gave the greatest N input from N fixation and mineralization of crop residues. The nutrient balance improved with increasing N rate (Pawar and Jadhav, 1995).

In a maize-wheat system at Ludhiana, which was continuously fertilized with 40-120 kg N ha⁻¹, 0-35 kg P ha⁻¹ and 0-33 kg K ha⁻¹, at the end of the 11th cropping cycle, the soil organic carbon, available nutrients and micronutrients declined from their original values (Harjit Singh *et al.*, 1995).

2.3.13. Results from long term fertilizer experiments

Results of long-term experiments provide the reasonable empirical basis upon which agricultural sustainability can be evaluated (Steiner, 1995). In the long-term studies, treatments are applied for a long enough time period to assess the management impacts on resource base.

The combination of longer rotation (corn-oats-hay) and manure application stabilised or even increased the organic carbon content of a silt loam soil (Susanne Aref and Wander, 1998). Manure application slowed soil organic matter losses in the continuous corn and corn-oats rotations and halted soil organic matter losses in the corn-oats hay rotation. However declining inherent productivity has not been noticed. Even in most soil organic matter depleted soils, technological innovations have continued to increase the yield. The yield in the fertilized corn-soybean rotation exceeded the yield in comparable continuous corn plots. The yields in U-NPK [NPK treatment applied to previously untreated plots), M-NPK (NPK treatment applied to previously manured plots) and H-NPK (high level NPK treatment applied to previously manured plots)] plots were similar indicating that rotation alone improved soil conditions sufficiently to allow the full benefit of fertilization to be realized.

In the long-term Deherain field experiment, 80 years of contrast management practices stabilised the soil organic matter content at a steady state level (Sabine Houot and Chaussod, 1995). The total soil organic matter content decreased in all the treatments

compared to the original value. Even after more than 80 years, the difference among the treatments was small. The organic carbon content was 34 and 13 per cent higher in the FYM and NPK plots respectively than in the control plots.

(The Western and Eastern series of the permanent manurial experiment at Coimbatore revealed that cattle manure application increased the organic carbon, total N and water holding capacity of the soil. Phosphorus application enhanced the available nutrient status and microbial population was higher in soils receiving cattle manure than in those receiving mineral fertilizers (Ramaswami *et al.*, 1979).)

The results of the long term experiments at Muzaffarnagar for 26 years and at Anakapalle for 33 years on the application of FYM and NPK to sugarcane revealed that soil fertility was similar both under organic as well as inorganic fertilizer treatments (Singh and Yadav, 1986). But application of organic manure or inorganic fertilizer alone failed to maintain the productivity of the soil. A balanced application of nutrients through both the types was needed to maintain crop productivity.

2.4. Economics of integrated nutrient management practices

The production potential and economic evaluation of different cropping systems revealed that at Morena, Madhya Pradesh, cost of cultivation was highest for sorghum-toria – wheat and lowest for fallow – mustard sequence (Tomar and Gautam, 1992). (At Coimbatore finger millet – cotton + greengram – sorghum + cowpea rotation gave the highest net returns (Arunachalam and Habeebullah, 1993; Subbian and Palaniappan, 1992).

(At Tikangarg, Madhya Pradesh, total net returns were highest in the soybeans-chickpea sequence followed by sesame – chickpea sequence (Tomar *et al.*, 1993). At Solapur, double cropping more than doubled the monetary returns compared with

growing safflower or chickpeas after fallow (Bhore *et al.*, 1994). At Dhaulakuan, Himachal Pradesh, among the various maize based cropping systems, maize-toria-wheat under irrigated conditions gave highest yields and net returns (Kharwara and Pathania, 1994).

At Pune, net returns were highest in cowpea – sorghum system compared to fallow-sorghum system (Vaidya *et al.*, 1994). At Sehore, Madhya Pradesh, yield, energy input, energy output, net energy return, energy use efficiency and energy productivity were highest and energy intensiveness was lowest in the soybean- wheat sequence. Energy parameters (except energy intensiveness) increased linearly with increase in *Kharif* applied P whereas application of 30 kg P₂O₅ ha⁻¹ to *Rabi* wheat was most energy efficient (Vyas *et al.*, 1995).

At Pantnagar, among the different maize based cropping systems in which N was applied only to maize ranging from 0-90 kg N ha⁻¹, the B/C ratio and grain production efficiency were highest in the lentil – maize system. The productivity was highest in the lentil – maize sequence in the first year and in the wheat-greengram-maize sequence in the second year. The productivity and grain production efficiency increased with rate of N application (Yadav, 1990).

From the above review , it is inferred that cropping systems with legume based rotations influence favourably the soil physical, chemical and biological properties and the growth and yield of the crops by improving the soil fertility level over seasons. Integrated use of inorganic fertilizers, organic manures, crop residues and micronutrients plays a major role in improving the soil fertility in the long run and enhancing the productivity of crops.

CHAPTER III

MATERIALS AND METHODS

Field experiments were conducted to investigate the effect of maize based cropping systems and integrated nutrient management practices on soil quality and crop productivity. The materials and methods used in the study are presented in this chapter.

3.1. Materials

3.1.1. Location and duration of the experiment

The experiment was initiated during January 1999 (summer season) at Field No. 37F of Tamil Nadu Agricultural University, Coimbatore (11°N latitude, 77°E longitude and 427 m above mean sea level). The effect of treatments on soil physical, chemical and biological properties and productivity of crops were studied, over 10 successive cropping seasons, upto April 2002. Experiments for the last seven cropping seasons, from summer 2000 to summer 2002, were conducted for this dissertation purpose and the results are elaborately discussed.

For making discussion convenient, the cropping seasons were grouped and referred to as cropping cycle I (summer 2000 - *khariif*2000 - *rabi* 2000), cropping cycle II (summer 2001 - *khariif*2001 - *rabi* 2001) and cropping cycle III (summer 2002).

3.1.2. Climate and weather

The mean annual rainfall at Coimbatore is 648 mm distributed over about 50 rainy days with a 30 per cent annual coefficient of variation. The annual mean maximum and minimum temperature are 31.5°C and 21.2°C respectively. The mean temperature, relative humidity, rainfall, potential evaporation and sunshine hours prevailed during the

period of cropping cycle I, II and III are given in Appendix-1 and illustrated in Fig. 1, 2 and 3.

3.1.3. Crop, varieties and season

The crops grown, characteristics of varieties and seasons of crops raised are presented in Table 1.

Table 1. Characteristics of crop varieties and season

Particulars	Maize	Sunflower	Cowpea
Season	December – April (Summer)	June – August (<i>Kharif</i>)	September – November (<i>Rabi</i>)
Variety	CO 1	CO 1	CO 4
Parentage	Unit selection from Indonesian population Suwan	Selection from Cernianka 66	Selection from Russian Giant
Duration (days)	105	85	85
Seed yield (kg ha ⁻¹)	6250	900	960
100 - seed weight (g)	21.5	4.5	11.5
Special features	Resistant to downy mildew, well- developed ears	Oil content: 37 per cent	Clusters project above the canopy, 3- 4 branches

Date of sowing and harvest			
Cropping cycle I :			
Date of sowing	21.1.2000	9.6.2000	22.9.2000
Date of harvest	12.5.2000	30.8.2000	11.12.2000
Cropping cycle II :			
Date of sowing	22.12.2000	8.6.2001	11.9.2001
Date of harvest	10.4.2001	5.9.2001	30.11.2001
Cropping cycle III :			
Date of sowing	21.12.2001		
Date of harvest	12.4.2002		

Fig. 1. Weather prevailed during Cropping cycle I (Jan 2000 - Dec 2000)

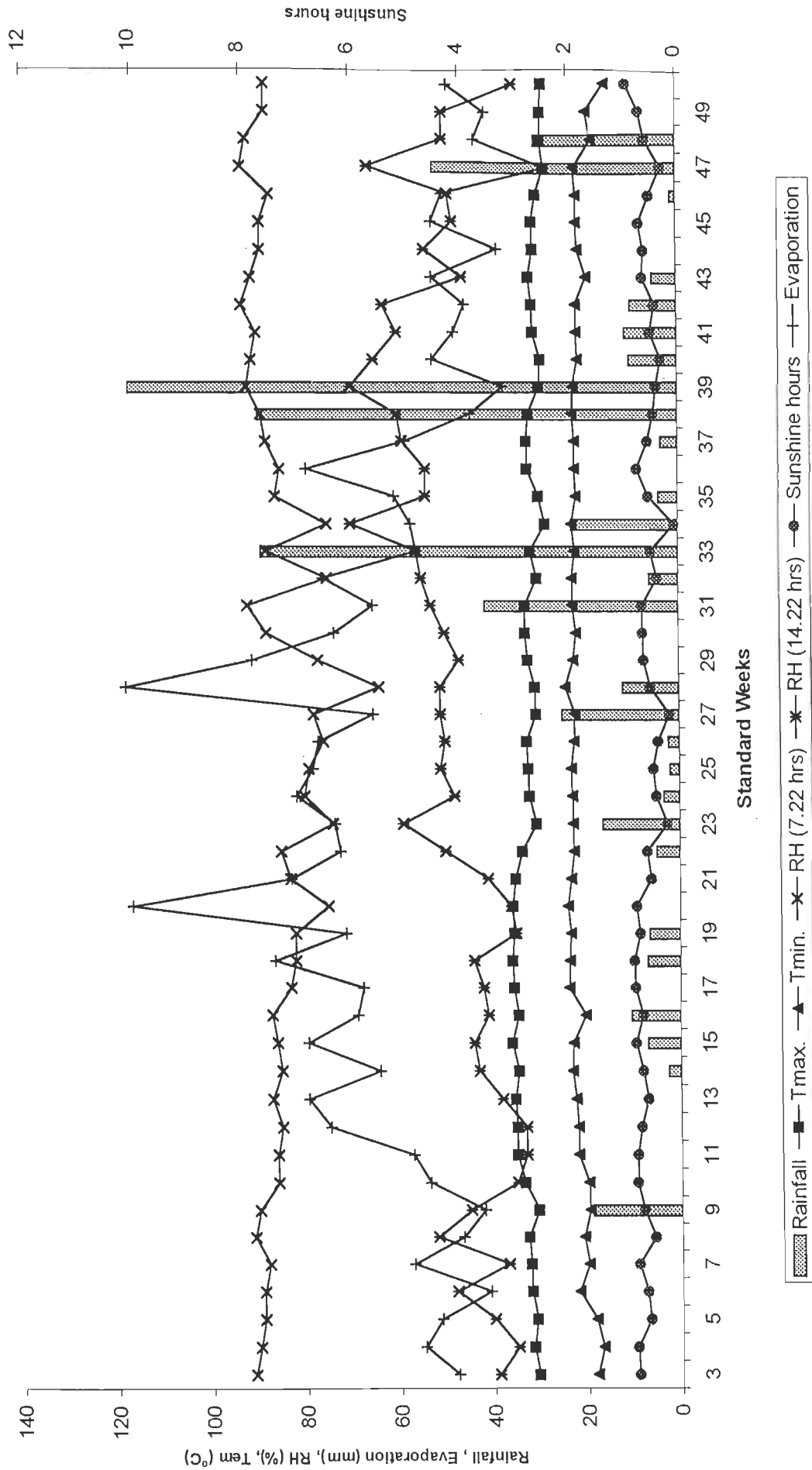


Fig. 2. Weather prevailed during Cropping cycle II (Dec 2000 - Nov 2001)

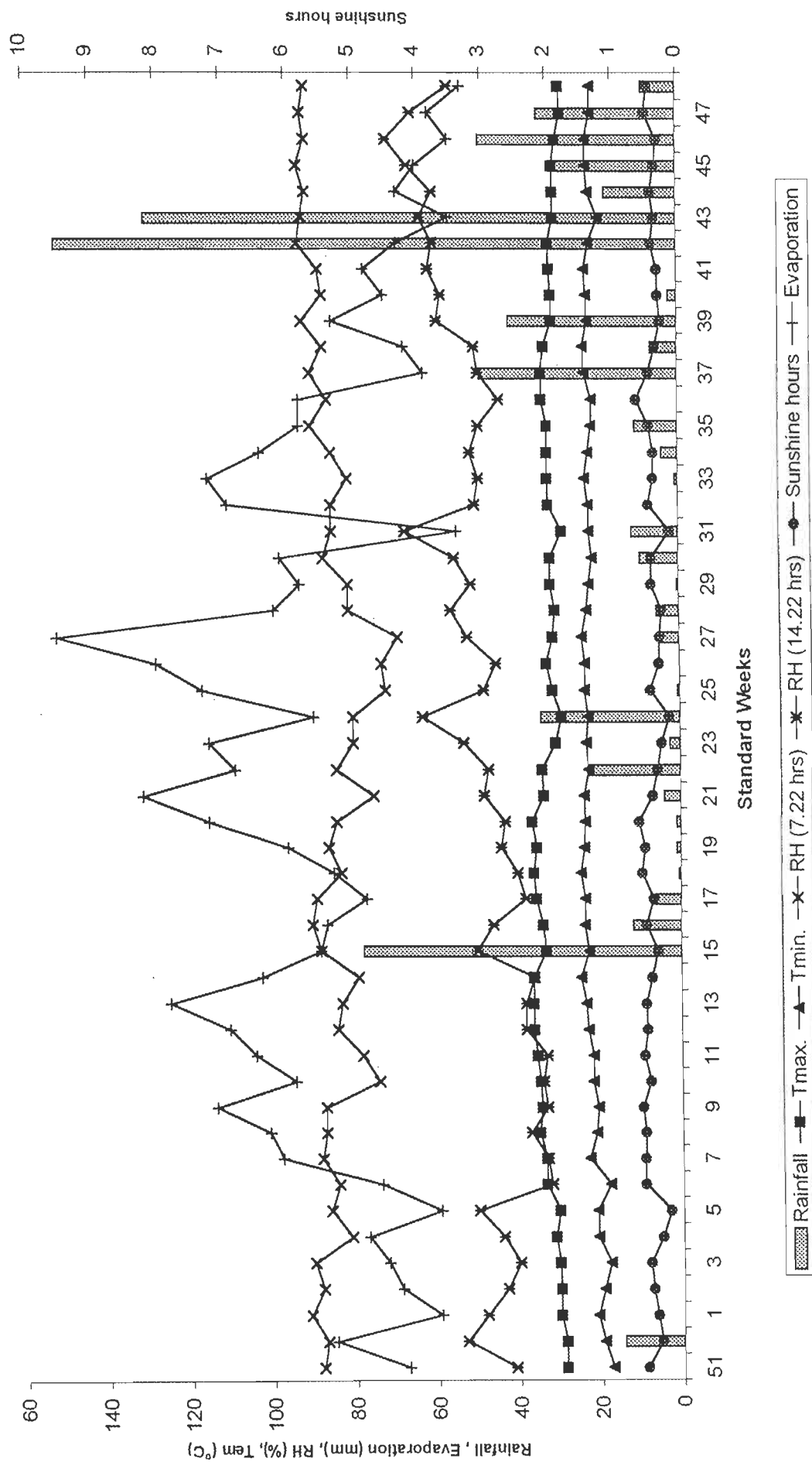
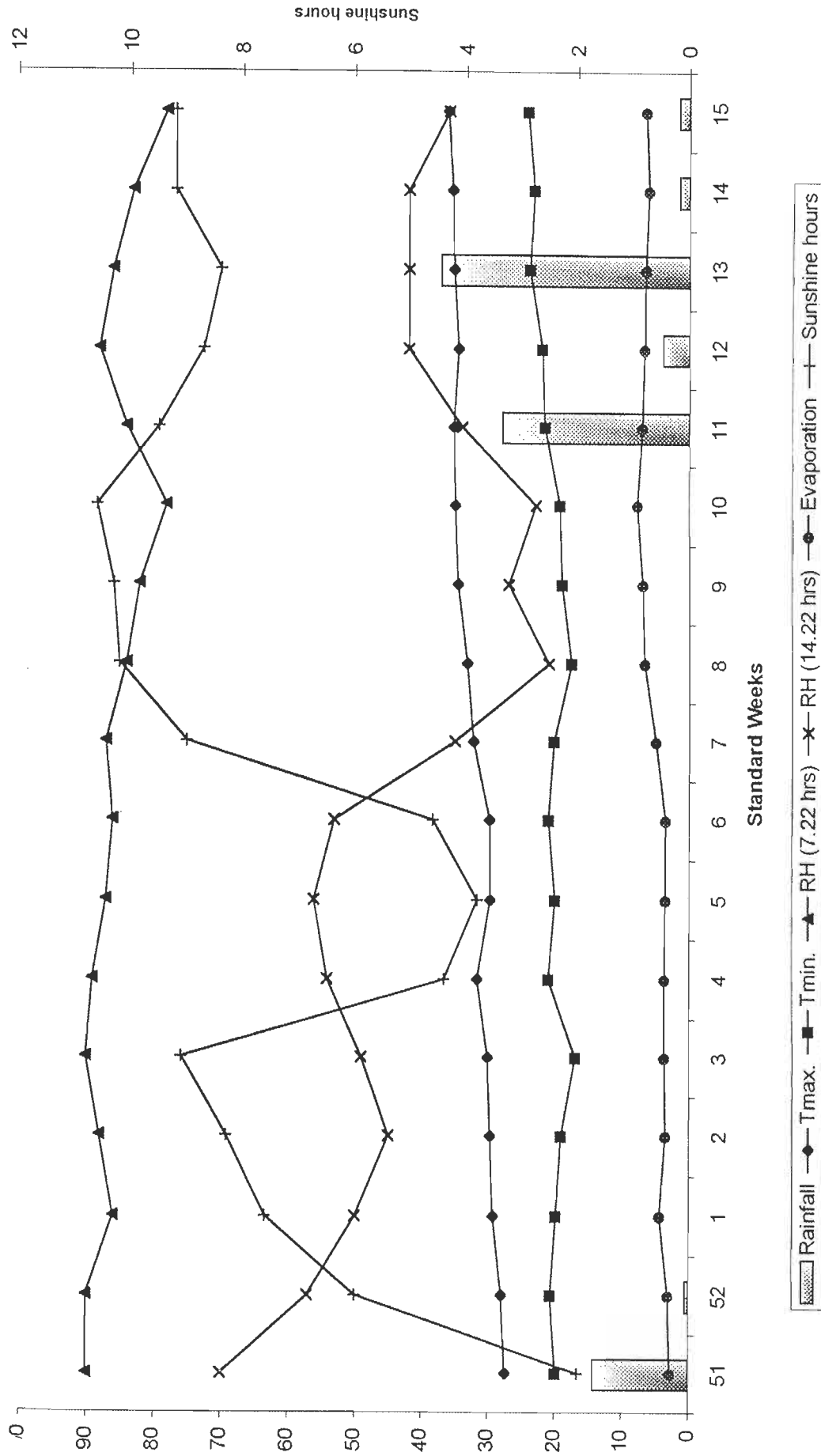


Fig. 3. Weather prevailed during summer 2002 (Dec 2001 - Apr 2002) cropping season



3.1.4. Soil characteristics

The soil of the experimental field was a mixed black and red soil classified as fine montmorillonitic, isohyperthermic Vertic Ustropepts. It was a very deep, moderately well drained, dark grayish brown, fine loamy, strongly structured soil overlying on coarse loamy soil. The important soil properties at the initiation of the experiment in January 1999 and at the end of *rabi* 1999 cropping season are presented in Table 2a and 2b.

3.2. Methods

3.2.1. Treatments, design and layout

The experiment was laid out in split plot design with three replications. Cropping systems were included as main plot treatments. The subplot treatments comprised of integrated nutrient management practices. The treatment details are as follows:

Main plot: Cropping systems

	Summer Dec. – Apr.	Kharif Jun. – Aug.	Rabi Sep. – Nov.
S ₁	Maize	Fallow	Fallow
S ₂	Maize	Fallow	Cowpea
S ₃	Maize	Sunflower	Cowpea

Sub-plot: Integrated nutrient management

- F₁ : 100 per cent recommended N :P₂O₅ :K₂O + FYM*
- F₂ : 150 per cent recommended N :P₂O₅ :K₂O + FYM
- F₃ : 100 per cent recommended N :P₂O₅ :K₂O + FYM + Zn** + Fe***
- F₄ : 150 per cent recommended N :P₂O₅ :K₂O + FYM + Zn + Fe

* FYM: 12.5 t ha⁻¹

** Zinc sulphate @ 25 kg ha⁻¹

*** Ferrous sulphate 1 per cent foliar spray

Table 2a. Soil characteristics of the experimental field at the inception of the experiment in January 1999

1.	Clay (%)	32.50
2.	Silt (%)	18.50
3.	Coarse sand (%)	20.80
4.	Fine sand (%)	28.20
5.	Texture	Sandy clay loam
6.	Bulk density (Mg m^{-3})	1.48
7.	Hydraulic conductivity (cm h^{-1})	2.50
8.	Total porosity ($\text{m}^3 100 \text{ m}^{-3}$)	45.90
9.	Capillary porosity ($\text{m}^3 100 \text{ m}^{-3}$)	27.10
10.	Non-capillary porosity ($\text{m}^3 100 \text{ m}^{-3}$)	18.80
11.	Field capacity (%)	26.30
12.	Permanent wilting point (%)	14.20
13.	pH	7.88
14.	EC (dSm^{-1})	0.81
15.	Organic carbon (%)	0.39
16.	Available N (kg ha^{-1})	218
17.	Available P (Kg ha^{-1})	12
18.	Available K (Kg ha^{-1})	558

Table 2b. Soil physical and chemical properties at the end of *rabi* 1999 cropping season

	OC (%)	Available nutrients (kg ha ⁻¹)			Bulk density (Mg m ⁻³)	Hydraulic conductivity (cm h ⁻¹)	Porosity (m ³ 100 m ⁻³)
		N	P	K			
Cropping systems							
S ₁	0.40	217	12.1	558	1.47	2.43	44.6
S ₂	0.42	222	12.4	561	1.46	2.52	46.0
S ₃	0.44	225	12.6	567	1.43	2.60	47.8
SEd	0.01	1	0.1	16	0.02	0.03	0.6
CD (P=0.05)	0.02	4	0.3	NS	NS	0.09	1.8
Integrated nutrient management							
F ₁	0.41	219	12.2	557	1.48	2.42	44.0
F ₂	0.43	222	12.4	564	1.45	2.52	46.7
F ₃	0.41	221	12.4	560	1.46	2.53	46.2
F ₄	0.43	224	12.5	566	1.43	2.60	47.7
SEd	0.02	12	0.7	31	0.03	0.06	1.2
CD (P=0.05)	NS	NS	NS	NS	NS	0.12	2.5

The layout of the treatments is presented in Fig. 4. The gross plot size was 5 x 3.6 m. The net plot size was 4.6 x 2.4 m for maize and 4.7 x 2.4 m for sunflower and cowpea.

3.2.2. Crop management

3.2.2.1. Method of crop residue management

Before sowing maize in January 2000, FYM was applied to all plots @ 12.5 t ha⁻¹ (on dry weight basis containing 0.50, 0.20 and 0.50 per cent N, P₂O₅ and K₂O respectively). The field was ploughed twice with non-inverting traditional plough (12 cm depth) and ridges were formed using ridge plough 60 cm apart. For raising the subsequent sunflower (Jun – Aug 2000), FYM (12.5 t ha⁻¹) was applied to all plots excluding those which were left as fallow. Residues of the previous maize crop were cut into 10 cm long pieces and spread over the respective plots. The plots were ploughed using traditional country plough and reformed in their respective places in which they were present in the previous season. The method of crop residue management and field preparation was similar for all the subsequent crops.

3.2.2.2. Maize

Recommended dose of 135:62.5:50 kg ha⁻¹ N: P₂O₅:K₂O was applied in the form of urea (46 per cent N), single super phosphate (16 per cent P₂O₅) and muriate of potash (60 per cent K₂O), respectively. Twenty five per cent of N and entire P₂O₅ and K₂O were applied as basal. Fertilizers were applied 5 cm deep in furrows opened at 2/3rd the distance from the top of the ridge and covered with soil. Zinc sulphate (25 kg ha⁻¹) was mixed with sand in equal proportion and applied on the surface for F₃ and F₄ plots. Maize seeds (20 kg ha⁻¹) were treated with *Azospirillum* (600 g ha⁻¹ of seeds). Two seeds hill⁻¹ were sown at 4 cm depth in the same row in which fertilizers were placed with an intra-row

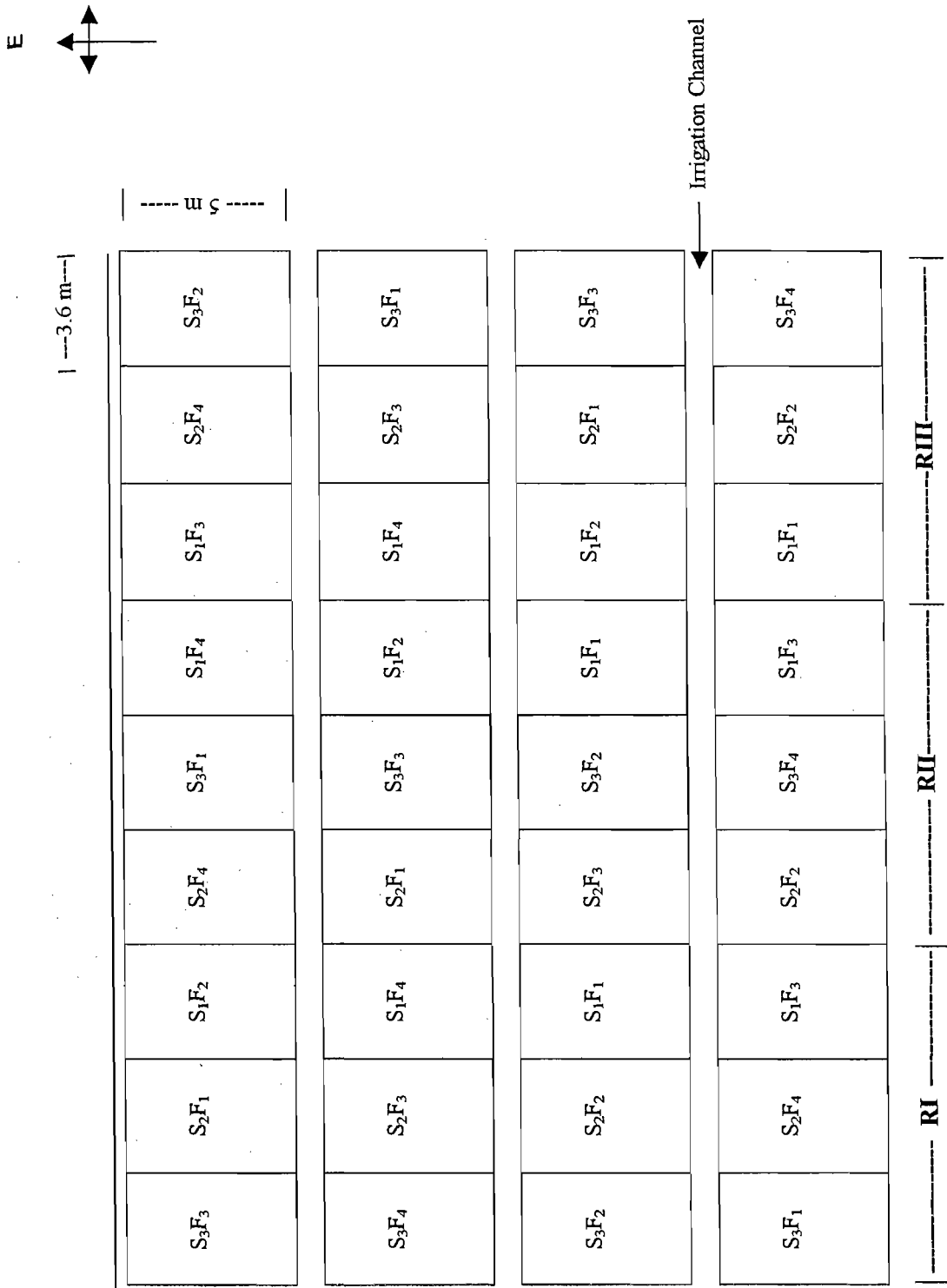


Fig. 4. Layout of the treatments in the experimental field

spacing of 20 cm and irrigation was given immediately. Atrazine 50 WP (500 g ha⁻¹) was sprayed (900 l ha⁻¹ spray volume) on 3rd day after sowing using Backpack sprayer fitted with flat pan nozzle. Thinning was done on 7th day after sowing leaving one healthy seedling hill⁻¹. Half the dose of N was top dressed in furrows (5 cm deep) opened 10 cm away from the base of the plants on 25th day after sowing. Hand weeding and earthing up were done on 30 DAS. Remaining 25 per cent of N was applied on 45th day after sowing adopting the same method followed for first top dressing. Ferrous sulphate 1 per cent foliar spray (500 l ha⁻¹ spray volume) was given on 60th day after sowing. Irrigation was given whenever necessary. Need based plant protection measures were followed.

3.2.2.3. Sunflower

Entire dose of fertilizers (40:20:20 kg N:P₂O₅:K₂O ha⁻¹) were applied as basal in the same form used for maize. Zinc sulphate (25 kg ha⁻¹) was applied as basal adopting the same method followed for maize for F₃ and F₄ treatments. Seeds (15 kg ha⁻¹) were treated with *Trichoderma viridie* @ 4g kg⁻¹ and *Azospirillum* @ 600 g ha⁻¹ of seeds and sown (2 seeds hill⁻¹) on both the side of the ridges which were 60 cm apart at 3 cm depth in the same row in which fertilizers were placed with an intra-row spacing of 15 cm. Fluchloralin was applied @ 2 l ha⁻¹ on 3rd day after sowing. Thinning and gap filling were done on 7 DAS. Hand weeding was done on 30th day after sowing. Foliar spray with ferrous sulphate 1 per cent solution was given on 40th day after sowing. The field was irrigated and plant protection measures were followed whenever necessary.

3.2.2.4. Cowpea

A fertilizer dose of 25:50 kg ha⁻¹ of N and P₂O₅ was applied in the same form used for maize. Zinc sulphate @ 25 kg ha⁻¹ was applied as basal following the same method adopted for maize for F₃ and F₄ plots. Seeds (20 kg ha⁻¹) were treated with *Rhizobium* (600 g ha⁻¹ of seeds) and sown (2 seeds hill⁻¹) on both the sides of the ridges

formed 60 cm apart with an intra-row spacing of 15 cm. Thinning and gap filling were done on the 7th day after sowing and hand weeding on the 30th day after sowing. Foliar spray with ferrous sulphate 1 per cent solution was given on 40th day after sowing. Plant protection measures were carried out based on the requirement.

3.2.3. Biometric observations

3.2.3.1. Dry matter production

In the sample row, five plants were selected at random at harvest, cut close to the ground level and dried at 70°C to constant weight and the DMP was expressed in kg ha⁻¹.

3.2.3.2. Seed yield

Cobs, capitulum and pods of maize, sunflower and cowpea, respectively were harvested from the net plots, threshed and dried to 12 per cent moisture content under sun. The seed yields were expressed in kg ha⁻¹.

3.2.3.3. Stover, stalk and haulm yield

Stover, stalk and haulm of maize, sunflower and cowpea, respectively from the net plots were allowed for sun drying after harvest for four days and their weights were recorded. A well-mixed 500 g of sample was collected for each crop at the time of weighing for the determination of moisture content. Stover, stalk and haulm yields were expressed on dry weight basis in kg ha⁻¹.

3.2.3.4. Root dry weight

On the day of harvest of each crop, a 1 m x 1 m x 0.5 m pit was dug at a place selected at random, the excavated soil was sieved in water, roots were collected, dried at 70°C to constant weight, and the root weight was expressed in kg ha⁻¹.

3.2.3.5. Crop residue addition

Total amount of crop residues added to the soil was obtained by adding the stover yield and root dry weight and expressed in kg ha^{-1} .

3.2.4. Soil analysis

3.2.4.1. Collection of soil samples and processing

Soil samples were collected within one week of harvest for determination of physical, chemical and biological properties. Measurement of hydraulic conductivity, bulk density and porosity was made using core samples collected at two randomly selected sampling points in the furrows. The core sampler was driven manually to 15 cm depth. For determination of available water capacity, size distribution of aggregates and all chemical and biological characteristics, bulk samples were used. A 'V' shaped cut was made to 15 cm depth at 5 randomly selected sampling points in the furrows and an uniform 2 cm thick slice was removed from one side. Soil thus collected from all the 5 sampling points in a plot was pooled, mixed thoroughly and 1500 g of sub sample was obtained by quartering. For aggregate analysis, 300 g of air dry solid clods (5-8 mm) were collected by sieving. For determination of organic carbon, 500 g of sample was thoroughly ground using wooden pestle and mortar and the entire quantity was passed through 0.2 mm sieve and for available N, P and K it was passed through 2 mm sieve. For determination of microbial population, the field moist sample was passed through 2 mm sieve and plating was done on the day of collection of the sample. Wherever the determination of moisture content of the sample was necessary, it was dried at 105°C to constant weight and weighed after cooling.

3.2.4.2. Bulk density

Mass of the solids of the oven-dry core sample and the volume of the core sample were recorded. Bulk density was calculated as the ratio of the mass to its volume and expressed in Mg m^{-3} (Dakshinamurthy and Gupta, 1967).

3.2.4.3. Hydraulic conductivity

Over the saturated core sample, a constant head of water was maintained and the volume of water that flowed out of the sample at equilibrium was recorded at 25 minutes interval. Hydraulic conductivity was calculated using Darcy's equation and expressed in cm hr^{-1} (Dakshinamurthy and Gupta, 1967).

3.2.4.4. Pore size distribution

Principle of capillary rise was employed which states that if a negative pressure equivalent to 'h' cm of water is applied to an initially saturated soil sample, the volume of water extracted is equal to the volume of pores having an effective radius greater than the 'r' corresponding to the value of 'h' in the equation. The volumetric moisture content at saturation represents total volume of pores. Buchner funnel was used to extract water from saturated core samples by applying a negative pressure. The volumetric water content when equilibrium was reached with a negative pressure equivalent to 50 cm of water represents the volume of capillary pores. The volume of non-capillary pores was obtained by the difference of total and capillary porosity. Pore volume was expressed in percentage (Dakshinamurthy and Gupta, 1967).

3.2.4.5. Available soil moisture

Pressure plate apparatus was used to study water retention characteristics. The water retained by an initially wet soil (passed through 2 mm sieve) at equilibrium point

when extraction pressure equivalent to 0.03 MPa and 1.5 MPa was applied represents moisture content at field capacity and permanent wilting point, respectively. Available soil moisture was obtained by the difference of field capacity and permanent wilting point and expressed in cm m^{-1} (Dakshinamurthy and Gupta, 1967).

3.2.4.6. Size distribution of aggregates

Fifty gram of soil aggregates (5-8 mm size) were soaked in water for 5 minutes and sieved in water in a nest of standard sieves (5.0, 2.0, 1.0, 0.50 and 0.25 mm mesh size) for 10 min with a frequency of 30 cycles min^{-1} and stroke length of 3.8 cm. Percentage of water stable aggregates (> 0.25 mm) was calculated after correction for sand (Dakshinamurthy and Gupta, 1967).

3.2.4.7. Chemical properties

The following methods were employed for soil chemical analysis.

Analysis	Method	Reference
Organic carbon (%)	Wet digestion method	Walkley and Black (1934)
Available nitrogen (kg ha^{-1})	Alkaline potassium permanganate method	Subbiah and Asija (1956)
Available phosphorus (kg ha^{-1})	Olsen's method	Olsen <i>et al.</i> (1954)
Available potassium (kg ha^{-1})	Neutral normal ammonium acetate method	Stanford and English (1949)

3.2.4.8. Population of bacteria, fungi and actinomycetes

Serial dilution method was followed for counting the population of bacteria, fungi and actinomycetes and the population was expressed as colony forming units g^{-1} of soil (CFU g^{-1} of soil). The following media were used:

Species	Medium	Reference
Bacteria	Soil extract agar	Collings and Lyne (1968)
Fungi	Martin's rose bengal agar	Martin (1950)
Actinomycetes	Ken Knight's medium	Ken Knight and Muncie (1939)

3.2.5. Nutrient uptake

The samples collected for estimation of dry matter production at harvest were used for analysis of NPK content. The entire oven dry samples were cut into 2 cm long pieces, thoroughly mixed, 100 g of sub sample was weighed and ground thoroughly in a stainless steel mill. The methods adopted for NPK analysis are as follows:

Nutrient	Method	Reference
Nitrogen	Microkjeldahl	Humphries, 1956
Phosphorus	Triple acid digestion (colorimetry)	Jackson, 1973
Potassium	Triple acid digestion (flame photometry)	Jackson, 1973

The N, P and K contents were multiplied by the corresponding dry matter production and the uptake was expressed in kg ha^{-1} .

3.2.6. Nutrient balance

The net gain in available nitrogen, phosphorus and potassium during the period of cropping cycle I and the cropping cycles II and III put together was calculated using the corresponding available nutrient status at the beginning and at the end of the specified period. The fraction of nutrients mineralized and added to the soil was assumed as 25 and 20 per cent of the nutrients present in FYM and cowpea residues respectively and 15 per

cent for maize and sunflower residues. The direct effect of application of fertilizers, crop residues and FYM was accounted for computing nutrient balance. The residual and cumulative effects were not accounted in the calculation (Sadanandan and Mahapatra, 1973; Subbian, 1989). The overall net gain at the end of summer 2002 season compared to the *rabi* 1999 season was thus calculated and expressed in kg ha^{-1} .

3.2.7. Economics

Cost of cultivation, gross return, net return and benefit cost ratio were calculated using the price of inputs and produce that prevailed during the cropping season.

3.2.8. Statistical analysis

The data were subjected to statistical analysis and if found significant, critical difference was worked out at five per cent probability level and non significant differences were indicated as NS (Gomez and Gomez, 1984). Wherever interaction was noticed, the same was also presented. The \log_{10} transformation was done for the analysis of microbial population. The dry matter production, seed, stalk and root biomass yield of sunflower were analysed following the procedure as that used for a randomized block design and for cowpea the same were analysed similar to that of a split plot design.

CHAPTER IV

RESULTS

Field experiments were conducted at Tamil Nadu Agricultural University over seven successive cropping seasons from summer 2000 to summer 2002 to study the effect of maize based cropping systems and integrated nutrient management practices on soil quality and productivity of crops. The results are presented in this chapter. The summer 2000 - *khariif* 2000 - *rabi* 2000 cropping cycle is referred to as cropping cycle I, summer 2001 - *khariif* 2001 - *rabi* 2001 cropping cycle as cropping cycle II and summer 2002 cropping season as cropping cycle III.

4.1. Dry matter production at harvest (Table 3)

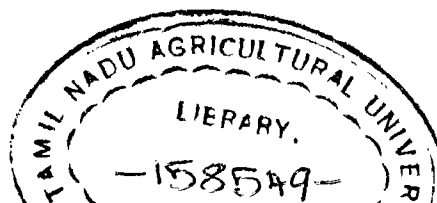
4.1.1. Maize

The data on DMP at harvest revealed that the influence of cropping systems on DMP was significant in all the seasons. The DMP of maize under maize-sunflower-cowpea (S_3) system was on par with maize-fallow-cowpea (S_2) system in summer 2000 and in the other two seasons (Summer 2001 and Summer 2002), S_3 system recorded significantly higher DMP than S_2 system. The maize-fallow-fallow (S_1) system produced significantly lesser dry matter in all the three seasons compared to the other two systems. There was increase in DMP over the cropping seasons from summer 2000 to summer 2002 due to different cropping systems.

Integrated nutrient management practices exerted significant influence on DMP in all the seasons. Higher DMP was recorded under 150% NPK + FYM + Zn + Fe (F_4) and it was on par with 150% NPK + FYM (F_2) in all the seasons. The 150% NPK + FYM (F_2) and 100% NPK + FYM + Zn + Fe (F_3) were on par in DMP in summer 2001 and

Table 3. Dry matter production of crops at harvest (kg ha⁻¹)

	Maize			Sunflower		Cowpea	
	Summer 2000	Summer 2001	Summer 2002	<i>Kharif</i> 2000	<i>Kharif</i> 2001	<i>Rabi</i> 2000	<i>Rabi</i> 2001
Cropping systems							
S ₁	12532	13023	13433	-	-	-	-
S ₂	13063	13729	14506	-	-	3176	3591
S ₃	13386	14595	16071	3758 ¹	4332 ¹	3294	3798
SEd	168	241	255	-	-	44	51
CD (P=0.05)	465	669	708	-	-	NS	NS
Integrated nutrient management							
F ₁	12183	13139	14103	3420	3860	3011	3496
F ₂	13289	13877	14918	3909	4508	3270	3735
F ₃	12634	13568	14285	3576	4110	3209	3670
F ₄	13869	14544	15375	4125	4850	3450	3879
SEd	295	320	350	86	114	104	77
CD (P=0.05)	620	673	736	210	280	226	168

¹ Not statistically analyzed

summer 2002. The dry matter produced under the 100% NPK + FYM + Zn + Fe (F₃) and 100% NPK + FYM (F₁) were on par and significantly lesser than the other two treatments in all the seasons. Integrated nutrient management practices increased the DMP across the cropping seasons.

The interaction effect of cropping systems and integrated nutrient management practices on dry matter production of maize was not significant in all the three seasons.

4.1.2. Sunflower

Sunflower performed better during *kharif* 2001 with comparatively higher DMP than that obtained during *kharif* 2000 in S₃ system. Significant difference in DMP of sunflower was observed due to integrated nutrient management practices in *kharif* 2000 and *kharif* 2001. In both the seasons, the 150% NPK + FYM + Zn + Fe (F₄) registered significantly higher values of DMP than the 150% NPK + FYM (F₂). The 100% NPK + FYM + Zn + Fe (F₃) and 100% NPK + FYM (F₁) were on par in DMP and significantly inferior to the other two treatments. Considerable increase in DMP was noticed in *kharif* 2001 compared to the *kharif* 2000 season under all the four integrated nutrient management treatments.

4.1.3. Cowpea

Cropping systems had no significant influence on DMP of cowpea in both *rabi* 2000 and *rabi* 2001. Numerically higher values of DMP were recorded under the maize-sunflower-cowpea (S₃) system compared to the maize-fallow-cowpea (S₂) system.

Integrated nutrient management practices exerted significant impact on DMP in both the seasons. The 150% NPK+FYM+Zn+ Fe (F₄) recorded higher DMP but it was on par with 150% NPK+FYM (F₂). The DMP values recorded under the 150% NPK + FYM

(F₂) and 100% NPK + FYM + Zn + Fe (F₃) were on par in both the seasons. The 100% NPK + FYM + Zn + Fe (F₃) and 100% NPK + FYM (F₁) were on par in DMP in *rabi* 2000 but were significantly different in *rabi* 2001. Compared to *rabi* 2000, the DMP was considerably higher in *rabi* 2001 under all the four integrated nutrient management treatments.

The interaction effect of cropping system and integrated nutrient management practices on dry matter production of cowpea was not significant in both the seasons.

4.2. Root dry weight at harvest (Table 4)

4.2.1. Maize

Cropping systems had no significant effect on root dry weight of maize in summer 2000 but it was significantly influenced by the systems during summer 2001 and summer 2002. Significantly higher root dry weight of maize was recorded under maize-sunflower-cowpea (S₃) system than the other two systems in both summer 2001 and summer 2002. Root dry weight under the maize-fallow-fallow (S₁) system was on par with maize-fallow-cowpea (S₂) system in summer 2001 but in summer 2002 the S₂ system produced significantly higher root dry weight than the S₁ system. Considerable increase in root dry weight due to cropping systems was recorded over the cropping seasons.

Significant difference due to integrated nutrient management practices on root dry weight of maize was observed in all the three seasons. The 150% NPK + FYM + Zn + Fe (F₄) significantly increased the root dry weight compared to 150% NPK + FYM (F₂) in summer 2001 but in summer 2000 and summer 2002, these two treatments were on par. Root dry weight of maize under the 150% NPK + FYM (F₂) and 100% NPK + FYM + Zn + Fe (F₃) were on par in all the three seasons. The 100% NPK + FYM (F₁) recorded

Table 4. Root dry weight of crops at harvest (kg ha⁻¹)

	Maize			Sunflower		Cowpea	
	Summer 2000	Summer 2001	Summer 2002	<i>Kharif</i> 2000	<i>Kharif</i> 2001	<i>Rabi</i> 2000	<i>Rabi</i> 2001
Cropping systems							
S ₁	2005	2084	2149	-	-	-	-
S ₂	2090	2197	2321	-	-	516	584
S ₃	2150	2335	2571	606 ¹	699 ¹	540	618
SEd	42	47	47	-	-	21	10
CD (P=0.05)	NS	129	130	-	-	NS	NS
Integrated nutrient management							
F ₁	1949	2102	2256	552	623	465	569
F ₂	2126	2221	2387	630	727	532	608
F ₃	2021	2171	2286	577	663	522	597
F ₄	2230	2327	2460	665	782	594	631
SEd	56	38	54	14	24	31	13
CD (P=0.05)	117	80	114	34	60	67	27

¹ Not statistically analyzed

the least values of root dry weight and it was on par with 100% NPK + FYM + Zn + Fe (F₃). Across the cropping seasons, marginal increase in root dry weight was noticed due to the integrated nutrient management practices.

There was no significant interaction effect between cropping systems and integrated nutrient management practices on root dry weight of maize in all the three seasons.

4.2.2. Sunflower

Sunflower during *rabi* 2001 registered marginally higher root dry weight than during *rabi* 2000 under S₃ system. Integrated nutrient management practices had significant impact on root dry weight of sunflower in both *kharif* 2000 and *kharif* 2001. The 150% NPK + FYM + Zn + Fe (F₄) recorded significantly higher root dry weight in *kharif* 2000 but in *kharif* 2001, it was on par with 150% NPK + FYM (F₂). Root dry weight under 150% NPK + FYM (F₁) was on par with 100% NPK + FYM + Zn + Fe (F₃) in both the seasons. In *kharif* 2001, the root dry weight of sunflower was considerably higher during *kharif* 2001 when compared to *kharif* 2000.

4.2.3. Cowpea

The effect of cropping systems on root dry weight of cowpea was not significant in both *rabi* 2000 and *rabi* 2001. However, a numerical increase in root dry weight was recorded under maize-sunflower-cowpea (S₃) system compared to maize-fallow-cowpea (S₂) system.

Integrated nutrient management practices were significantly different in influencing the root dry weight of cowpea in both the seasons. Both 150% NPK + FYM + Zn + Fe (F₄) and 150% NPK + FYM (F₂) were on par in root dry weight and significantly

superior to the other two treatments. In *rabi* 2000, the root dry weight of cowpea under 150% NPK + FYM (F₂), 100% NPK + FYM + Zn + Fe (F₃) and 100% NPK + FYM (F₁) were on par. In *rabi* 2001, the root dry weight under F₂ and F₃ treatments were on par and F₁ treatment recorded significantly lower root dry weight.

The interaction effect of cropping systems and integrated nutrient management practices on root dry weight of cowpea was not significant.

4.3. Grain yield (Table 5)

4.3.1. Maize

Cropping systems had no significant influence on grain yield of maize in summer 2000 but the effect was significant in summer 2001 and summer 2002. Maize grain yield was significantly higher under maize-sunflower-cowpea (S₃) system than the other two systems in both summer 2001 and summer 2002. The grain yield of maize under maize-fallow-fallow (S₁) system was significantly lower than the other two systems in both summer 2001 and summer 2002 seasons. Across the cropping seasons, considerable increase in grain yield of maize was noticed due to cropping systems.

The effect of integrated nutrient management practices on maize grain yield was significant in all the three seasons. Significantly higher grain yield was recorded under 150% NPK + FYM + Zn + Fe (F₄) in summer 2000 but in summer 2001 and summer 2002, it was on par with 150% NPK + FYM (F₂). There was no significant difference in the grain yields under 150% NPK + FYM (F₂), 100% NPK + FYM + Zn + Fe (F₃) and 100% NPK + FYM (F₁) in summer 2001 and the treatments F₂ and F₃ behaved similarly and were on par in grain yield during summer 2000 and summer 2002. The 100% NPK + FYM (F₁) recorded comparatively lower grain yield and was on par with 100% NPK +

Table 5. Grain yield of crops (kg ha⁻¹)

	Maize			Sunflower		Cowpea	
	Summer 2000	Summer 2001	Summer 2002	<i>Kharif</i> 2000	<i>Kharif</i> 2001	<i>Rabi</i> 2000	<i>Rabi</i> 2001
Cropping systems							
S ₁	4499	4659	4789	-	-	-	-
S ₂	4673	4894	5173	-	-	693	781
S ₃	4772	5193	5688	952 ¹	1132 ¹	717	825
SEd	79	57	67	-	-	10	12
CD (P=0.05)	NS	157	185	-	-	NS	NS
Integrated nutrient management							
F ₁	4382	4721	5014	900	1013	658	762
F ₂	4746	4938	5289	1026	1180	712	811
F ₃	4528	4845	5131	936	1073	700	799
F ₄	4935	5157	5431	1077	1263	749	840
SEd	86	108	119	26	40	15	26
CD (P=0.05)	182	228	250	64	98	32	NS

¹ Not statistically analyzed

FYM + Zn + Fe (F₃) in all the three seasons. Considerable increase in grain yield of maize was observed over the seasons due to integrated nutrient management practices.

Cropping systems and integrated nutrient management practices produced no significant interaction effect on grain yield of maize in all the three seasons.

4.3.2. Sunflower

The grain yield of sunflower under maize-sunflower-cowpea (S₃) system during *kharif* 2001 was marginally higher than *kharif* 2000. Integrated nutrient management practices had significant impact on the grain yield of sunflower in both *kharif* 2000 and 2001. The 150% NPK + FYM + Zn + Fe (F₄) and 150% NPK + FYM (F₂) recorded comparable yields but were significantly superior to the other two treatments. The grain yield under 100% NPK + FYM (F₁) was on par with that of 100% NPK + FYM + Zn + Fe (F₃). The yield of sunflower under different treatments was numerically higher in *kharif* 2001 compared to *kharif* 2000.

4.3.3. Cowpea

Cropping systems did not have any significant influence on the grain yield of cowpea in both *rabi* 2000 and *rabi* 2001. A numerical increase in grain yield of cowpea was noticed under maize-sunflower-cowpea (S₃) system compared to the maize-fallow-cowpea (S₂) system.

Integrated nutrient management practices had significant impact on grain yield of cowpea in *rabi* 2000 but not in *rabi* 2001. In *rabi* 2000, significantly higher grain yield was recorded under 150% NPK + FYM + Zn + Fe (F₄). The yield under 150% NPK + FYM (F₂) did not differ significantly from that under 100% NPK + FYM + Zn + Fe (F₃). The 100% NPK + FYM (F₁) registered significantly lower grain yield in *rabi* 2000.

The grain yield of cowpea was higher in *rabi* 2001 compared to *rabi* 2000 under all the integrated nutrient management practices.

4.4. Stover, stalk and haulm yield (Table 6)

4.4.1. Maize

Cropping systems had significant effect on stover yield of maize in all the three seasons. Significantly higher stover yield was recorded under maize-sunflower-cowpea (S_3) system than the other two systems and it was on par with maize-fallow-cowpea (S_2) system during summer 2000. The maize-fallow-fallow (S_1) system recorded significantly lower stover yield in all the three seasons. The increase in the stover yield of maize was considerable across the seasons due to cropping systems.

Integrated nutrient management practices significantly influenced the maize stover yield in all the three seasons. Stover yield was significantly higher under 150% NPK + FYM + Zn + Fe (F_4) in summer 2000 and summer 2002 but in summer 2001, it was on par with 150% NPK + FYM (F_2). The 150% NPK + FYM (F_2), 100% NPK + FYM + Zn + Fe (F_3) and 100% NPK + FYM (F_1) were on par in stover yields in summer 2002 but in summer 2000 and summer 2001, only F_2 and F_3 were on par. Stover yields of maize under 100% NPK + FYM (F_1) and 100% NPK + FYM + Zn + Fe (F_3) were on par and significantly lower than F_2 and F_4 . Stover yield of maize increased over the cropping seasons due to different integrated nutrient management practices.

The interaction effect of cropping systems and integrated nutrient management practices on stover yield of maize was not significant.

Table 6. Stover, stalk and haulm yield of maize, sunflower and cowpea, respectively (kg ha⁻¹)

	Maize			Sunflower		Cowpea	
	Summer 2000	Summer 2001	Summer 2002	<i>Kharif</i> 2000	<i>Kharif</i> 2001	<i>Rabi</i> 2000	<i>Rabi</i> 2001
Cropping systems							
S ₁	8316	8830	9123	-	-	-	-
S ₂	8857	9325	9852	-	-	2615	2958
S ₃	9092	9946	10857	3038 ¹	3505 ¹	2713	3130
SEd	241	163	124	-	-	36	42
CD (P=0.05)	671	454	345	-	-	NS	NS
Integrated nutrient management							
F ₁	8239	8924	9570	2763	3120	2478	2878
F ₂	8796	9433	10010	3160	3646	2693	3078
F ₃	8558	9208	9711	2892	3326	2643	3023
F ₄	9427	9903	10485	3339	3928	2843	3198
SEd	235	239	215	146	144	86	64
CD (P=0.05)	495	501	453	357	354	186	139

¹ Not statistically analyzed

4.4.2. Sunflower

The stalk yield of sunflower under maize-sunflower-cowpea (S_3) system during *kharif* 2001 was marginally higher when compared to *kharif* 2000. Integrated nutrient management practices significantly influenced the stalk yield of sunflower in both *kharif* 2000 and *kharif* 2001. The 150% NPK + FYM + Zn + Fe (F_4) recorded higher stalk yield and it was on par with 150% NPK + FYM (F_2). The stalk yield under 150% NPK + FYM (F_2) and 150% NPK + FYM + Zn + Fe (F_4) were on par. Stalk yield of sunflower under 100% NPK + FYM + Zn + Fe (F_3) and 100% NPK + FYM (F_1) were on par and significantly lower than the other two treatments in both the seasons. Considerable increase in stalk yield was noticed in *kharif* 2001 compared to *kharif* 2000.

4.4.3. Cowpea

Haulm yield of cowpea was not significantly influenced by cropping systems. However, the haulm yield under the maize-sunflower-cowpea (S_3) system was marginally higher than the maize-fallow-cowpea (S_2) system in both the seasons.

Integrated nutrient management practices had significant impact on the haulm yield of cowpea in both the seasons. Application of 150% NPK + FYM + Zn + Fe (F_4) and 150% NPK + FYM (F_2) recorded significantly higher haulm yield over the other two treatments in both the seasons and were on par with each other. The 150% NPK + FYM (F_2) and 100% NPK + FYM + Zn + Fe (F_3) were on par in haulm yields in both the seasons. Haulm yield under the 100% NPK + FYM + Zn + Fe (F_3) and 100% NPK + FYM (F_1) were on par and significantly inferior than the other two treatments. Notable increase in haulm yield was observed over the seasons due to different integrated nutrient management practices. There was no significant interaction effect between cropping systems and integrated nutrient management practices on haulm yield of cowpea.

4.5. Crop residue addition (Table 7)

Cropping systems significantly influenced the amount of maize residues added to the soil. In summer 2000 and summer 2002, the maize residues added to the soil was on par and significantly higher under the maize-sunflower-cowpea (S₃) and maize-fallow-cowpea (S₂) systems than the maize-fallow-fallow system (S₁). In summer 2001, the maize-fallow-cowpea (S₂) and maize-fallow-fallow (S₁) systems were on par in the quantity of maize crop residues returned to the soil. In summer 2002, the maize-sunflower-cowpea (S₃), maize-fallow-cowpea (S₂) and maize-fallow-fallow (S₁) systems were significantly different with respect to the quantity of maize residues added to the soil.

The maize-sunflower-cowpea (S₃) and maize-fallow-cowpea (S₂) systems did not significantly influence the quantity of cowpea residues added to the soil in both *rabi* 2000 and *rabi* 2001.

Integrated nutrient management practices significantly influenced the quantity of crop residues added to the soil in all the seasons except in summer 2001 in which all the four integrated nutrient management practices were on par in the quantity of maize residues added to the soil. In summer 2000 and summer 2002, the quantity of maize residues added to the soil was significantly higher at 150% NPK + FYM + Zn + Fe (F₄) and 150% NPK + FYM (F₂) than 100% NPK + FYM + Zn + Fe (F₃) and 100% NPK + FYM (F₁) treatments. The quantity of sunflower residues added to the soil was also higher at 150% NPK + FYM + Zn + Fe (F₄) and 150% NPK + FYM (F₂) than the other two treatments in both the *kharif* 2000 and *kharif* 2001. The 100% NPK + FYM + Zn + Fe (F₃) and 100% NPK + FYM (F₁) were on par in the quantity of sunflower residues added to the soil. The quantity of cowpea residues added to the soil was

Table 7. Crop residue addition (kg ha⁻¹)

	Cropping cycle I			Cropping cycle II			Cropping cycle III
	Summer 2000	<i>Kharif</i> 2000	<i>Rabi</i> 2000	Summer 2001	<i>Kharif</i> 2001	<i>Rabi</i> 2001	Summer 2002
	Maize	Fallow/ Sunflower	Fallow/ Cowpea	Maize	Fallow/ Sunflower	Fallow/ Cowpea	Maize
Cropping systems							
S ₁	10488	-	-	10906	-	-	11272
S ₂	10947	-	3130	11521	-	3542	12199
S ₃	11234	3644 ¹	3236	12031	4203 ¹	3747	13508
SEd	152	-	42	279	-	50	157
CD	424	-	NS	773	-	NS	438
(P=0.05)							
Integrated nutrient management							
F ₁	10188	3315	2942	11016	3743	3447	11827
F ₂	11143	3790	3224	11653	4373	3685	12537
F ₃	10580	3469	3164	11378	3989	3619	11997
F ₄	11646	4004	3403	11897	4710	3829	12944
SEd	256	175	102	360	173	76	268
CD	538	428	223	NS	425	165	563
(P=0.05)							

¹ Not statistically analysed

significantly higher under the 150% NPK + FYM + Zn + Fe (F₄) and 150% NPK + FYM (F₂) than the other two treatments in both *rabi* 2000 and *rabi* 2001. The 100% NPK + FYM + Zn + Fe (F₃) and 100% NPK + FYM (F₁) were on par in *rabi* 2000 but in *rabi* 2001, the former added significantly higher quantity of cowpea residues to the soil than the latter.

4.6. Bulk density (Table 8)

The results clearly indicated that bulk density of soil was not significantly influenced by cropping systems during the first cropping cycle and also during the subsequent summer 2001 season of the second cropping cycle. In *kharif* 2001, *rabi* 2001 and summer 2002, significant reduction in bulk density was noticed under maize-sunflower-cowpea (S₃) system. Bulk density under this (S₃) system was significantly lower than maize-fallow-cowpea (S₂) system in *kharif* 2001 but were comparable in *rabi* 2001 and summer 2002. Bulk density under the maize-fallow-fallow (S₁) system was on par with maize-fallow-cowpea system (S₂) in *kharif* 2001 and it remained significantly higher than the other two systems in *rabi* 2001 and summer 2002. Over the cropping seasons, the reduction in bulk density was very minimum under maize-fallow-fallow system (S₁) compared to the other two systems. Bulk density increased during the fallow period in the maize-fallow-cowpea system (S₂) in the first cropping cycle. In the maize-fallow-fallow system (S₁), the bulk density during the fallow phase increased in the first cropping cycle and remained unaltered in the second cropping cycle.

Integrated nutrient management practices produced no significant impact on bulk density. However, comparatively lower values of bulk density were recorded with 150% NPK + FYM + Zn + Fe (F₄) and 150% NPK + FYM (F₂) treatments. The reduction in

Table 8. Bulk density (Mg m^{-3})

	Cropping cycle I			Cropping cycle II			Cropping cycle III
	Summer 2000	<i>Kharif</i> 2000	<i>Rabi</i> 2000	Summer 2001	<i>Kharif</i> 2001	<i>Rabi</i> 2001	Summer 2002
	Maize	Fallow/ Sunflower	Fallow/ Cowpea	Maize	Fallow/ Sunflower	Fallow/ Cowpea	Maize
Cropping systems							
S ₁	1.43	1.43	1.45	1.41	1.41	1.41	1.38
S ₂	1.43	1.45	1.42	1.39	1.38	1.33	1.30
S ₃	1.42	1.42	1.38	1.35	1.33	1.30	1.27
SEd	0.01	0.03	0.03	0.02	0.01	0.02	0.02
CD (P=0.05)	NS	NS	NS	NS	0.04	0.06	0.06
Integrated nutrient management							
F ₁	1.44	1.45	1.44	1.39	1.40	1.38	1.34
F ₂	1.43	1.43	1.41	1.37	1.36	1.35	1.31
F ₃	1.43	1.43	1.42	1.40	1.38	1.35	1.33
F ₄	1.41	1.41	1.40	1.37	1.36	1.32	1.30
SEd	0.03	0.04	0.04	0.03	0.03	0.02	0.03
CD (P=0.05)	NS	NS	NS	NS	NS	NS	NS

bulk density over the cropping seasons was marginal during the first cropping cycle and it was comparatively higher during the second cropping cycle.

The interaction effect of cropping systems and integrated nutrient management practices on bulk density was not significant.

4.7. Non-capillary porosity (Table 9)

Cropping systems significantly altered the non-capillary pore space in all the cropping seasons. The maize-sunflower-cowpea system (S₃) recorded highest non-capillary porosity and it was superior to other two systems in all the cropping seasons. At the end of the first and second cropping cycle, the increase in non-capillary porosity was higher under the maize-sunflower-cowpea system (S₃) than the maize-fallow-cowpea system (S₂). During the fallow phase, there was a decrease in non-capillary porosity under the maize-fallow-fallow system (S₁) in the cropping cycles I and II and under the maize-fallow-cowpea system (S₂) in the first cropping cycle.

Integrated nutrient management practices had significant effect on non-capillary porosity in all the cropping seasons except in summer 2001. The 150% NPK + FYM + Zn + Fe (F₄) and 150% NPK + FYM + Zn + Fe (F₂) were on par with higher value of non-capillary porosity in all the seasons except in summer 2000. In *kharif* 2000, *rabi* 2000 and summer 2001, the non-capillary porosity values under 150% NPK + FYM (F₂), 100% NPK + FYM + Zn + Fe (F₃) and 100% NPK + FYM (F₁) were on par. The effect of 100% NPK + FYM + Zn + Fe (F₃) and 100% NPK + FYM (F₁) on non-capillary porosity was comparable. At the end of the second cropping cycle, the increase in non-capillary porosity was higher in 150% NPK + FYM + Zn + Fe (F₄).

Table 9. Non capillary porosity (%)

	F ₁	F ₂	F ₃	F ₄	Mean	Source	SEd	CD (P = 0.05)
Summer 2000 (Maize)								
S ₁	16.7	19.0	15.9	17.0	17.2	S	0.4	1.0
S ₂	18.9	19.7	17.7	20.7	19.2	F	0.5	1.0
S ₃	19.2	21.7	19.5	21.3	20.4	S at F	0.8	NS
Mean	18.3	20.1	17.7	19.7		F at S	0.8	NS
Kharif 2000 (Fallow/Sunflower)								
S ₁	18.0	17.4	15.7	18.0	17.3	S	0.4	1.1
S ₂	17.4	18.1	19.2	20.0	18.7	F	0.4	0.9
S ₃	18.9	21.2	21.0	22.3	20.8	S at F	0.8	1.8
Mean	18.1	18.9	18.6	20.1		F at S	0.8	1.6
Rabi 2000 (Fallow/Cowpea)								
S ₁	16.6	17.1	15.3	16.4	16.3	S	0.2	0.5
S ₂	21.6	19.6	18.5	20.6	20.1	F	0.4	0.8
S ₃	19.4	24.3	21.4	22.9	22.0	S at F	0.6	1.3
Mean	19.2	20.3	18.4	20.0		F at S	0.6	1.4
Summer 2001 (Maize)								
S ₁	15.5	19.1	17.6	18.5	17.7	S	0.3	0.9
S ₂	21.6	19.4	20.5	20.3	20.4	F	1.0	2.2
S ₃	23.2	24.5	22.6	24.3	23.7	S at F	1.0	2.2
Mean	20.1	21.0	20.2	21.0		F at S	1.1	2.3
Kharif 2001 (Fallow/Sunflower)								
S ₁	10.0	19.5	16.5	17.1	17.3	S	0.3	0.9
S ₂	19.7	20.2	20.7	23.2	21.0	F	0.5	1.0
S ₃	22.7	24.1	23.3	24.8	23.7	S at F	0.8	1.7
Mean	19.5	21.3	20.2	21.7		F at S	0.8	1.7
Rabi 2001 (Fallow/Cowpea)								
S ₁	15.6	18.5	18.2	17.7	17.5	S	0.5	1.4
S ₂	21.5	22.0	22.0	26.1	22.9	F	0.6	1.3
S ₃	26.6	26.7	24.5	26.8	26.2	S at F	1.0	2.3
Mean	21.2	22.4	21.6	23.5		F at S	1.1	2.2
Summer 2002 (Maize)								
S ₁	17.9	18.8	19.1	18.9	18.7	S	0.5	1.2
S ₂	22.9	23.7	22.7	27.7	26.5	F	0.6	1.3
S ₃	25.4	27.0	25.9	27.7	26.5	S at F	1.0	2.3
Mean	22.1	23.2	22.6	23.8		F at S	1.1	2.2

There was significant interaction effect between cropping systems and integrated nutrient management practices on non-capillary porosities in all the seasons except during summer 2000. The maize-sunflower-cowpea (S₃) system with 150% NPK + FYM + Zn + Fe (F₄) recorded significantly higher non-capillary porosity values when compared to other systems.

4.8. Capillary porosity (Table 10)

Capillary porosity was not significantly altered due to cropping systems in all the seasons. The difference in capillary pore space between cropping systems was only marginal except in summer 2001 and summer 2002. The maize-sunflower-cowpea system (S₃) recorded numerically higher values of capillary porosity than the other two systems. Capillary porosity decreased due to fallowing in the maize-fallow-fallow system (S₁) in the first cropping cycle.

The integrated nutrient management practices had no significant effect on capillary porosity in all the seasons except in *rabi* 2000 in which capillary porosity at 150% NPK + FYM + Zn + Fe (F₄) was significantly higher than the other three treatments. At the end of second cropping cycle, the variation in capillary porosity between the treatments was only marginal.

There was no significant interaction effect between cropping systems and integrated nutrient management practices on capillary porosity.

4.9. Total porosity (Table 11)

Significant difference in total porosity was observed due to cropping systems in all the seasons except in summer 2000 and *rabi* 2000 in which the variation in total porosity between the maize-sunflower-cowpea (S₃) and maize-fallow-cowpea (S₂)

Table 10. Capillary porosity (%)

	Cropping cycle I			Cropping cycle II			Cropping cycle III
	Summer 2000	<i>Kharif</i> 2000	<i>Rabi</i> 2000	Summer 2001	<i>Kharif</i> 2001	<i>Rabi</i> 2001	Summer 2002
	Maize	Fallow/Sunflower	Fallow/Cowpea	Maize	Fallow/Sunflower	Fallow/Cowpea	Maize
Cropping systems							
S ₁	27.9	27.6	27.5	27.5	27.7	28.0	27.6
S ₂	27.7	28.3	27.9	28.9	28.5	27.8	28.3
S ₃	28.2	28.3	28.3	28.6	28.2	28.0	28.8
SEd	0.5	0.5	0.3	0.4	0.5	0.3	0.5
CD (P=0.05)	NS	NS	NS	NS	NS	NS	NS
Integrated nutrient management							
F ₁	27.6	27.6	27.2	27.7	27.3	27.8	27.7
F ₂	28.0	28.2	27.4	28.6	28.1	27.9	28.2
F ₃	28.0	28.1	28.1	28.4	28.5	28.0	28.3
F ₄	28.0	28.2	29.0	28.5	28.6	28.1	28.7
SEd	0.7	0.5	0.6	0.9	0.7	0.6	0.8
CD (P=0.05)	NS	NS	1.3	NS	NS	NS	NS

Table 11. Total porosity (%)

	Cropping cycle I			Cropping cycle II			Cropping cycle III
	Summer 2000	<i>Kharif</i> 2000	<i>Rabi</i> 2000	Summer 2001	<i>Kharif</i> 2001	<i>Rabi</i> 2001	Summer 2002
	Maize	Fallow/ Sunflower	Fallow/ Cowpea	Maize	Fallow/ Sunflower	Fallow/ Cowpea	Maize
Cropping systems							
S ₁	45.0	44.9	43.9	45.1	45.1	45.5	46.3
S ₂	46.9	47.0	48.0	49.2	49.4	50.8	51.8
S ₃	48.6	49.1	50.4	52.2	52.0	54.2	55.4
SEd	0.6	0.5	1.0	0.6	0.9	1.0	0.6
CD (P=0.05)	1.8	1.5	2.8	1.7	2.5	2.7	1.8
Integrated nutrient management							
F ₁	45.9	45.7	46.4	47.8	46.7	49.0	49.8
F ₂	48.1	47.2	47.8	49.6	49.4	50.3	51.4
F ₃	45.7	46.8	46.7	48.0	48.6	49.6	50.9
F ₄	47.6	48.3	48.9	49.9	50.6	51.6	52.5
SEd	1.1	1.0	0.8	1.1	1.2	1.2	0.9
CD (P=0.05)	NS	NS	1.7	NS	2.5	NS	NS

systems was not significant. The maize-sunflower-cowpea system (S₃) significantly increased the total porosity and it was superior to the other two systems in all the cropping seasons. At the end of the first cropping cycle, a decrease in porosity was noticed due to fallowing under maize-fallow-fallow system (S₁) but an increase was recorded during the *rabi* 2001 fallow phase in the second cropping cycle.

The effect of integrated nutrient management practices on total porosity was not significant in all the seasons except in *rabi* 2000 and *kharif* 2001. In these two seasons, total porosity under the 150% NPK + FYM + Zn + Fe (F₄) was significantly higher than the 100% NPK + FYM + Zn + Fe (F₃) and 100% NPK + FYM (F₁) and it was comparable with 150% NPK + FYM (F₂). At the end of the first and the second cropping cycles, application of 150% NPK + FYM + Zn + Fe (F₄) recorded highest values of total porosity and it was superior to other treatments.

There found to be no significant interaction effect due to cropping systems and integrated nutrient management practices on total porosity.

4.10. Hydraulic conductivity (Table 12)

Cropping systems significantly influenced the hydraulic conductivity in all the seasons except in summer 2000 and *kharif* 2000. The maize-sunflower-cowpea system (S₃) recorded higher values of hydraulic conductivity; however it was not significantly superior to maize-fallow-cowpea system (S₂) in all the seasons except in *rabi* 2000. The maize-fallow-fallow system (S₁) registered significantly lower values of hydraulic conductivity than the other two systems in all the seasons except in summer 2000 and *kharif* 2000. Hydraulic conductivity increased over the cropping seasons except in the fallow phase of both maize-fallow-cowpea (S₂) and maize-fallow-fallow (S₁) systems in the first cropping cycle.

Table 12. Hydraulic conductivity (cm hr^{-1})

	Cropping cycle I			Cropping cycle II			Cropping cycle III
	Summer 2000	<i>Kharif</i> 2000	<i>Rabi</i> 2000	Summer 2001	<i>Kharif</i> 2001	<i>Rabi</i> 2001	Summer 2002
	Maize	Fallow/ Sunflower	Fallow/ Cowpea	Maize	Fallow/ Sunflower	Fallow/ Cowpea	Maize
Cropping systems							
S ₁	2.50	2.46	2.42	2.49	2.49	2.54	2.59
S ₂	2.59	2.55	2.59	2.66	2.67	2.71	2.77
S ₃	2.60	2.61	2.67	2.74	2.74	2.82	2.87
SEd	0.04	0.04	0.03	0.05	0.05	0.03	0.07
CD (P=0.05)	NS	NS	0.08	0.13	0.15	0.10	0.16
Integrated nutrient management							
F ₁	2.51	2.48	2.51	2.57	2.56	2.63	2.69
F ₂	2.60	2.56	2.58	2.65	2.65	2.70	2.77
F ₃	2.54	2.52	2.54	2.60	2.63	2.70	2.73
F ₄	2.61	2.58	2.62	2.68	2.69	2.75	2.78
SEd	0.06	0.07	0.06	0.07	0.05	0.06	0.07
CD (P=0.05)	NS	NS	NS	NS	NS	NS	NS

Integrated nutrient management practices did not influence significantly the hydraulic conductivity in all the seasons. Marginally higher values were recorded with 150% NPK + FYM + Zn + Fe (F₄) followed by 150% NPK + FYM + Zn + Fe (F₂) and 100% NPK + FYM (F₃). Application of 100% NPK + FYM (F₁) recorded the least values of hydraulic conductivity.

The interaction effect of cropping systems and integrated nutrient management practices on hydraulic conductivity was not significant.

4.11. Water stable aggregates (Table 13)

Cropping systems influenced the percentage of water stable aggregates (> 0.25 mm) significantly in all the seasons. Significantly higher water stable aggregation was registered under maize-sunflower-cowpea system (S₃) than the other two systems. The maize-fallow-fallow system (S₁) recorded the least values of water stable aggregates than the other two systems. Water stable aggregation increased over the cropping seasons except during the fallow phase (*kharif* 2000) of the maize-fallow-fallow system (S₁) in the first cropping cycle and the increase was more pronounced under the maize-sunflower-cowpea (S₃) and maize-fallow-cowpea (S₂) systems than the maize-fallow-fallow system (S₁). At the end of the first and the second cropping cycles, the maize-sunflower-cowpea system (S₃) recorded higher water stable aggregates followed by the maize-fallow-cowpea system (S₂).

Integrated nutrient management practices did not have any significant effect on water stable aggregates in all the seasons except in summer 2001 in which the 100% NPK + FYM (F₁) differed with significantly lower values than F₄ and was on par with F₂ and F₃ treatments. Over the cropping seasons, water stable aggregates increased marginally due to integrated nutrient management practices.

Table 13. Water stable aggregates (>25 mm) (%)

	Cropping cycle I			Cropping cycle II			Cropping cycle III
	Summer 2000	<i>Kharif</i> 2000	<i>Rabi</i> 2000	Summer 2001	<i>Kharif</i> 2001	<i>Rabi</i> 2001	Summer 2002
	Maize	Fallow/Sunflower	Fallow/Cowpea	Maize	Fallow/Sunflower	Fallow/Cowpea	Maize
Cropping systems							
S ₁	59.0	58.7	59.2	60.8	60.9	61.1	62.7
S ₂	63.4	63.6	65.9	67.8	69.5	71.8	73.7
S ₃	66.4	67.0	69.8	71.8	74.1	76.5	78.0
SEd	0.8	1.1	1.3	0.9	1.5	1.0	1.0
CD (P=0.05)	2.1	3.1	3.6	2.4	4.2	2.6	2.7
Integrated nutrient management							
F ₁	61.8	61.7	63.3	65.1	67.5	69.1	70.2
F ₂	63.6	63.5	65.1	67.3	68.0	69.3	70.9
F ₃	62.1	62.8	65.0	66.8	67.8	69.3	71.7
F ₄	64.2	64.3	66.3	68.1	69.3	71.4	73.0
SEd	1.5	1.5	1.5	1.3	1.2	1.6	1.6
CD (P=0.05)	NS	NS	NS	2.6	NS	NS	NS

There was no significant interaction between cropping systems and integrated nutrient management practices on water stable aggregates.

4.12. Field capacity (Table 14)

Field capacity was significantly influenced by cropping systems in all the seasons. All the three cropping systems exhibited significantly different moisture contents at field capacity in all the seasons except in summer 2000 in which the maize-fallow-cowpea (S₂) and maize-fallow-fallow (S₁) systems were comparable and in summer 2001 and *kharif* 2001, maize-sunflower-cowpea (S₃) and maize-fallow-cowpea (S₂) systems behaved similarly. In both the maize-fallow-cowpea (S₂) and maize-fallow-fallow (S₁) systems, field capacity decreased during the fallow period in the first cropping cycle. In general, field capacity increased due to cropping systems over the cropping seasons. The maize-sunflower-cowpea (S₃) system recorded higher moisture content at field capacity at the end of the second cropping cycle.

Integrated nutrient management practices significantly influenced the field capacity in all the cropping seasons except in summer 2002. All the three treatments except 100% NPK + FYM (F₁) behaved in a similar manner in influencing the field capacity in all the cropping seasons except in *rabi* 2001 in which 100% NPK + FYM + Zn + Fe (F₃) differed significantly with lower values than F₄ and F₂ treatments. In all the cropping seasons, the field capacity values with 100% NPK + FYM + Zn + Fe (F₃) and 100% NPK + FYM (F₁) were on par. At the end of the first and second cropping cycles, notable increase in field capacity was observed due to integrated nutrient management practices.

The interaction effect of cropping systems and integrated nutrient management practices on field capacity was not significant.

Table 14. Field capacity (%)

	Cropping cycle I			Cropping cycle II			Cropping cycle III
	Summer 2000	<i>Kharif</i> 2000	<i>Rabi</i> 2000	Summer 2001	<i>Kharif</i> 2001	<i>Rabi</i> 2001	Summer 2002
	Maize	Fallow/ Sunflower	Fallow/ Cowpea	Maize	Fallow/ Sunflower	Fallow/ Cowpea	Maize
Cropping systems							
S ₁	26.5	26.3	26.1	26.6	27.0	27.2	28.0
S ₂	27.6	27.9	29.3	30.1	30.9	31.9	32.8
S ₃	28.9	29.4	30.9	31.7	32.4	34.1	35.1
SEd	0.4	0.3	0.2	0.6	0.6	0.6	0.6
CD (P=0.05)	1.1	0.7	0.6	1.6	1.5	1.7	1.7
Integrated nutrient management							
F ₁	26.7	27.1	27.7	28.6	29.2	30.0	31.0
F ₂	28.2	28.3	29.9	29.6	30.7	31.8	32.5
F ₃	27.2	27.4	28.2	29.1	29.5	30.6	31.5
F ₄	28.4	28.6	29.3	30.5	30.9	31.8	32.8
SEd	0.6	0.6	0.6	0.7	0.7	0.5	0.9
CD (P=0.05)	1.3	1.3	1.4	1.5	1.5	1.1	NS

4.13. Permanent wilting point (Table 15)

Permanent wilting point was significantly influenced by cropping systems in all the seasons except *rabi* 2000. All the three cropping systems differed significantly from each other in influencing the permanent wilting point except in summer 2000 in which the maize-sunflower-cowpea (S_3) and maize-fallow-cowpea (S_2) systems behaved similarly. In the first cropping cycle, moisture content at permanent wilting point decreased under the maize-fallow-fallow (S_1) system during the fallow phase. At the end of the first and second cropping cycles, moisture content increased considerably under the maize-sunflower-cowpea system (S_3).

Moisture content at permanent wilting point was significantly influenced by integrated nutrient management practices in all the seasons except in summer 2000, *rabi* 2000 and *kharif* 2001. The influence on moisture content at permanent wilting point due to 150% NPK + FYM + Zn + Fe (F_4), 150% NPK + FYM (F_2) and 100% NPK + FYM + Zn + Fe (F_3) was similar in all the seasons except in summer 2002 in which the latter differed from the rest of the two significantly. The effect of 100% NPK + FYM + Zn + Fe (F_3) and 100% NPK + FYM (F_1) on permanent wilting point was on par. In general, soil moisture content was improved over the cropping seasons due to integrated nutrient management practices. At the end of the first and the second cropping cycle 150% NPK + FYM + Zn + Fe (F_4), 150% NPK + FYM (F_2) and 100% NPK + FYM + Zn + Fe (F_3) recorded higher moisture content.

The interaction effect between cropping systems and integrated nutrient management practices on field capacity was absent.

Table 15. Permanent wilting point (%)

	Cropping cycle I			Cropping cycle II			Cropping cycle III
	Summer 2000	<i>Kharif</i> 2000	<i>Rabi</i> 2000	Summer 2001	<i>Kharif</i> 2001	<i>Rabi</i> 2001	Summer 2002
	Maize	Fallow/ Sunflower	Fallow/ Cowpea	Maize	Fallow/ Sunflower	Fallow/ Cowpea	Maize
Cropping systems							
S₁	13.8	13.6	13.5	13.8	13.9	14.0	14.4
S₂	15.0	15.0	15.5	15.8	16.2	16.9	17.2
S₃	15.2	15.6	15.9	16.7	16.4	17.9	18.5
SEd	0.2	0.3	1.0	0.2	0.6	0.3	0.4
CD (P=0.05)	0.5	0.7	NS	0.6	1.8	0.9	1.1
Integrated nutrient management							
F₁	14.4	14.3	14.6	15.1	15.0	15.7	16.2
F₂	14.7	14.9	15.4	15.7	16.0	16.4	17.0
F₃	14.5	14.6	14.9	15.2	15.6	16.0	16.3
F₄	15.0	15.1	15.7	15.9	15.5	16.9	17.3
SEd	0.3	0.3	1.4	0.4	0.7	0.5	0.3
CD (P=0.05)	NS	0.7	NS	0.8	NS	0.9	0.7

4.14. Available soil moisture (Table 16)

Significant influence on available soil moisture due to cropping systems was noticed in all the seasons. The maize-sunflower-cowpea (S_3) and maize-fallow-cowpea (S_2) systems were equally effective in increasing the available water storage capacity in all the seasons except in summer 2000 and *rabi* 2001 in which the former was significantly superior to the latter. The maize-fallow-cowpea (S_2) and maize-fallow-fallow (S_1) systems had similar available water in summer 2000 and *kharif* 2000 and in the rest of the seasons, they differed significantly. Available water storage capacity decreased during the fallow period in maize-fallow-fallow system (S_1) in cropping cycles I and II. At the end of cropping cycle I and II, an increase in available water storage capacity was recorded due to cropping systems.

Available water storage capacity increased significantly due to integrated nutrient management practices in all the seasons except in *kharif* 2000, *kharif* 2001 and summer 2002. The 150% NPK + FYM (F_2) recorded significantly higher available water in *rabi* 2001 and in the remaining seasons it was comparable with 150% NPK + FYM + Zn + Fe (F_4).

The interaction effect of cropping systems and integrated nutrient management practices on available soil moisture was not significant.

4.15. Organic carbon (Table 17)

Cropping systems exerted significant change in organic carbon content in all the seasons. The maize - sunflower - cowpea system (S_3) led to build up of soil organic carbon content and it was superior to maize-fallow-cowpea system (S_2) in all the seasons

Table 16. Available soil moisture (cm m^{-1})

	Cropping cycle I			Cropping cycle II			Cropping cycle III
	Summer 2000	<i>Kharif</i> 2000	<i>Rabi</i> 2000	Summer 2001	<i>Kharif</i> 2001	<i>Rabi</i> 2001	Summer 2002
	Maize	Fallow/ Sunflower	Fallow/ Cowpea	Maize	Fallow/ Sunflower	Fallow/ Cowpea	Maize
Cropping systems							
S ₁	18.0	18.2	18.1	18.6	18.5	18.6	18.8
S ₂	18.3	18.7	19.5	19.8	20.3	19.9	20.3
S ₃	19.4	19.5	20.1	20.2	20.6	21.1	20.9
SEd	0.3	0.3	0.2	0.3	0.4	0.3	0.4
CD (P=0.05)	0.9	0.8	0.7	0.8	1.0	0.8	1.0
Integrated nutrient management							
F ₁	17.9	18.6	18.6	18.9	19.9	19.5	19.7
F ₂	19.3	19.1	19.6	19.8	20.1	20.6	20.2
F ₃	18.1	18.3	18.8	19.4	19.3	19.7	20.0
F ₄	18.9	19.2	19.9	20.0	19.8	19.6	20.1
SEd	0.5	0.4	0.4	0.5	0.5	0.4	0.6
CD (P=0.05)	1.0	NS	0.9	1.0	NS	0.9	NS

Table 17. Organic carbon (%)

	Cropping cycle I			Cropping cycle II			Cropping cycle III
	Summer 2000	<i>Kharif</i> 2000	<i>Rabi</i> 2000	Summer 2001	<i>Kharif</i> 2001	<i>Rabi</i> 2001	Summer 2002
	Maize	Fallow/ Sunflower	Fallow/ Cowpea	Maize	Fallow/ Sunflower	Fallow/ Cowpea	Maize
Cropping systems							
S ₁	0.42	0.42	0.43	0.45	0.45	0.45	0.48
S ₂	0.41	0.44	0.48	0.50	0.49	0.54	0.57
S ₃	0.47	0.47	0.52	0.54	0.56	0.60	0.63
SEd	0.01	0.01	0.01	0.01	0.01	0.02	0.01
CD (P=0.05)	0.02	0.02	0.02	0.02	0.04	0.07	0.02
Integrated nutrient management							
F ₁	0.39	0.42	0.46	0.47	0.48	0.51	0.54
F ₂	0.45	0.45	0.48	0.51	0.50	0.54	0.56
F ₃	0.44	0.45	0.46	0.49	0.49	0.52	0.55
F ₄	0.45	0.46	0.49	0.52	0.52	0.56	0.58
SEd	0.01	0.01	0.01	0.01	0.03	0.02	0.01
CD (P=0.05)	0.02	0.02	0.02	0.02	NS	NS	0.03

except in *rabi* 2001. There was poor build up of organic carbon content under the maize-fallow-fallow system (S_1) compared to the maize-fallow-cowpea system (S_2) in all the seasons except in summer 2000, *khariif* 2000 and *khariif* 2001. Organic carbon increased over the seasons in maize-sunflower-cowpea (S_3) and maize-fallow-cowpea (S_2) systems. However, in the maize-fallow-cowpea system (S_2), a decrease in soil organic carbon status was noticed during the fallow period in cropping cycle II. The increase in organic carbon in the maize-fallow-fallow system (S_1) over the seasons was only marginal and there was no increase in organic carbon content during the fallow phase of both the cropping cycles I and II.

Integrated nutrient management practices significantly influenced the organic carbon content in all seasons except in *khariif* 2001 and *rabi* 2001. The 150% NPK + FYM + Zn + Fe (F_4) recorded significantly higher values of organic carbon; however, it was on par with 150% NPK + FYM (F_2) in all the seasons. Application of 150% NPK + FYM + Zn + Fe (F_4) recorded higher values of organic carbon and was statistically on par with 100% NPK + FYM + Zn + Fe (F_3) in all the seasons except in *rabi* 2000 and summer 2001. The organic carbon content was significantly less under 100% NPK + FYM (F_1) than all the other treatments in all the seasons except in *rabi* 2000, summer 2001 and summer 2002 in which it was on par with 100% NPK + FYM + Zn + Fe (F_3).

At the end of the first and the second cropping cycles, maize-sunflower-cowpea (S_3) system with 150% NPK + FYM + Zn + Fe (F_4) and 150% NPK + FYM (F_2) resulted in comparatively higher organic carbon than the other treatments.

The interaction effect of cropping systems and integrated nutrient management practices on organic carbon was not significant in all the seasons.

4.16. Available nitrogen (Table 18)

Significant increase in soil available nitrogen was noticed due to cropping systems in all the seasons except summer 2000 and *kharif* 2000. Soil available nitrogen status was significantly higher under maize-sunflower-cowpea system (S₃) and it was on par with maize-fallow-cowpea system (S₂) in all the seasons. The maize-fallow-cowpea (S₂) system was superior to the maize-fallow-fallow system (S₁) in increasing the available nitrogen content in all the seasons. Available nitrogen content decreased during the fallow phase in the maize-fallow-fallow system (S₁) in the cropping cycles I and II and in the maize-fallow-cowpea system (S₂) in cropping cycle II. At the end of the first and the second cropping cycles, soil available nitrogen increased considerably under maize-sunflower-cowpea (S₃) and maize-fallow-cowpea (S₂) systems but not under maize-fallow-fallow system (S₁).

Integrated nutrient management practices did not influence the available nitrogen status in all the cropping seasons. Numerically higher values were recorded by 150% NPK + FYM + Zn + Fe (F₄) and 150% NPK + FYM (F₂) treatments over the other two treatments. Across the cropping seasons, available nitrogen content increased due to integrated nutrient management practices.

The interaction effect of cropping systems and integrated nutrient management practices on available nitrogen was not significant.

Table 18. Available nitrogen (kg ha^{-1})

	Cropping cycle I			Cropping cycle II			Cropping cycle III
	Summer 2000	<i>Kharif</i> 2000	<i>Rabi</i> 2000	Summer 2001	<i>Kharif</i> 2001	<i>Rabi</i> 2001	Summer 2002
	Maize	Fallow/ Sunflower	Fallow/ Cowpea	Maize	Fallow/ Sunflower	Fallow/ Cowpea	Maize
Cropping systems							
S ₁	221	221	220	224	222	221	225
S ₂	227	227	233	236	235	241	245
S ₃	228	230	236	240	242	248	252
SEd	3	3	3	4	4	4	6
CD (P=0.05)	NS	NS	9	10	11	10	17
Integrated nutrient management							
F ₁	223	224	228	231	231	234	238
F ₂	226	227	229	234	234	238	242
F ₃	225	225	229	232	231	236	240
F ₄	227	229	231	236	235	238	243
SEd	5	5	5	6	6	5	13
CD (P=0.05)	NS	NS	NS	NS	NS	NS	NS

4.17. Available phosphorus (Table 19)

Cropping systems significantly improved the available soil phosphorus status in all the seasons except summer 2000, summer 2001 and *khariif* 2001. Soil available phosphorus was significantly higher under the maize-sunflower-cowpea system (S_3) and it was on par with maize-fallow-cowpea system (S_2) in all the seasons. Available phosphorus status under the maize-fallow-fallow system (S_1) remained significantly lower than the other two systems except in summer 2000 and *khariif* 2000 in which it was similar with the other two systems. Build up in available phosphorus with time was only marginal under the maize-fallow-fallow system (S_1) but it was appreciable under the other two systems. In both the S_1 and S_2 systems which included a fallow period, a marginal decrease in available phosphorus occurred in the cropping cycles I and II during the fallow phase.

Integrated nutrient management practices had no significant effect on soil available phosphorus status in all the seasons. All the four treatments showed no considerable difference in available phosphorus content within the seasons. However notable build up of available phosphorus was seen at the end of the second cropping cycle due to integrated nutrient management practices.

There found to be no significant interaction effect between cropping systems and integrated nutrient management practices on soil available phosphorus.

4.18. Available potassium (Table 20)

The effect of cropping systems on soil available potassium was not significant in all the seasons except in summer 2002 in which the available potassium under the maize-fallow-fallow (S_1) system was significantly less than the other two systems. Considerable build up in available potassium was recorded at the end of the second cropping cycle

Table 19. Available phosphorus (kg ha⁻¹)

	Cropping cycle I			Cropping cycle II			Cropping cycle III
	Summer 2000	<i>Kharif</i> 2000	<i>Rabi</i> 2000	Summer 2001	<i>Kharif</i> 2001	<i>Rabi</i> 2001	Summer 2002
	Maize	Fallow/ Sunflower	Fallow/ Cowpea	Maize	Fallow/ Sunflower	Fallow/ Cowpea	Maize
Cropping systems							
S ₁	12.4	12.3	12.2	12.5	12.4	12.4	12.6
S ₂	12.7	12.5	12.9	13.1	13.0	13.4	13.6
S ₃	12.9	13.0	13.2	13.3	13.5	13.8	14.1
SEd	0.2	0.2	0.2	0.3	0.6	0.2	0.2
CD (P=0.05)	NS	0.6	0.6	NS	NS	0.5	0.5
Integrated nutrient management							
F ₁	12.6	12.5	12.6	12.8	12.9	13.0	13.2
F ₂	12.8	12.6	12.8	12.9	13.0	13.1	13.5
F ₃	12.6	12.5	12.7	12.9	13.0	13.0	13.4
F ₄	12.8	12.7	12.9	13.2	13.0	13.4	13.6
SEd	0.3	0.3	0.2	0.7	0.4	0.3	0.3
CD (P=0.05)	NS	NS	NS	NS	NS	NS	NS

Table 20. Available potassium (kg ha^{-1})

	Cropping cycle I			Cropping cycle II			Cropping cycle III
	Summer 2000	<i>Kharif</i> 2000	<i>Rabi</i> 2000	Summer 2001	<i>Kharif</i> 2001	<i>Rabi</i> 2001	Summer 2002
	Maize	Fallow/ Sunflower	Fallow/ Cowpea	Maize	Fallow/ Sunflower	Fallow/ Cowpea	Maize
Cropping systems							
S ₁	563	566	559	566	560	564	572
S ₂	567	559	565	572	580	584	598
S ₃	572	568	582	591	593	603	614
SEd	8	5	10	10	14	24	7
CD (P=0.05)	NS	NS	NS	NS	NS	NS	19
Integrated nutrient management							
F ₁	560	560	564	571	570	577	588
F ₂	570	568	572	579	579	586	602
F ₃	565	565	566	574	581	581	590
F ₄	573	564	574	582	582	590	599
SEd	13	14	14	11	27	19	13
CD (P=0.05)	NS	NS	NS	NS	NS	NS	NS

under the maize-sunflower-cowpea (S_3) and maize-fallow-cowpea (S_2) systems compared to the maize-fallow-fallow system (S_1).

The influence of integrated nutrient management practices on available potassium was also not significant in all the seasons. Only a marginal difference was observed due to different treatments within seasons. However, over the cropping seasons, appreciable increase in available potassium was noticed due to different integrated nutrient management practices.

There was no significant interaction effect between cropping systems and integrated nutrient management practices on soil available potassium in all the seasons.

4.19. Population of bacteria (Table 21)

Microbial population responded significantly to different cropping systems in all the seasons. The maize-sunflower-cowpea system (S_3) recorded significantly higher microbial population than the other two systems in all the seasons except in *kharif* 2001 in which the maize-fallow-cowpea system (S_2) had higher bacterial population and in summer 2002 both the systems were on par. Bacterial population was significantly less under maize-fallow-fallow system (S_1) compared to the two other systems. The overall pattern across the cropping seasons showed an increase in population of bacteria. During the fallow period, considerable decrease in population of bacteria was noticed under the maize-fallow-fallow (S_1) system in the cropping cycles I and II and under the maize-fallow-cowpea (S_2) system in cropping cycle I.

The integrated nutrient management practices influenced significantly the population of bacteria in all the cropping seasons. The response of bacterial population to different treatments was not consistent across the seasons. Bacterial population with

Table 21. Population* of bacteria

	F ₁	F ₂	F ₃	F ₄	Mean	Source	SEd	CD (P = 0.05)
Summer 2000 (Maize)								
S ₁	2.009 (102)	1.945 (88)	2.045 (111)	2.143 (139)	2.031 (107)	S	0.006	0.016
S ₂	1.945 (88)	2.185 (153)	2.017 (104)	2.146 (140)	2.068 (117)	F	0.022	0.046
S ₃	2.079 (120)	2.256 (180)	2.137 (137)	1.964 (92)	2.103 (127)	S at F	0.033	0.071
Mean	2.006 (101)	2.124 (133)	2.062 (115)	2.078 (120)		F at S	0.038	0.079
Kharif 2000 (Fallow/Sunflower)								
S ₁	1.954 (90)	1.863 (73)	2.079 (120)	2.0 (100)	1.965 (92)	S	0.017	0.047
S ₂	2.033 (108)	2.124 (133)	2.045 (111)	1.987 (97)	2.043 (110)	F	0.021	0.044
S ₃	2.009 (102)	2.228 (169)	2.182 (152)	2.295 (197)	2.173 (149)	S at F	0.036	0.081
Mean	1.992 (98)	2.066 (116)	2.096 (125)	2.087 (122)		F at S	0.036	0.077
Rabi 2000 (Fallow/Cowpea)								
S ₁	1.806 (64)	1.724 (53)	1.996 (99)	2.083 (121)	1.888 (77)	S	0.029	0.080
S ₂	2.041 (110)	2.188 (154)	2.134 (136)	2.286 (193)	2.159 (144)	F	0.039	0.081
S ₃	2.279 (190)	2.223 (167)	2.253 (179)	2.305 (202)	2.263 (183)	S at F	0.064	0.144
Mean	2.036 (109)	2.032 (108)	2.125 (133)	2.221 (166)		F at S	0.067	0.140

* Log₁₀ transformed values; figures in parenthesis are original values expressed as 10⁶ CFU (colony forming units) g⁻¹ of soil

Table 21. Continued.....

	F ₁	F ₂	F ₃	F ₄	Mean	Source	SEd	CD (P = 0.05)
Summer 2001 (Maize)								
S ₁	1.845 (70)	2.041 (110)	1.863 (73)	2.1459 (141)	1.964 (92)	S	0.008	0.023
S ₂	2.149 (141)	2.00 (100)	2.193 (156)	2.243 (175)	2.142 (137)	F	0.032	0.068
S ₃	2.134 (136)	2.324 (211)	2.303 (201)	2.346 (222)	2.275 (188)	S at F	0.049	0.104
Mean	2.037 (109)	2.113 (130)	2.114 (130)	2.245 (176)		F at S	0.056	0.118
Kharif 2001 (Fallow/Sunflower)								
S ₁	2.00 (100)	1.945 (88)	2.083 (121)	2.158 (144)	2.040 (110)	S	0.016	0.043
S ₂	2.233 (171)	2.083 (121)	2.220 (166)	2.279 (190)	2.200 (158)	F	0.017	0.035
S ₃	2.173 (149)	2.041 (110)	2.344 (221)	2.009 (102)	2.138 (137)	S at F	0.028	0.061
Mean	2.132 (136)	2.016 (104)	2.214 (164)	2.143 (139)		F at S	0.029	0.061
Rabi 2001 (Fallow/Cowpea)								
S ₁	1.935 (86)	2.033 (108)	2.000 (100)	2.090 (123)	2.009 (102)	S	0.016	0.043
S ₂	2.204 (160)	2.324 (211)	2.286 (193)	2.378 (239)	2.296 (198)	F	0.014	0.061
S ₃	2.3075 (203)	2.250 (178)	2.400 (251)	2.430 (269)	2.345 (221)	S at F	0.026	0.06
Mean	2.144 (139)	2.199 (158)	2.225 (168)	2.298 (199)		F at S	0.024	0.051
Summer 2002 (Maize)								
S ₁	2.037 (109)	2.114 (130)	2.079 (120)	2.152 (142)	2.092 (124)	S	0.015	0.041
S ₂	2.301 (200)	2.382 (241)	2.332 (215)	2.350 (224)	2.340 (219)	F	0.013	0.027
S ₃	2.201 (159)	2.348 (223)	2.441 (276)	2.476 (299)	2.365 (232)	S at F	0.025	0.058
Mean	2.177 (150)	2.279 (190)	2.282 (191)	2.324 (211)		F at S	0.023	0.047

* Log₁₀ transformed values; figures in parenthesis are original values expressed as 10⁶ CFU (colony forming units) g⁻¹ of soil

150% NPK + FYM + Zn + Fe (F₄), 150% NPK + FYM (F₂) and 100% NPK + FYM + Zn + Fe (F₃) were on par in summer 2000 and *kharif* 2000. The bacterial population with 150% NPK + FYM (F₂) and 100% NPK + FYM + Zn + Fe (F₃) were on par in summer 2001, *rabi* 2001 and summer 2002. In *kharif* 2001, the population under 150% NPK + FYM + Zn + Fe (F₄) and 100% NPK + FYM (F₁) were similar. Population of bacteria was significantly less under 100% NPK + FYM (F₁) in all the seasons except during *kharif* 2001.

The interaction effect of cropping systems and integrated nutrient management practices on the population of bacteria was significant. At the end of the summer 2002, the maize-sunflower-cowpea system with 150% NPK + FYM + Zn + Fe (F₄) recorded higher population of bacteria followed by maize-sunflower-cowpea (S₃) system with 100% NPK + FYM + Zn + Fe (F₃).

4.20. Population of fungi (Table 22)

Cropping systems had significant influence on population of fungi in all the seasons. The maize-sunflower-cowpea (S₃) system recorded higher fungal population in all the seasons except *rabi* 2000 and summer 2002 in which it was on par with the maize-fallow-cowpea system (S₂). Across the cropping seasons, fungal population increased due to different cropping systems. At the end of the second cropping cycle, the increase was higher under the maize-sunflower-cowpea (S₃) and maize-fallow-cowpea (S₂) systems than the maize-fallow-fallow (S₁) system.

Table 22. Population* of fungi

	F ₁	F ₂	F ₃	F ₄	Mean	Source	SEd	CD (P = 0.05)
Summer 2000 (Maize)								
S ₁	1.505 (32)	1.279 (19)	1.771 (59)	1.909 (81)	1.602 (40)	S	0.026	0.071
S ₂	1.724 (53)	1.881 (76)	1.771 (59)	1.909 (81)	1.816 (65)	F	0.013	0.027
S ₃	2.037 (109)	1.959 (91)	1.881 (76)	2.009 (102)	1.968 (93)	S at F	0.032	0.081
Mean	1.746 (56)	1.696 (50)	1.803 (64)	1.936 (86)		F at S	0.022	0.047
Kharif 2000 (Fallow/Sunflower)								
S ₁	1.477 (30)	1.799 (63)	1.681 (48)	1.833 (68)	1.68 (49)	S	0.011	0.030
S ₂	1.839 (69)	1.949 (89)	1.681 (48)	1.833 (65)	1.816 (65)	F	0.020	0.042
S ₃	1.724 (53)	1.978 (95)	1.959 (91)	1.799 (63)	1.857 (72)	S at F	0.032	0.069
Mean	1.666 (46)	1.904 (80)	1.764 (58)	1.814 (65)		F at S	0.034	0.072
Rabi 2000 (Fallow/Cowpea)								
S ₁	1.623 (42)	1.826 (67)	1.491 (31)	1.909 (81)	1.700 (50)	S	2.022	0.062
S ₂	2.021 (105)	2.057 (144)	1.839 (69)	2.068 (117)	1.990 (98)	F	0.017	0.035
S ₃	1.909 (81)	2.033 (108)	2.205 (106)	2.107 (128)	2.073 (103)	S at F	0.034	0.081
Mean	1.843 (70)	1.967 (93)	1.772 (59)	2.022 (105)		F at S	0.029	0.061

* Log₁₀ transformed values; figures in parenthesis are original values expressed as 10⁴ CFU (colony forming units) g⁻¹ of soil

Table 22. Continued.....

	F ₁	F ₂	F ₃	F ₄	Mean	Source	SEd	CD (P = 0.05)
Summer 2001 (Maize)								
S ₁	1.690 (49)	1.857 (72)	1.826 (67)	2.009 (102)	1.838 (69)	S	0.010	0.027
S ₂	1.851 (71)	1.996 (99)	1.881 (76)	2.045 (111)	1.936 (86)	F	0.016	0.035
S ₃	2.065 (116)	1.935 (86)	2.076 (119)	2.158 (144)	2.054 (113)	S at F	0.027	0.058
Mean	1.857 (72)	1.923 (84)	1.922 (84)	2.067 (117)		F at S	0.028	90.059
Kharif 2001 (Fallow/Sunflower)								
S ₁	1.799 (65)	1.580 (38)	1.898 (79)	1.949 (89)	1.793 (62)	S	0.029	0.079
S ₂	2.021 (105)	2.057 (114)	1.949 (89)	1.799 (63)	1.949 (89)	F	0.022	0.046
S ₃	1.949 (89)	2.068 (117)	2.093 (124)	2.107 (128)	2.051 (112)	S at F	0.043	0.104
Mean	1.916 (82)	1.890 (78)	1.975 (94)	1.942 (87)		F at S	0.038	0.079
Rabi 2001 (Fallow/Cowpea)								
S ₁	1.591 (39)	1.79 (63)	1.935 (86)	1.708 (51)	1.749 (56)	S	0.014	0.040
S ₂	1.996 (99)	2.100 (126)	2.021 (105)	2.107 (128)	2.052 (113)	F	0.012	0.026
S ₃	2.065 (116)	2.182 (152)	2.179 (151)	2.185 (153)	2.148 (141)	S at F	0.023	0.055
Mean	2.074 (119)	2.022 (105)	2.040 (110)	1.995 (99)		F at S	0.021	0.049
Summer 2002 (Maize)								
S ₁	1.839 (69)	1.954 (90)	1.756 (57)	1.973 (94)	1.872 (74)	S	0.014	0.038
S ₂	2.065 (116)	1.935 (86)	2.083 (121)	2.100 (126)	2.041 (110)	F	0.010	0.022
S ₃	2.083 (121)	1.909 (81)	2.124 (133)	2.185 (153)	4.071	S at F	0.021	0.049
Mean	1.990 (98)	1.926 (84)	1.980 (95)	4.083 (121)		F at S	0.018	0.038

* Log₁₀ transformed values; figures in parenthesis are original values expressed as 10⁴ CFU (colony forming units) g⁻¹ of soil

Integrated nutrient management practices significantly influenced the fungal population in all the seasons. All the four treatments were significantly different in all the seasons except in *kharif* 2001 in which 150% NPK + FYM + Zn + Fe (F₄) was on par with 100% NPK + FYM + Zn + Fe (F₃). Fungal population was higher with 150% NPK + FYM + Zn + Fe (F₄) in four out of seven seasons. The effect of different INM treatments on fungal population was not consistent across the seasons.

At the end of the summer 2002 season, the population of fungi was found higher under maize-sunflower-cowpea (S₃) system with 150% NPK + FYM + Zn + Fe (F₄) followed by the same system with 100% NPK + FYM + Zn + Fe (F₃) treatment.

4.21. Population of actinomycetes (Table 23)

Significant effect of cropping systems on population of actinomycetes was noticed in all the cropping seasons. Population of actinomycetes was significantly higher in maize-sunflower-cowpea (S₃) system in all the seasons except in *kharif* 2001 in which the maize-fallow-cowpea system (S₂) was superior. In *rabi* 2001 and summer 2002, both the S₃ and S₂ systems were on par recording equal values of actinomycetes population. Actinomycetes population was significantly lower under maize-fallow-fallow (S₁) system in all the seasons. Across the cropping seasons, the increase in actinomycetes population was higher under the maize-sunflower-cowpea (S₃) and maize-fallow-cowpea (S₂) systems and it was minimum under the maize-fallow-fallow (S₁) system. Population of actinomycetes decreased during the fallow period under the maize-fallow-cowpea (S₂) system in the first cropping cycle and under the maize-fallow-fallow (S₁) system in the cropping cycles I and II.

Integrated nutrient management practices significantly influenced the population of actinomycetes in all the cropping seasons. The 150% NPK + FYM + Zn + Fe (F₄)

Table 23. Population* of actinomycetes

	F ₁	F ₂	F ₃	F ₄	Mean	Source	SEd	CD (P = 0.05)
Summer 2000 (Maize)								
S ₁	1.959 (91)	1.903 (80)	2.000 (100)	2.107 (128)	1.988 (97)	S	0.006	0.015
S ₂	1.887 (77)	2.140 (138)	1.969 (93)	2.104 (127)	2.020 (105)	F	0.019	0.040
S ₃	2.029 (107)	2.215 (164)	2.090 (123)	1.929 (85)	2.061 (115)	S at F	0.09	0.062
Mean	1.954 (90)	4.082 (121)	2.016 (104)	2.042 (110)		F at S	0.033	0.069
Kharif 2000 (Fallow/Sunflower)								
S ₁	1.898 (79)	1.820 (66)	2.029 (107)	1.920 (91)	1.920 (83)	S	0.011	0.031
S ₂	1.982 (96)	2.083 (121)	2.000 (100)	1.949 (89)	1.990 (100)	F	0.016	0.034
S ₃	1.954 (90)	2.182 (152)	2.130 (135)	2.253 (179)	2.126 (134)	S at F	0.027	0.059
Mean	1.940 (87)	2.022 (105)	2.048 (112)	2.050 (112)		F at S	0.028	0.059
Rabi 2000 (Fallow/Cowpea)								
S ₁	1.756 (57)	1.681 (48)	1.949 (89)	2.045 (111)	1.852 (71)	S	0.017	0.048
S ₂	1.987 (97)	2.143 (139)	2.083 (121)	2.246 (176)	2.111 (129)	F	0.013	0.027
S ₃	2.228 (169)	2.182 (152)	2.207 (161)	2.277 (189)	2.221 (166)	S at F	0.026	0.063
Mean	1.985 (97)	1.998 (100)	2.075 (119)	2.187 (154)		F at S	0.022	0.048

* Log₁₀ transformed values; figures in parenthesis are original values expressed as 10⁵ CFU (colony forming units) g⁻¹ of soil

Table 23. Continued.....

	F ₁	F ₂	F ₃	F ₄	Mean	Source	SEd	CD (P = 0.05)
Summer 2001 (Maize)								
S ₁	1.792 (62)	2.000 (99)	1.820 (66)	2.107 (128)	1.924 (84)	S	0.018	0.049
S ₂	2.097 (125)	1.954 (90)	2.146 (140)	2.207 (161)	2.097 (125)	F	0.010	0.021
S ₃	2.079 (120)	2.279 (190)	2.253 (179)	2.305 (202)	2.227 (169)	S at F	0.023	0.058
Mean	1.985 (97)	2.073 (118)	2.069 (117)	2.204 (160)		F at S	0.017	0.036
Kharif 2001 (Fallow/Sunflower)								
S ₁	1.949 (89)	1.903 (80)	2.037 (109)	2.121 (132)	1.997 (99)	S	0.014	0.040
S ₂	2.176 (150)	2.037 (109)	2.170 (148)	2.238 (173)	2.153 (143)	F	0.013	0.027
S ₃	2.124 (133)	2.000 (100)	2.299 (199)	1.973 (94)	2.097 (125)	S at F	0.024	0.056
Mean	2.078 (120)	1.975 (94)	2.166 (147)	2.109 (129)		F at S	0.022	0.046
Rabi 2001 (Fallow/Cowpea)								
S ₁	1.881 (76)	1.987 (97)	1.954 (90)	2.049 (112)	1.963 (92)	S	0.014	0.039
S ₂	2.152 (142)	2.283 (192)	2.241 (174)	2.342 (220)	2.252 (179)	F	0.007	0.016
S ₃	2.253 (179)	2.204 (160)	2.314 (206)	2.389 (245)	2.288 (194)	S at F	0.018	0.045
Mean	2.091 (123)	2.154 (143)	2.166 (143)	2.258 (181)		F at S	0.013	0.027
Summer 2002 (Maize)								
S ₁	1.987 (97)	2.072 (118)	2.033 (108)	2.107 (128)	2.045 (111)	S	0.016	0.045
S ₂	2.246 (176)	2.337 (217)	2.281 (191)	2.310 (204)	2.291 (195)	F	0.007	0.016
S ₃	2.152 (142)	2.308 (203)	2.395 (248)	2.439 (275)	2.322 (210)	S at F	0.019	0.050
Mean	2.125 (133)	2.236 (172)	2.234 (171)	2.283 (192)		F at S	0.012	0.027

* Log₁₀ transformed values; figures in parenthesis are original values expressed as 10⁵ CFU (colony forming units) g⁻¹ of soil

recorded significantly higher population in five out of the seven seasons. In *kharif* 2000, the actinomycetes population under 150% NPK + FYM + Zn + Fe (F₄), 150% NPK + FYM (F₂) and 100% NPK + FYM + Zn + Fe (F₃) were on par and in summer 2000, the former two were on par. The 150% NPK + FYM (F₂) and 100% NPK + FYM + Zn + Fe (F₃) were on par in population of actinomycetes in summer 2001, *rabi* 2001 and summer 2002. The actinomycetes population was significantly lower under the 100% NPK + FYM (F₁) in all the seasons except in *kharif* 2001 in which it was superior to the 150% NPK + FYM (F₂). Across the cropping seasons, actinomycetes population increased due to different integrated nutrient management practices.

The interaction effect between cropping systems and integrated nutrient management practices showed that the population of actinomycetes was higher under maize-sunflower-cowpea system with 150% NPK + FYM with and without micronutrient application.

4.22. Nutrient uptake by maize (Table 24)

Cropping systems and integrated nutrient management practices had significant impact on nitrogen, phosphorus and potassium uptake by maize in all the three seasons. The interaction effect of cropping systems and integrated nutrient management practices on nutrient uptake by maize was not significant.

4.22.1. Nitrogen

Nitrogen uptake by maize was significantly higher under maize-sunflower-cowpea (S₃) system. The N uptake by maize under maize-fallow-fallow (S₁) system was significantly lower than S₃ and S₂ systems.

Table 24. Nutrient uptake by maize (kg ha⁻¹)

	Nitrogen			Phosphorus			Potassium		
	Sum 2000	Sum 2001	Sum 2002	Sum 2000	Sum 2001	Sum 2002	Sum 2000	Sum 2001	Sum 2002
Cropping systems									
S ₁	118	123	129	18.4	19.2	20.0	132	136	142
S ₂	125	133	142	19.3	20.4	21.7	138	147	156
S ₃	131	144	160	19.9	21.8	24.2	144	159	176
SEd	2	1	2	0.2	0.1	0.4	2	1	2
CD (P=0.05)	4	3	5	0.6	0.4	1.0	5	4	5
Integrated nutrient management									
F ₁	113	124	134	17.8	19.3	20.9	126	137	148
F ₂	130	138	150	19.8	20.8	22.5	144	151	164
F ₃	117	128	136	18.4	19.9	21.2	130	141	150
F ₄	136	144	154	20.7	21.8	23.2	150	159	169
SEd	3	3	3	0.3	0.2	0.5	3	3	3
CD (P=0.05)	5	6	7	0.7	0.5	1.0	7	7	6

The 150% NPK + FYM + Zn + Fe (F₄) recorded significantly higher N uptake by maize in summer 2000 but it was on par with the 150% NPK + FYM (F₂) in summer 2001 and summer 2002. Nitrogen uptake by maize under the 100% NPK + FYM + Zn + Fe (F₃) and 100% NPK + FYM (F₁) were on par and significantly lower than that under the other two treatments in all the seasons.

4.22.2. Phosphorus

Effect of cropping systems on phosphorus uptake by maize followed the same trend as that observed in nitrogen uptake except that the P uptake under the maize-sunflower-cowpea (S₃) and maize-fallow-cowpea (S₂) systems were on par in summer 2000.

Among the integrated nutrient management practices, the 150% NPK + FYM + Zn + Fe (F₄) recorded significantly higher phosphorus uptake by maize in summer 2000 and 2001 but it was on par with 150% NPK + FYM (F₂) in summer 2002. Phosphorus uptake by maize under 100% NPK + FYM + Zn + Fe (F₃) and 100% NPK + FYM (F₁) was on par and significantly lower to F₄ in summer 2000 and 2002 but in summer 2001 these two treatments were significantly different.

4.22.3. Potassium

The influence of cropping systems on potassium uptake by maize was similar as that of nitrogen uptake with maize-sunflower-cowpea (S₃) system recording significantly higher values than the other two systems.

The quantity of potassium removed by maize under 150% NPK + FYM + Zn + Fe (F₄) and 150% NPK + FYM (F₂) were on par and significantly higher than F₃ and F₁ systems in summer 2000 and summer 2002 but these two treatments were significantly

different in summer 2001. Potassium uptake by maize under 100% NPK + FYM + Zn + Fe (F₃) and 100% NPK + FYM (F₁) was on par and significantly lower than F₄ and F₂ systems.

4.23. Nutrient uptake by sunflower (Table 25)

Integrated nutrient management practices significantly influenced the NPK uptake by sunflower in both *kharif* 2000 and *kharif* 2001 seasons.

4.23.1. Nitrogen

Nitrogen uptake by sunflower under 150% NPK + FYM + Zn + Fe (F₄) and 150% NPK + FYM (F₂) were on par and significantly higher compared to 100% NPK + FYM + Zn + Fe (F₃) and 100% NPK + FYM (F₁). The 100% NPK + FYM + Zn + Fe (F₃) and 100% NPK + FYM (F₁) treatments were on par and recorded significantly lower values of nitrogen uptake when compared to F₂ and F₄ treatments.

4.23.2. Phosphorus

The phosphorus uptake followed the same trend as that of nitrogen uptake except that 150% NPK + FYM + Zn + Fe (F₄) and 150% NPK + FYM (F₂), treatments were significantly different in *kharif* 2001. The 150% NPK + FYM (F₂) recorded significantly higher values of phosphorus uptake than the 100% NPK + FYM + Zn + Fe (F₃). Application of 150% NPK + FYM (F₂) and 100% NPK + FYM + Zn + Fe (F₃) were on par in P uptake in *kharif* 2000.

4.23.3. Potassium

Potassium uptake also followed the same trend as that of nitrogen uptake except that 150% NPK + FYM (F₂) and 100% NPK + FYM + Zn + Fe (F₃) treatments behaved similarly with equal values of potassium uptake in *kharif* 2001.

Table 25. Nutrient uptake by sunflower (kg ha⁻¹)

	Nitrogen		Phosphorus		Potassium	
	<i>Kharif</i> 2000	<i>Kharif</i> 2001	<i>Kharif</i> 2000	<i>Kharif</i> 2001	<i>Kharif</i> 2000	<i>Kharif</i> 2001
Integrated nutrient management						
F ₁	39	45	6.0	6.8	43	49
F ₂	47	55	7.0	8.2	51	59
F ₃	41	48	6.3	7.2	45	52
F ₄	50	59	7.4	8.8	54	64
SEd	2	2	0.3	0.2	1	4
CD (P=0.05)	5	5	0.7	0.4	3	9



4.24. Nutrient uptake by cowpea (Table 26)

Cropping systems and integrated nutrient management practices had significant effect on NPK uptake by cowpea except that in *rabi* 2000 in which the effect of cropping systems on nitrogen uptake was not significant. The interaction effect of cropping systems and integrated nutrient management practices on nutrient uptake by cowpea was not significant.

4.24.1. Nitrogen

Significantly higher nitrogen uptake by cowpea was recorded under maize-sunflower-cowpea (S_3) system compared to the maize-fallow-cowpea (S_2) in *rabi* 2001. In *rabi* 2000, both the systems were on par in nitrogen uptake.

All the four integrated nutrient management practices were significantly different in influencing nitrogen uptake by cowpea in *rabi* 2000. The 150% NPK + FYM + Zn + Fe (F_4) recorded significantly higher values of nitrogen uptake in *rabi* 2000 but in *rabi* 2001, it was on par with 150% NPK + FYM (F_2). Nitrogen uptake by cowpea was significantly lower under 100% NPK + FYM (F_1) in *rabi* 2000 but in *rabi* 2001, it was on par with that of 100% NPK + FYM + Zn + Fe (F_3).

4.24.2. Phosphorus

Phosphorus uptake by cowpea was significantly higher under the maize-sunflower-cowpea system (S_3) compared to the maize-fallow-cowpea (S_2) in both the seasons.

Application of 150% NPK + FYM + Zn + Fe (F_4) recorded significantly higher phosphorus uptake than the other treatments in *rabi* 2000 but in *rabi* 2001, it was on par with 150% NPK + FYM (F_2). Phosphorus uptake by cowpea under 100% NPK + FYM

Table 26. Nutrient uptake by cowpea (kg ha⁻¹)

	Nitrogen		Phosphorus		Potassium	
	<i>Rabi</i> 2000	<i>Rabi</i> 2001	<i>Rabi</i> 2000	<i>Rabi</i> 2001	<i>Rabi</i> 2000	<i>Rabi</i> 2001
Cropping systems						
S ₂	45.3	51.5	7.2	8.1	48.5	55.5
S ₃	48.0	55.5	7.5	8.7	50.7	59.3
SEd	1.0	0.7	0.01	0.1	0.4	1.0
CD (P=0.05)	NS	2.8	0.10	0.3	1.6	3.0
Integrated nutrient management						
F ₁	42.5	50.0	6.8	7.9	45.5	53.0
F ₂	48.0	55.0	7.5	8.6	49.3	58.5
F ₃	45.5	52.0	7.2	8.3	49.5	56.0
F ₄	50.5	57.0	7.9	8.9	54.0	61.0
SEd	1.1	1.0	0.2	0.2	0.7	1.4
CD (P=0.05)	2.3	2.2	0.3	0.4	1.5	3.0

(F₁) was significantly lower than the other three treatments in *rabi* 2000 but in *rabi* 2001, it was on par with 100% NPK + FYM + Zn + Fe (F₃).

4.24.3. Potassium

The potassium uptake by cowpea under maize-sunflower-cowpea (S₃) system was significantly higher in both the seasons. Influence of integrated nutrient management practices on potassium uptake by cowpea was similar to that of phosphorus uptake except that the potassium uptake under 100% NPK + FYM + Zn + Fe (F₃) and 100% NPK + FYM (F₁) were on par in both *rabi* 2000 and *rabi* 2001.

4.25. Nutrient balance

4.25.1. Nitrogen balance (Table 27)

The net gain in available nitrogen during the cropping cycle I and cropping cycles II and III put together and overall net gain were higher under the maize-sunflower-cowpea (S₃) system followed by the maize-fallow-cowpea (S₂) system. The net gain in available N was minimum under the maize-fallow-fallow system (S₁). During the period of cropping cycle I, the 150% NPK + FYM + Zn + Fe (F₄) and 150% NPK + FYM (F₂) recorded marginally higher net gain under the maize-fallow-fallow system (S₁) than the other two treatments but under the maize-fallow-cowpea (S₂) and maize-sunflower-cowpea (S₃) systems, the 100% NPK + FYM + Zn + Fe (F₃) and 100% NPK + FYM (F₁) recorded marginally higher net gain than the other two treatments. During the period of cropping cycle II and III put together, the 100% NPK + FYM + Zn + Fe (F₃) and 100% NPK + FYM (F₁) recorded higher net gain under the maize-fallow-fallow system (S₁) than the other two treatments but under the maize-fallow-cowpea system, the reverse trend was observed. The overall net gain under the maize-fallow-fallow (S₁) system was same under all the four integrated nutrient management practices. Under the maize-

Table 27. Available nitrogen balance (kg ha⁻¹)

Treat- ment	Cropping cycle I														Cropping cycle II and III													
	Initial N (Rabi 1999)	N Addition through fertilizer, FYM and residues				N Removal by the crops				Net gain	Aval. N (Rabi 2000)	N Addition through fertilizer, FYM and residues				N Removal by the crops				Aval. N (Sum. 2002)	Net gain	Overall net gain compared to the rabi 1999						
		Summer 2000 Maize	Khairif 2000 Fallow/ Sunflower	Rabi 2000 Fallow/ Cowpea	Total	Summer 2000 Maize	Khairif 2000 Fallow/ Sunflower	Rabi 2000 Fallow/ Cowpea	Total			Summer 2001 Maize	Khairif 2001 Fallow/ Sunflower	Rabi 2001 Fallow/ Cowpea	Total	Summer 2001 Maize	Khairif 2001 Fallow/ Sunflower	Rabi 2001 Fallow/ Cowpea	Total									
S.F ₁	215	151	13.3	-	164	106	-	-	106	216	1	216	151	14.3	-	151	316	114	-	-	122	236	223	7	8			
S.F ₂	218	218	15.5	-	234	124	-	-	124	219	1	219	218	16.2	-	218	452	129	-	-	133	262	226	7	8			
S.F ₃	216	151	13.8	-	165	110	-	-	110	219	3	219	151	14.5	-	151	317	115	-	-	121	236	224	5	8			
S.F ₄	219	218	16.3	-	234	130	-	-	130	222	3	222	218	16.9	-	218	453	134	-	-	138	272	227	5	8			
S.F ₁	220	158	14.3	41	213	114	-	41	155	231	11	231	159	15.4	41	160	375	123	-	48	132	241	10	21				
S.F ₂	223	226	16.4	53	296	131	-	47	178	232	9	232	227	17.4	53	229	526	138	-	53	149	247	15	24				
S.F ₃	221	159	14.9	41	215	118	-	44	162	233	12	233	159	15.9	41	161	377	127	-	50	134	244	11	23				
S.F ₄	224	227	17.2	53	297	136	-	49	185	234	10	234	228	18.1	53	229	528	143	-	55	152	249	15	25				
S.F ₁	223	159	71	46	276	120	39	44	203	235	12	235	159	73	47	161	440	134	45	52	148	249	14	26				
S.F ₂	226	227	93	60	380	136	47	49	232	237	11	237	228	94	61	229	612	146	55	57	167	254	17	28				
S.F ₃	224	159	71	47	277	124	41	47	212	235	11	235	160	73	48	161	442	141	48	54	153	251	16	27				
S.F ₄	228	227	94	60	381	142	50	52	244	238	10	238	228	95	62	230	615	155	59	59	172	253	15	25				

fallow-cowpea (S_2) and maize-sunflower-cowpea (S_3) systems, the overall net gain followed the same trend observed during the cropping cycles II and III put together. The overall net gain was the same under the maize-sunflower-cowpea system (S_3) with 150% NPK + FYM + Zn + Fe (F_4) and 100% NPK + FYM + Zn + Fe (F_3).

4.25.2. Phosphorus balance (Table 28)

During the period of cropping cycle I, there was no net gain in available phosphorus under the maize-fallow-fallow (S_1) system except with 100% NPK + FYM (F_1). There was no marked difference in the net gain in available phosphorus during the cropping cycle I under the maize-sunflower-cowpea (S_3) and maize-fallow-cowpea (S_2) under all the four integrated nutrient management practices. The net gain during the period of cropping cycles II and III and overall net gain under the S_1 system followed the same trend. All the four integrated nutrient management practices exerted no marked difference in overall net gain in available phosphorus under the three cropping systems.

4.25.3. Potassium balance (Table 29)

During the period of cropping cycle I there was no considerable net gain in available potassium under the maize-fallow-fallow (S_1) and maize-fallow-cowpea (S_2) systems. There was no net gain under the S_1 system with 150% NPK + FYM + Zn + Fe (F_4) and under the S_2 system with 100% NPK + FYM + Zn + Fe (F_4). But considerable net gain in available potassium was recorded under the maize-sunflower-cowpea (S_3) system with 150% NPK + FYM + Zn + Fe (F_4) and 150% NPK + FYM (F_2) than the other two treatments. The net gain in available potassium under the maize-fallow-fallow (S_1) system during the period of cropping cycles II and III put together was higher at 150% NPK + FYM + Zn + Fe (F_4) and 150% NPK + FYM (F_2) than the other two treatments, but under the maize-fallow-cowpea (S_2) system there was no marked difference in the net gain between all the four integrated nutrient management practices.

Table 28. Available phosphorus balance (kg ha⁻¹)

Treat-ment	Cropping cycle I											Cropping cycle II and III															
	Initial P (Rabi 1999)	P Addition through fertilizer, FYM and residues					P Removal by the crops					Aval. P (Rabi 2000)	Net gain	Aval. P (Rabi 2000)	P Addition through fertilizer, FYM and residues					P Removal by the crops					Aval. P (Sum. 2002)	Net gain	Overall net gain compared to the rabi 1999
		Summer 2000 Maize	Khairif 2000 Fallow/Sunflower	Rabi 2000 Fallow/Cowpea	Total	Summer 2000 Maize	Khairif 2000 Fallow/Sunflower	Rabi 2000 Fallow/Cowpea	Total	Summer 2001 Maize	Khairif 2001 Fallow/Sunflower				Rabi 2001 Fallow/Cowpea	Total	Summer 2001 Maize	Khairif 2001 Fallow/Sunflower	Rabi 2001 Fallow/Cowpea	Total	Summer 2002 Maize	Khairif 2002 Fallow/Sunflower	Rabi 2002 Maize	Total			
S.F ₁	12.0	69	2.1	-	71	16.9	-	-	16.9	12.2	0.2	12.2	69	2.3	-	69	140	18.1	-	-	19.3	37.4	12.4	0.2	0.4		
S.F ₂	12.2	100	2.4	-	102	19.1	-	-	19.1	12.2	0	12.2	100	2.5	-	100	203	19.8	-	-	20.3	40.1	12.6	0.4	0.4		
S.F ₃	12.1	69	2.2	-	71	17.5	-	-	17.5	12.1	0	12.1	69	2.3	-	69	140	18.3	-	-	19.1	37.4	12.5	0.4	0.4		
S.F ₄	12.3	100	2.5	-	103	20.0	-	-	20.0	12.3	0	12.3	100	2.6	-	100	203	20.6	-	-	21.2	41.8	12.8	0.5	0.5		
S.F ₁	12.2	70	2.2	56	128	17.9	-	6.6	24.5	12.7	0.5	12.7	70	2.4	56	70	198	19.2	-	7.6	20.6	47.4	13.4	0.7	1.2		
S.F ₂	12.5	101	2.5	81	185	19.9	-	7.3	27.2	12.9	0.4	12.9	102	2.6	81	102	288	20.9	-	8.3	22.5	51.7	13.8	0.9	1.3		
S.F ₃	12.3	70	2.3	56	128	18.6	-	7.0	25.6	12.8	0.5	12.8	70	2.5	56	70	199	19.8	-	8.0	20.8	48.6	13.6	0.8	1.3		
S.F ₄	12.6	102	2.6	81	186	20.7	-	7.7	28.4	13.1	0.5	13.1	102	2.7	81	102	288	21.7	-	8.6	22.9	53.2	13.7	0.6	1.1		
S.F ₁	12.4	70	2.9	57	156	18.6	6.0	6.9	31.5	13.0	0.6	13.0	70	2.9	57	70	226	20.7	6.8	8.1	22.8	58.4	13.9	0.9	1.5		
S.F ₂	12.7	102	3.9	82	223	20.5	7.0	7.6	35.1	13.3	0.6	13.3	102	3.9	82	102	325	21.8	8.2	8.9	24.8	63.7	14.1	0.8	1.4		
S.F ₃	12.5	70	2.9	57	156	19.2	6.3	7.4	32.9	13.1	0.6	13.1	70	2.9	57	71	227	21.7	7.2	8.5	23.6	61.0	14.0	0.9	1.5		
S.F ₄	12.7	102	3.9	82	223	21.3	7.4	8.1	36.8	13.4	0.7	13.4	102	3.9	83	102	326	23.1	8.8	9.2	25.6	66.7	14.3	0.9	1.6		

Table 29. Available potassium balance (kg ha⁻¹)

Treatment	Cropping cycle I														Cropping cycle II and III																		
	K Addition through fertilizer, FYM and residues							K Removal by the crops							Aval. K (Rabi 2000)	Net gain	K Addition through fertilizer, FYM and residues							K Removal by the crops							Aval. K (Sum. 2002)	Net gain	Overall net gain compared to the rabi 1999
	Summer 2000 Maize	Kharif 2000 Fallow/Sunflower	Rabi 2000 Fallow/Cowpea	Total	Summer 2000 Maize	Kharif 2000 Fallow/Sunflower	Rabi 2000 Fallow/Cowpea	Total	Summer 2000 Maize	Kharif 2000 Fallow/Sunflower	Rabi 2000 Fallow/Cowpea	Total	Summer 2001 Maize	Kharif 2001 Fallow/Sunflower			Rabi 2001 Fallow/Cowpea	Total	Summer 2001 Maize	Kharif 2001 Fallow/Sunflower	Rabi 2001 Fallow/Cowpea	Total	Summer 2002 Maize	Kharif 2002 Fallow/Sunflower	Rabi 2002 Fallow/Cowpea	Total							
S.F ₁	66	14.7	-	81	118	-	-	118	558	3	558	66	15.9	-	66	148	127	-	-	253	135	-	-	568	10	13							
S.F ₂	91	17.2	-	108	137	-	-	137	560	1	560	91	17.9	-	91	200	142	-	-	283	146	-	-	573	13	14							
S.F ₃	66	15.3	-	81	122	-	-	122	559	4	559	66	16.1	-	66	148	128	-	-	256	134	-	-	570	11	15							
S.F ₄	91	18.0	-	109	143	-	-	143	561	0	561	91	18.7	-	91	201	148	-	-	295	152	-	-	577	16	16							
S.F ₁	73	15.8	15.6	104	126	-	44	170	559	4	559	74	17.0	15.6	76	183	136	-	51	316	146	-	-	587	28	32							
S.F ₂	100	18.1	15.6	134	144	-	50	194	570	7	570	100	19.0	15.6	102	237	152	-	56	368	164	-	-	396	26	33							
S.F ₃	74	16.5	15.6	106	131	-	47	178	560	0	560	75	17.6	15.6	76	184	140	-	54	326	148	-	-	589	29	29							
S.F ₄	100	18.9	15.6	135	150	-	53	203	571	6	571	101	19.9	15.6	102	239	158	-	59	370	167	-	-	600	29	35							
S.F ₁	74	52	22	148	133	43	47	223	575	15	575	75	54	22.7	77	229	148	49	55	387	164	61	183	616	29	51							
S.F ₂	100	65	23	188	150	51	52	253	587	22	587	101	66	24.3	103	294	160	59	61	436	183	58	169	611	33	44							
S.F ₃	75	53	22	150	137	45	50	232	578	11	578	75	55	23.1	77	230	156	52	58	401	169	63	189	620	31	50							
S.F ₄	101	66	23	190	156	54	55	265	589	19	589	102	67	24.9	103	297	170	64	63	454	189	63	189	620	31	50							

The net gain in available potassium under the maize-sunflower-cowpea (S_3) system was higher under 150% NPK + FYM + Zn + Fe (F_4) and 100% NPK + FYM (F_2) than the other two treatments during the period of cropping cycles II and III put together. The overall net gain in available potassium was higher under the maize-sunflower-cowpea (S_3) system followed by the maize-fallow-cowpea (S_2) system. There was no marked difference in overall net gain in available potassium with 150% NPK + FYM + Zn + Fe (F_4), 150% NPK + FYM (F_2) and 100% NPK + FYM (F_1) under the maize-fallow-cowpea (S_2) and maize-sunflower-cowpea (S_3) systems but the 100% NPK + FYM + Zn + Fe (F_3) recorded lower values than the other three treatments.

4.26. Economics (Table 30 and 31)

Cost of cultivation, gross return and net return were higher under the maize-sunflower-cowpea (S_3) system compared to the other two systems in the cropping cycles I and II. The net returns were the least under maize-fallow-fallow (S_1) system in both the cropping cycles. However, the B/C ratio was higher under S_1 system followed by S_2 and S_3 systems in the cropping cycles I and II.

The 150% NPK + FYM + Zn + Fe (F_4) and 150% NPK + FYM (F_2) recorded higher gross and net return and B/C ratio in the cropping cycles I and II. Only a marginal difference in net returns was noticed between these two treatments. The 100% NPK + FYM + Zn + Fe (F_3) and 100% NPK + FYM (F_1) recorded lower economic returns and the difference between these two treatments was also very narrow. The maize-sunflower-cowpea system (S_3) with 150% NPK + FYM + Zn + Fe (F_4) recorded the highest gross return of Rs. 61329 ha^{-1} and net return of Rs. 33980 ha^{-1} in the first cropping cycle and Rs.48086 and Rs.40469 ha^{-1} respectively in the second cropping cycle. The maize-fallow-fallow system with 150% NPK + FYM + Zn + Fe (S_1F_4) registered the highest B/C ratio (2.85) in the first and second (2.87) cropping cycles.

Table 30. Economics (Cropping cycle I)

	Cost of cultivation (Rs. ha ⁻¹)	Gross return (Rs. ha ⁻¹)	Net return (Rs. ha ⁻¹)	B/C ratio
S ₁ F ₁	11072	29400	18328	2.66
S ₁ F ₂	11535	32340	20805	2.80
S ₁ F ₃	11445	30429	18984	2.66
S ₁ F ₄	11908	33796	22068	2.85
S ₂ F ₁	17823	41190	23367	2.31
S ₂ F ₂	18889	44557	25668	2.36
S ₂ F ₃	18451	42924	24473	2.33
S ₂ F ₄	19517	46486	26969	2.38
S ₃ F ₁	24937	54188	29251	2.17
S ₃ F ₂	26466	58868	32402	2.22
S ₃ F ₃	25820	56296	30476	2.18
S ₃ F ₄	27349	61329	33980	2.24

Table 31. Economics (Cropping cycle II)

	Cost of cultivation (Rs. ha ⁻¹)	Gross return (Rs. ha ⁻¹)	Net return (Rs. ha ⁻¹)	B/C ratio
S ₁ F ₁	11183	31276	20093	2.80
S ₁ F ₂	11650	33173	21523	2.85
S ₁ F ₃	11559	31493	19934	2.72
S ₁ F ₄	12027	34503	22476	2.87
S ₂ F ₁	18001	44565	26564	2.47
S ₂ F ₂	19078	47284	28206	2.48
S ₂ F ₃	18636	46169	27533	2.47
S ₂ F ₄	19712	49023	29311	2.49
S ₃ F ₁	25186	60862	35676	2.42
S ₃ F ₂	26731	64533	37802	2.41
S ₃ F ₃	26078	63584	37506	2.44
S ₃ F ₄	27622	68086	40464	2.46

CHAPTER V

DISCUSSION

Field experiments were conducted at Tamil Nadu Agricultural University for seven successive cropping seasons (Summer 2000 - summer 2002) to study the effect of maize based cropping systems and integrated nutrient management practices in relation to physical, chemical and microbiological properties of the soil and crop yields. The experimental results are discussed in this chapter.

5.1. Effect of cropping systems and integrated nutrient management practices on the growth and yield of the component crops (Fig. 5 and 6)

The systems with three (S_3) and two (S_2) crops in an annual cycle increased the dry matter production of the component crop of maize by 20 and 11 per cent respectively compared to the system with one crop in an annual cycle (S_1). The dry matter production of the component crop cowpea was not significantly influenced by cropping systems with two (S_2) and three (S_3) crops in an annual cycle. The nutrient requirement of cowpea was less and both S_2 and S_3 systems were equally effective in improving the available nutrient status of the soil and hence they showed no significant difference in dry matter production of cowpea. The dry matter production of sunflower in the S_3 system had also increased by 15 per cent in the second cropping cycle compared to the first cropping cycle. The cropping systems with three (S_3) and two (S_2) crops in an annual cycle had improved the soil properties such as bulk density, available water capacity and available nutrients over the cropping seasons which resulted in increased dry matter production of maize, sunflower and cowpea in the cropping cycle II compared to the cropping cycle I.

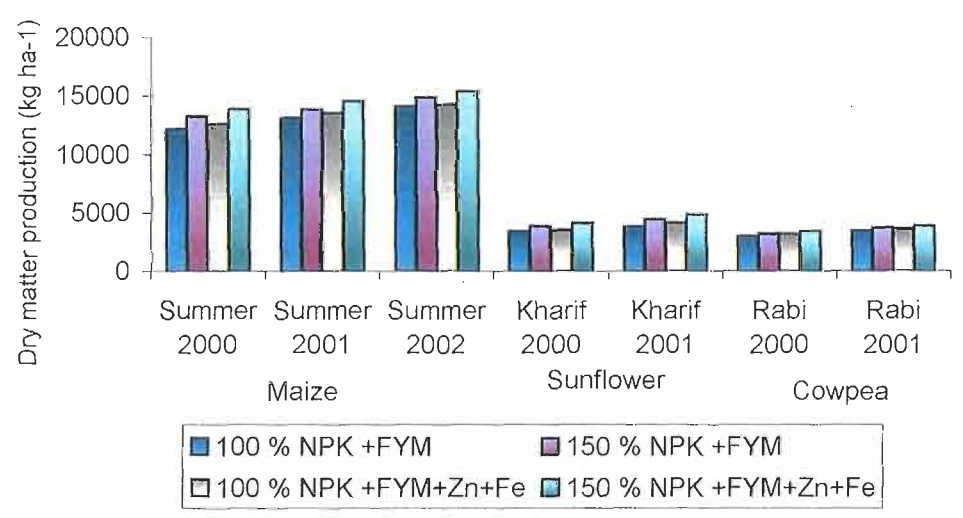
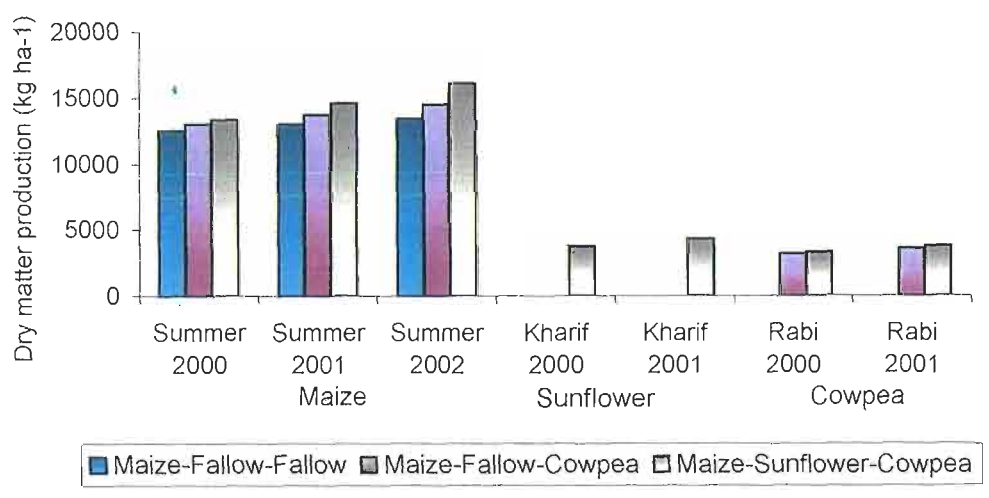


Fig 5 Drymatter production of the component crops under different cropping systems and integrated nutrient management practices

The dry matter production of maize was higher at higher rate of fertilizer application (150% NPK) by eight and six per cent respectively with and without micronutrient application compared to the corresponding values at lower rate (100% NPK) in the cropping cycle III. The dry matter production of sunflower and cowpea were also higher at higher rate of fertilization (150% NPK) with micronutrients by 18 and six per cent respectively in the cropping cycle II. At higher rate of fertilization, the available nutrient status of the soil had increased which resulted in increased dry matter production of the component crops.

The effect of cropping systems on the root dry weight of the component crops was similar to that of dry matter production. The root dry weight of maize was higher in the rotations with three (S_3) and two (S_2) crops in an annual cycle by 19 and eight per cent respectively compared to the rotation with one crop (S_1). The root dry weight of cowpea was higher by six per cent in the system with three crops (S_3) in an annual cycle compared to the system with two crops (S_2) in the cropping cycle II. The root dry weight of sunflower was higher by 15 per cent in the cropping cycle II compared to the cropping cycle I. The S_3 and S_2 systems had decreased the bulk density and improved the porosity, available water capacity and available nutrients which ultimately favoured better root growth.

The root dry weight of maize had increased at higher rate (150%) of fertilizer application with and without micronutrient application by eight and six per cent respectively compared to the lower rate (100%) in the cropping cycle III. The corresponding increase in the root dry weight of sunflower was 18 and 16 per cent respectively in the cropping cycle II. The root dry weight of cowpea had also increased by six and seven per cent respectively at higher rate of fertilization with and without

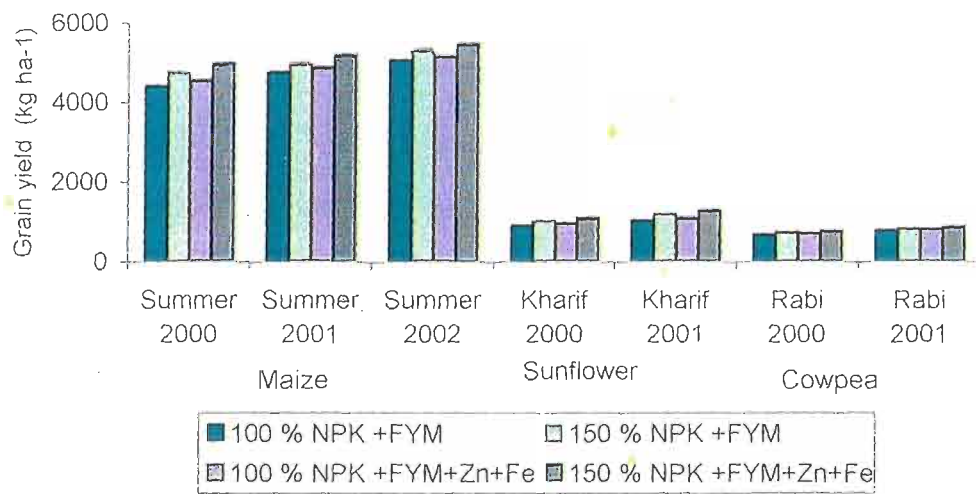
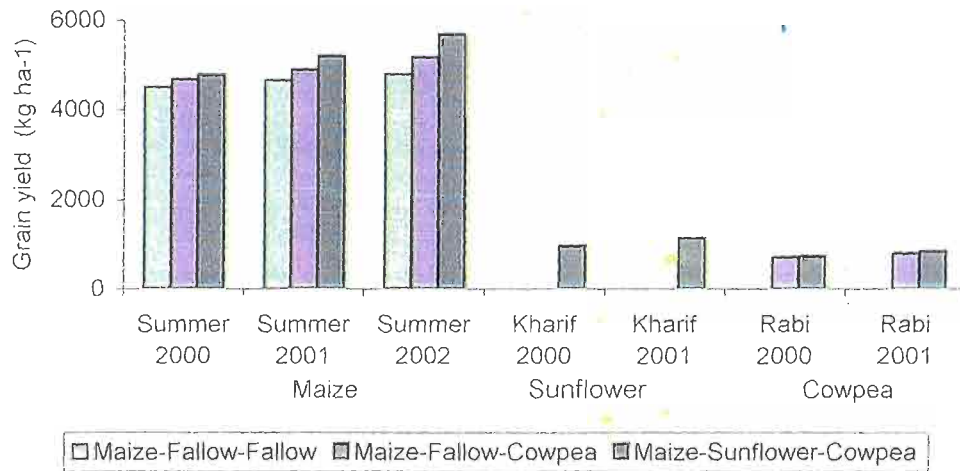


Fig 6. Grain yield of the component crops under different cropping systems and integrated nutrient management practices

micronutrient application in the cropping cycle II. In addition to the application of FYM, the higher amount of crop residues added to the soil at higher rate of fertilization had increased the available water and nutrients and thereby increased the root dry weight.

The grain yield of maize was higher by 18 and 9 per cent respectively in the cropping systems with three (S_3) and two (S_2) crops in an annual cycle compared to the system with one crop (S_1). The grain yield of sunflower was higher by 19 per cent in the cropping cycle II compared to the cropping cycle I. The grain yield of cowpea was also higher in the cropping cycle II by 15 and 13 per cent respectively under the systems with three (S_3) and two (S_2) crops in an annual cycle compared to the cropping cycle I. Increase in maize grain yield under the S_3 and S_2 systems may partly be traced back to the N effect and rotation effect. The increased root dry weight of maize under the S_3 and S_2 systems led to better water relations and higher nutrient absorption and thereby increased the grain yield. The S_3 and S_2 systems had increased the soil organic carbon content which permitted intense utilization of mineral fertilizers and increased the yield of the component crops. The S_3 and S_2 systems had increased the amount of residues added to the soil and thereby increased the soil nutrient status, which in turn increased the dry matter production and yield of the component crops.

Compared to the yield in the cropping cycle II, the increase in the grain yield of maize in the cropping cycle III was higher by 10 and 6 per cent respectively in the S_3 and S_2 systems where it was preceded by cowpea but there was only marginal increase under the systems where the previous two seasons were left as fallow (S_1). Due to the absence of any input of exogenous organic material to the soil continuously for two fallow seasons, the S_1 system showed no considerable improvement in soil properties and hence the increase in yield was minimum under this system.

The grain yield of maize was higher by six and five per cent, respectively at higher rate (150% NPK) of fertilization with micronutrient application compared to the corresponding values at lower rate (100% NPK) in the cropping cycle III. The corresponding increase in grain yield of sunflower was 18 and 16 per cent, respectively in the cropping cycle II. The grain yield of cowpea was also higher at higher rate of fertilization with and without micronutrient application by five and six per cent, respectively in the cropping cycle II.

The effect of cropping systems on stover, stalk and haulm yield of maize, sunflower and cowpea was similar to that of grain yield. Under the system with three crops in an annual cycle (S_3), the stover yield of maize was higher by 13 per cent compared to the system with one crop (S_1) in the cropping cycle II. The haulm yield of cowpea was higher by six per cent under the system with three (S_3) crops in annual cycle compared to the system with two crops (S_2) in the cropping cycle II. The increase in the stover, stalk and haulm yield of maize, sunflower and cowpea at higher rate of fertilization with micronutrient application was eight, 18 and six per cent, respectively compared to the corresponding values at lower rate (100%) in the cropping cycle II.

Lower rate of crop residue addition ($10906 \text{ kg ha}^{-1} \text{ annum}^{-1}$ during cropping cycle II) and higher frequency of fallowing resulted in no considerable build up in organic matter content under the system with two seasons of fallowing (S_1) which was reflected on lower grain and stover yield. Increased soil organic matter content under the systems with three (S_3) and two (S_2) crops in an annual cycle created favourable soil environment through the improvement of physical properties of the soil which in turn facilitated the growth of roots, regulation of the soil water regime, uptake of nutrients and ultimately increased the grain yield of crops.

The increase in grain yield of all the three component crops due to application of micronutrients was only marginal compared to no micronutrient application in all the seasons. The FYM and crop residues added to the soil during the previous seasons might have contributed sufficient Zn and Fe to the soil invariably under all the treatments. The enhanced microbial activity under cropping systems with three (S_3) two (S_2) crops in annual cycle increased the availability of major as well as micronutrients such as Mn, Cu, Zn and Fe which in turn increased the nutrient uptake and yield. Application of FYM served as a good source of nutrients and improved the crop growth and yield. The FYM accelerated the development of active roots deep into the soil and helped to maintain their activity until late growth stages. The humified organic materials originating from crop residues and FYM not only supplemented N, P, K and other nutrients but also had favourable physiological effects. The humic substances and their decomposition products present in FYM can favourably influence the growth and metabolism of plants and the fulvic acid fractions of FYM can increase the yield of crops.

The systems with three (S_3) and two (S_2) crops in an annual cycle with higher rate of fertilization (S_3F_4 and S_3F_2) had increased the quantity of crop residues added to the soil which in turn increased the grain yield of the component crops. The increase in grain yield due to crop residue addition is attributed to the increase in available nutrients through residue decomposition, favourable nutrient release pattern and improvement of soil structure. Some of the nitrogenous compounds formed during the decomposition of crop residues can serve as slow release N fertilizers for plant nutrition and increase the yield because they are more resistant to microbial degradation than the original material.

Cropping systems with two (S_2) and three crops (S_3) in the rotation supported higher population of bacteria, fungi and actinomycetes (232×10^6 , 118×10^4 and $210 \times$

10^5 CFU g^{-1} of soil respectively in cropping cycle III under S_3) in the soil which in turn had favourable effect on yield. It is reported that amino compounds, which are synthesized by soil microorganisms, are partially stabilized against microbial degradation by various processes. This leads to a temporary enrichment of organic nitrogenous substances in the soil which can serve as slow-release N fertilizers for plant nutrition and increase the yield.

5.2. Effect of Cropping systems on soil physical properties

Cropping systems with three (S_3) and two (S_2) crops in an annual cycle significantly influenced the soil physical properties owing to the variations in the quantities of above and below-ground residues produced. At the end of the second cropping cycle, the rotations with three crops (S_3) and two crops (S_2) in a cycle had significantly lowered the bulk density (1.30 and 1.33 $Mg\ m^{-3}$, respectively) than the rotation with one crop (S_1) in a cycle (1.41 $Mg\ m^{-3}$). The corresponding increase in total porosity was 18 and 11 per cent, respectively under S_3 and S_2 systems compared to the initial value of 45.9 $m^3\ 100\ m^{-3}$ and the increase in hydraulic conductivity was 13 and eight per cent, respectively compared to the initial value of 2.5 $cm\ hr^{-1}$. The rotations with three (S_3) and two (S_2) crops in a cycle added greater amounts of crop residues (11981 and 15063 $kg\ ha^{-1}$, respectively during cropping cycle II) to the soil and thereby decreased the bulk density and enhanced the porosity compared to the systems that included two seasons of fallowing (S_1). The intensive system (S_3) with crops in all the three seasons had more spatial (number of crops being grown at a given time) as well as temporal (sequence of crops being grown) diversity. Biological diversity is an important tool in improving soil properties and crop yield (Karlen *et al.*, 1994).

At the end of the second cropping cycle, the increase in the percentage of water stable aggregates under rotations with three (S_3) and two (S_2) crops in a cycle was 25 and 18 per cent, respectively compared to the rotation with one crop in a cycle (S_1). The increase in available water capacity under the S_3 and S_2 systems was 13 and 7 per cent, respectively compared to the S_1 system. The increased crop residue addition under the system with three (S_3) and two (S_2) crops in a cycle contributed considerably to the build up of soil organic carbon content and thereby improved aggregation and available water capacity. The increased crop residue addition (11981 kg ha^{-1}) under the rotation with three crops (S_3) in a cycle in cropping cycle II) contributed considerably to the formation of aggregates. Microaggregates are formed into relatively less stable macroaggregates ($> 250 \mu\text{m}$) by enmeshing effect of plant roots and fungal hyphae. Golchin *et al.* (1994) observed that encrustation of root debris by mineral particles is an important mechanism leading to the rapid formation of microaggregates.

The increase in soil aggregate stability under the systems with three (S_3) and two (S_2) crops in an annual cycle is partly due to certain types of organic substances released from the roots and produced by microorganisms (Chan *et al.*, 1994). The roots themselves can move and bind soil particles together and form aggregates. Localized drying of the soil as a result of absorption of water by roots could stabilize aggregates to some extent. The root surface has higher population of microorganisms compared to rhizosphere and nonrhizosphere soil. The rotations with two (S_2) and three (S_3) crops in a cycle with diverse crops stimulated root growth and hence increased the population of microorganisms in the soil which in turn improved aggregate formation. The process of aggregation mainly involves stabilization of microaggregates ($> 250 \mu\text{m}$) against disruption by organomineral complexes and polysaccharides. These stabilizing materials

are the byproducts of the biological degradation of soil organic matter by microorganisms (Haynes and Beare, 1996).

Inclusion of high yielding crops in the rotation increased the quantity of residues returned to the soil and hence improved the soil physical properties. The magnitude of the influence on soil properties depends on the quality of the residues as well. Easily decomposable substrates such as legume residues improve soil physical properties for a greater extent than less easily decomposable materials such as residues of cereal crops. Legume residues are very low in humus content and produce intense effects on soil structural stability. The greater improvement in soil physical properties under the systems with three (S_3) and two (S_2) crops in a cycle is partly attributed to the inclusion of cowpea in the rotation. The organic matter content of the soil under the system which included two seasons of fallowing (S_1) was low. The aggregates under the S_1 system were hence weaker than those from the rotations, which included legumes (S_2 and S_3) and exhibited considerable slaking upon rapid wetting. Similar results were also reported by Misra *et al.* (1999). The quality of the maize crop residues, which followed cowpea in the rotation was also higher in terms of relatively higher nutrient content which enhanced the soil microbial population and thus improved the related soil properties to a great extent.

The improvement in soil physical properties was greater under the systems with three (S_3) and two (S_2) crops in an annual cycle since they included different crops in the rotation. The effectiveness of different crops in the S_3 and S_2 rotations in improving the soil structure and stability at different depths is related to the variation with depth in the amount of water extracted, the amount of root biomass deposited and the resistance of the residue-derived organic carbon to complete mineralization.

The population of soil fauna such as earthworms increases under intensive cropping systems because of adequate supply of crop residues which serve as an important source of food (Watts *et al.*, 2001). The growing roots and earthworms under the S₃ and S₂ systems created a favourable soil environment through the formation of biopores. Crop rotation which included fallowing for two seasons (S₁) added only less amount of residues (10906 kg ha⁻¹ in the cropping cycle II) to the soil. Hence it showed no considerable improvement in soil physical properties owing to shortage of organic matter as also reported by Benbi *et al.* (1998).

5.3. Effect of integrated nutrient management practices on soil physical properties (Fig. 7, 8 and 9)

The improvement in soil physical properties under different integrated nutrient management practices is attributed to the accumulation of soil organic matter resulting from continuous application of FYM, fertilizers and large amounts of crop and root residues. However, the difference in crop residue addition between the treatments within a season was too small to exert significant difference in soil physical properties.

At the end of the second cropping cycle, bulk density decreased at higher rate (150%) of fertilization (1.32 and 1.35 Mg m⁻³ with and without micronutrient application respectively) compared to the initial value of 1.48 Mg m⁻³. The corresponding values under lower rate of fertilization were 1.35 and 1.38 Mg m⁻³ respectively. The increase in total porosity at the end of the second cropping cycle was 12 and 10 per cent at higher rate of fertilization with and without micronutrient application, respectively compared to the initial value of 45.9 per cent. The corresponding increase under lower rate of fertilization was 10 and seven per cent, respectively. The integrated nutrient management practices significantly increased the organic carbon content of the soil across the cropping seasons. Increase in organic carbon was accompanied by increased porosity and

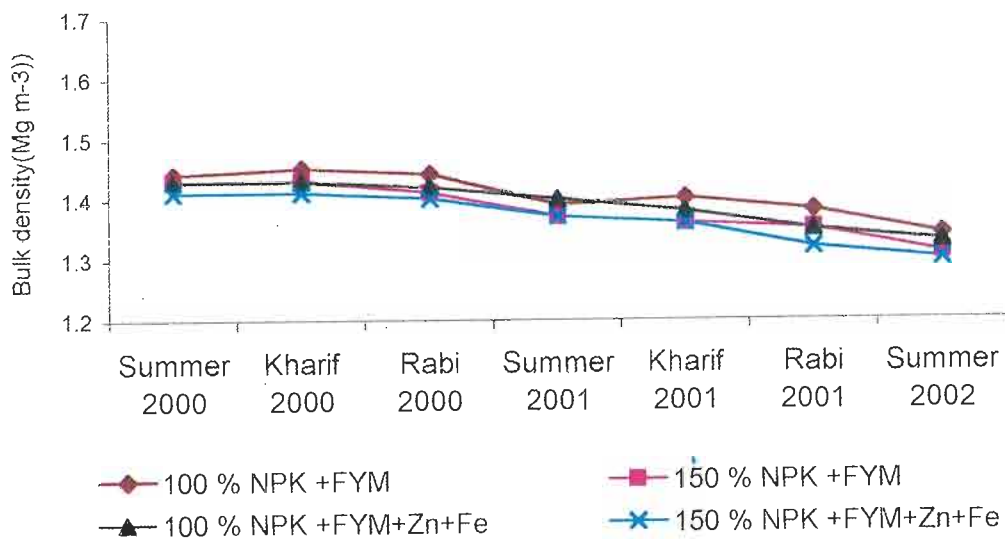
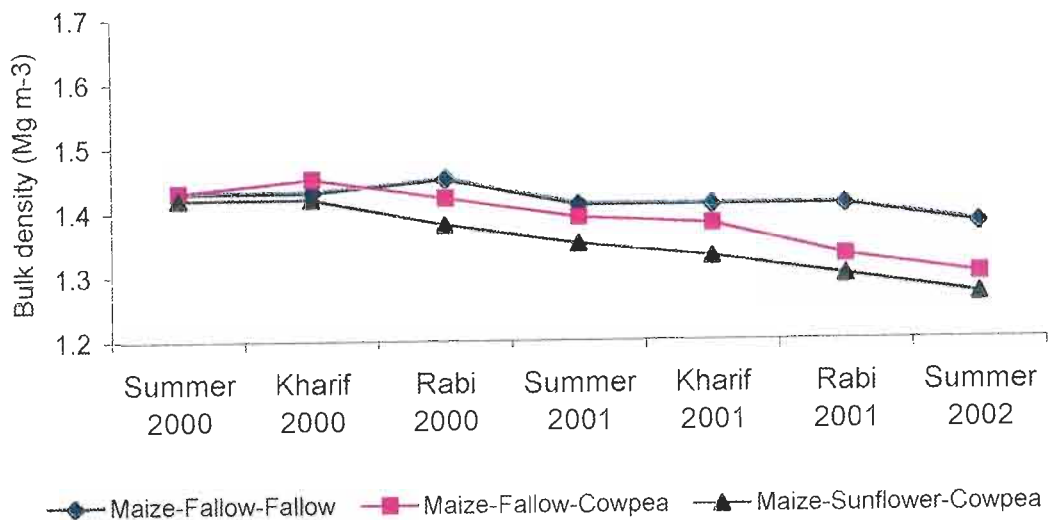


Fig 7. Bulk density under different cropping systems and integrated nutrient management practices

aggregate stability, which resulted in lower soil bulk density. It is well established that the quality rather than quantity of organic matter is more important in structural improvement of soils. Not all kinds of organic matter are active stabilizing agents. The particulate organic matter level is significantly correlated with macroaggregate stability (Chan, 1997). Particulate organic matter is the organic fraction in 53-2000 μm soil separates. With higher residue input rates under different integrated nutrient management practices, this fraction had increased which in turn improved soil aggregate stability (Six *et al.*, 1998).

The increase in available soil moisture at higher rate of fertilization with (19.6 cm m^{-1}) and without micronutrients (20.6 cm m^{-1}) at the end of the second cropping cycle compared to the initial value of 17.9 cm m^{-1} was 10 and 15 per cent, respectively. The corresponding increase at lower rate of fertilization was 10 and nine per cent (19.7 and 19.5 cm m^{-1}), respectively. Organic matter is an important determinant of water holding capacity of the soil. The increase in water retention is not due to organic matter itself but to its effect on aggregation and aggregate size distribution (Darwish *et al.*, 1995).

Application of FYM improved the soil physical properties to a greater extent. The FYM had long-term effects on soil physical properties and maintained a basic level of stability. Coarse nature of FYM physically prevented close packing of the soil and thus decreased the bulk density. The FYM had high water holding capacity and hence improved the available soil moisture (Ekwue, 1992). The FYM counteracted the deleterious effect upon bulk density that might be caused by the continued use of mineral fertilizers. Application of FYM increased the proportion of water stable aggregates and their mean weight diameter.

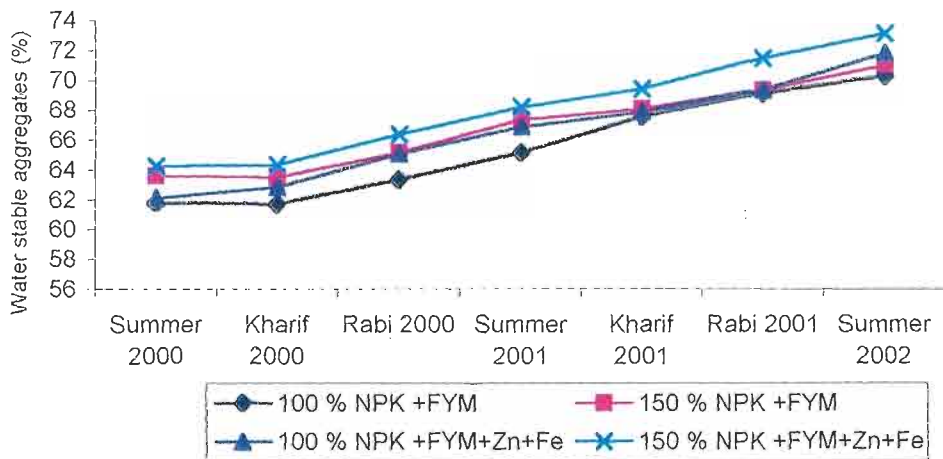
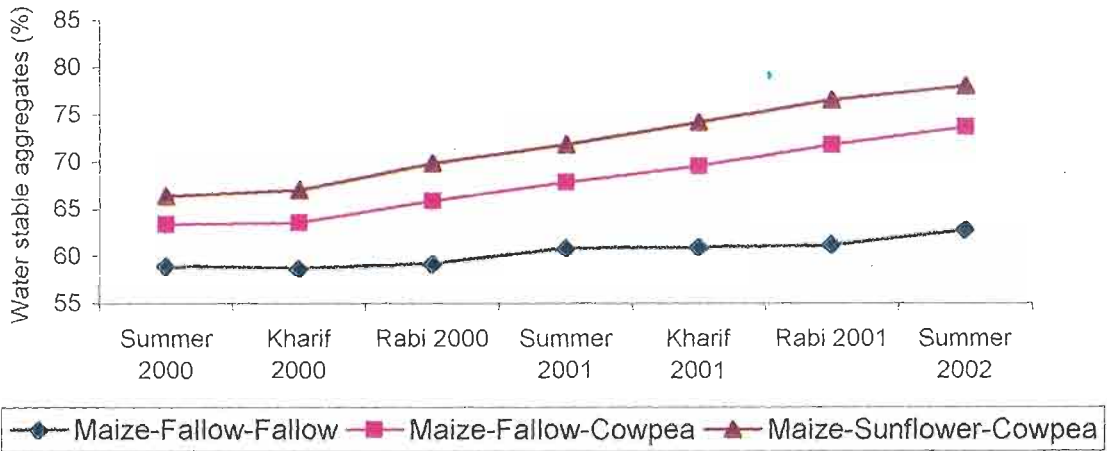


Fig 8. Water stable aggregates under different cropping systems and integrated nutrient management practices

At the end of the second cropping cycle the increase in hydraulic conductivity at higher rate of fertilization combined with micronutrients was 10 per cent (2.75 cm hr^{-1}) compared to the initial value of 2.5 cm hr^{-1} . The corresponding increase at lower rate of fertilization was eight per cent (2.70 cm hr^{-1}). Integrated nutrient management practices increased the residue input rates which in turn improved the hydraulic conductivity. Addition of crop residues increased the hydraulic conductivity by modifying mainly soil structure, proportion of macropores and aggregate stability.

Addition of cowpea residues under the systems with three (S_3) and two (S_2) crops in an annual cycle also contributed much to the improvement of soil physical properties. The increased stability under the S_3 and S_2 systems was directly related to the ease of microbial decomposition of the cowpea residues. The products released from decaying crop residues probably furnished all of the polysaccharides and related substances which acted as cementing agents in aggregate formation. Incorporation of plant debris into soil microaggregates protected it from further rapid decomposition which led to carbon sequestration (Golchin *et al.*, 1994).

The improvement in soil physical properties at higher rate of fertilization is largely a consequence of increased production of crop residues and roots compared to lower rate of fertilization. With increased rate of crop residue inputs at higher rate of fertilization, the population of bacteria, fungi and actinomycetes increased (211×10^6 , 121×10^4 and $192 \times 10^5 \text{ CFU g}^{-1}$ of soil respectively with micronutrients in the cropping cycle III). Fungal mycelia increased the size and strength of the aggregates by producing an external reinforcing net of hyphae. The larger the aggregates, the greater was their strength. The fungi were able to synthesize binding agents from soil organic matter which

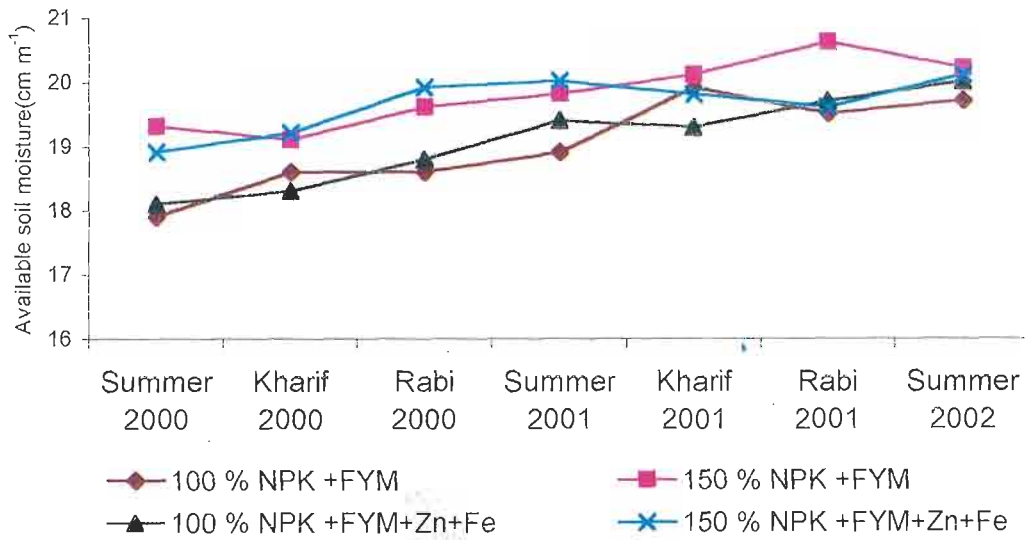
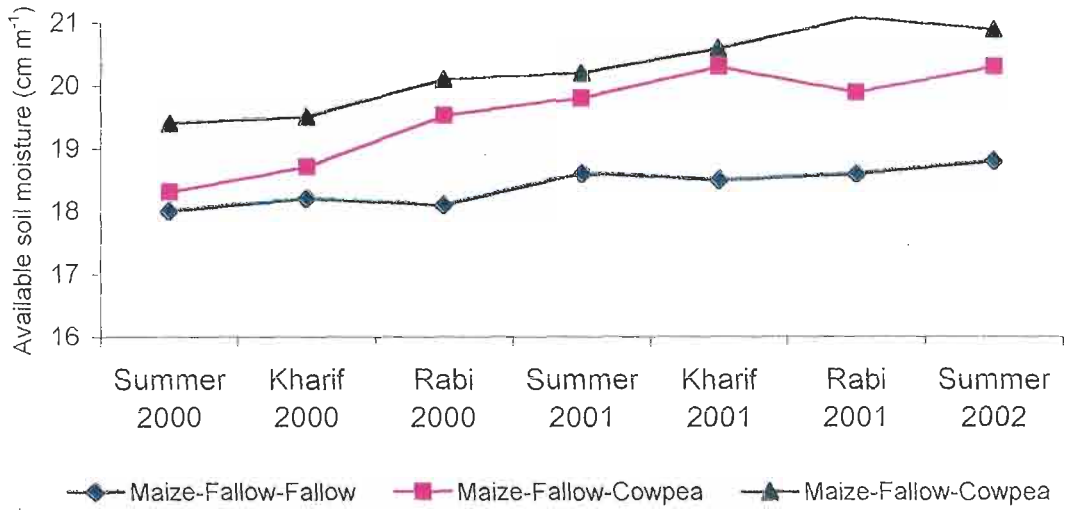


Fig 9 Available soil moisture under different cropping systems and integrated nutrient management practices

helped to form stable aggregates. The fungi acted both as aggregate forming and aggregate stabilizing agents. By ramifying through the soil, fungal hyphae might have brought the soil particles together and forced their contact with the binding agents. The decomposition of fungal hyphae might have yielded products that were better aggregate stabilizers than those from most other sources.

5.4. Effect of cropping systems on soil chemical properties

In the cropping cycle III, the increase in organic carbon content (Fig. 10) under the systems which included three (S_3) and two (S_2) crops in a cropping cycle was 31 and 19 per cent (0.63 and 0.57%), respectively compared to the rotation which included one crop (S_1) in an annual cycle (0.48%). At the end of the second cropping cycle, the increase in organic carbon content under the S_3 , S_2 and S_1 systems was 54, 38 and 15 per cent (0.60, 0.54 and 0.45%), respectively compared to the initial value of 0.39 per cent. Increased cropping index under the S_3 and S_2 systems enhanced the crop residue addition which resulted in a significant increase in soil organic matter concentration compared to the S_1 system. The increase in available nutrient status of the soil under the S_3 and S_2 systems was related to the increased soil organic carbon content. Crop rotation benefits under the S_3 and S_2 systems derived from soil organic matter were attributed to the release of nutrients through mineralisation of soil organic matter. Soil organic matter favourably influenced many of the soil quality indicators that increased the nutrient availability. Increase in water infiltration and aggregate formation and stability, lower bulk density, higher water retention capacity and improvement in soil aeration are due to the favourable effect of soil organic matter.

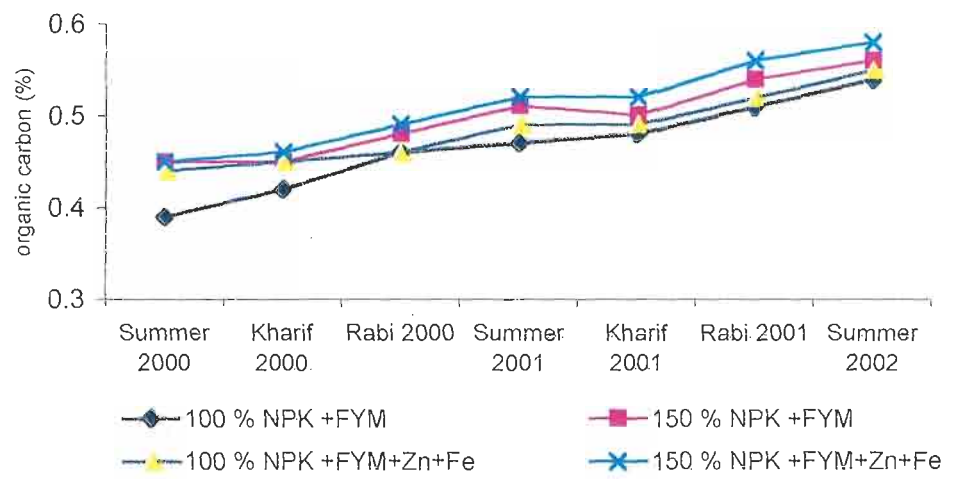
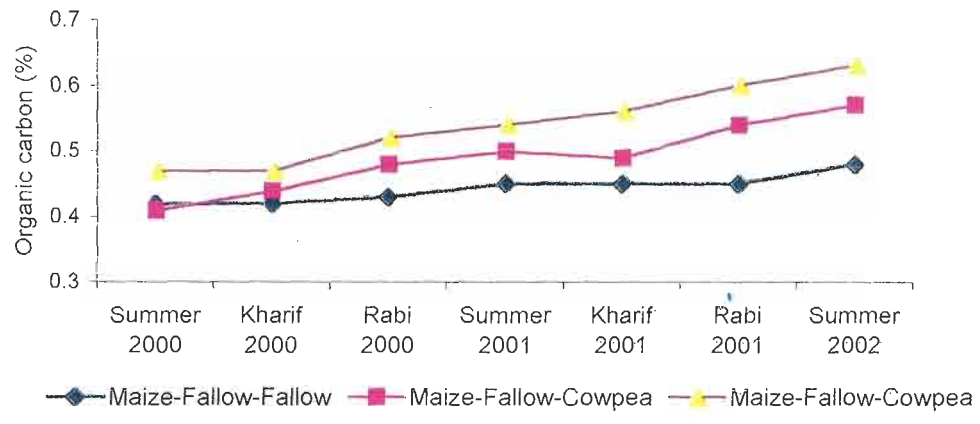


Fig 10 Organic carbon under different cropping systems and integrated nutrient management practices

The systems with three (S_3) and two (S_2) crops in an annual cycle increased the available nitrogen content (Fig. 11) of the soil by 14 and 11 per cent, respectively compared to the initial value of 218 kg ha^{-1} . The corresponding increase under the system with two seasons of fallowing (S_1) was only marginal. The increase in available N content under the rotations which included three (S_3) and two (S_2) crops in an annual cycle is attributed to the increased rate of crop residue addition and inclusion of cowpea in the rotation. The N benefits under the S_3 and S_2 systems had been attributed to the transfer of biologically fixed N. Additional mineral N under the S_3 and S_2 systems compared with the S_1 system might have resulted from the rapid mineralization of organic N derived from rhizodeposition rather than from a lower N demand by cowpea (Unkovich *et al.*, 1997). The cowpea residues had relatively higher nutrient content compared to the maize and sunflower residues which in turn enhanced the N mineralization and its availability (Kuo *et al.*, 1996). The particulate organic matter level is significantly correlated with the quality of the residues. The cowpea residues might have increased the particulate organic matter content more than the maize and sunflower crop residues with higher C/N ratio which in turn increased the N mineralization and its availability. (Wilson *et al.*, 2001).

The rotations with three (S_3) and two (S_2) crops in an annual cycle increased the available phosphorus content (Fig. 12) of the soil by 18 and 13 per cent, respectively in cropping cycle III compared to the initial value of 12 kg ha^{-1} . The corresponding increase under the system with two seasons of fallowing (S_1) was only five per cent. The S_3 and S_2 rotations increased the crop residues added to the soil (11981 and 15063 kg ha^{-1}

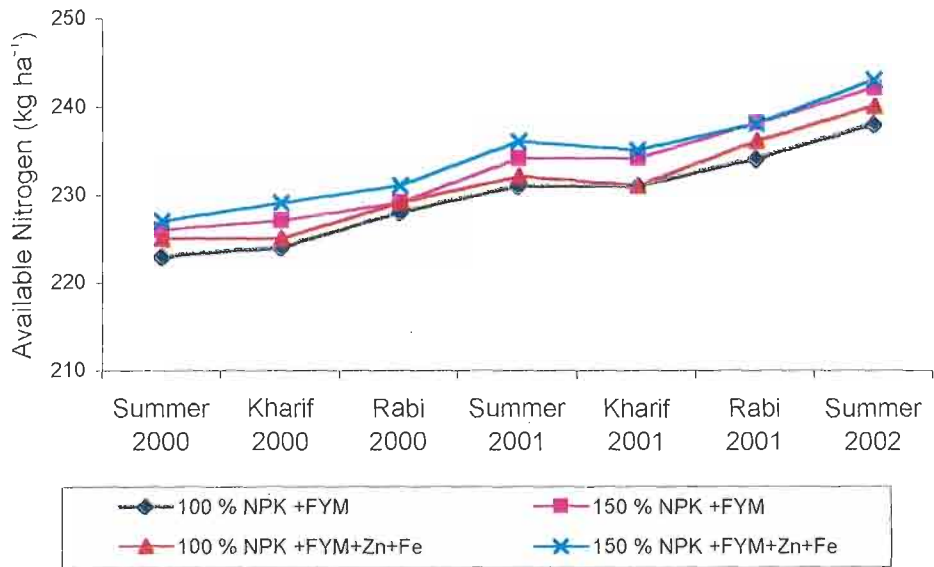
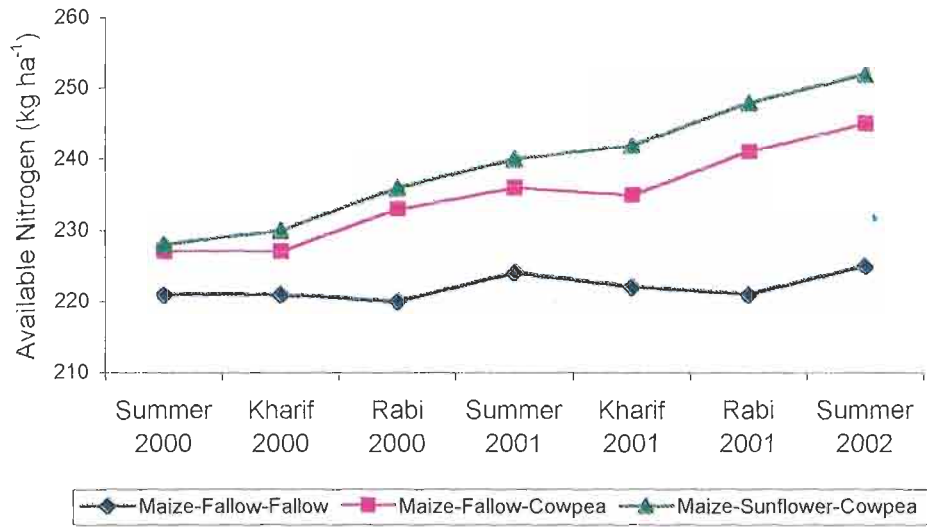


Fig 11. Available nitrogen content under different cropping systems and integrated nutrient management practices

respectively in cropping cycle II) which in turn increased the nutrient availability. The dead roots and root exudates have accounted to 12-18 per cent of the photosynthates and formed a significant proportion of biologically active soil organic matter (Oades and Waters, 1991; Srivastava and Singh, 1991). Large pools of biologically active soil organic matter might have contributed to the increased nutrient availability under the S_3 and S_2 systems as also reported by Franzluebbers *et al.* (1995). Inclusion of cowpea under the S_3 and S_2 systems resulted in a beneficial redistribution of potassium in the upper soil layers from deep in the soil profile and thus increased the availability of potassium (Fig. 13). The systems with three (S_3) and two (S_2) crops in an annual cycle supported higher population of bacteria, fungi and actinomycetes in the soil (232×10^6 , 118×10^4 and 210×10^5 CFU g^{-1} of soil respectively under S_3 in cropping cycle III) which in turn enhanced the decomposition and release of nutrients from the added crop residues. Availability of micronutrients such as iron, copper and zinc might have increased under the S_3 and S_2 systems because of microbiologically enhanced chelation.

5.5. Effect of integrated nutrient management practices on soil chemical properties

At the end of summer 2002 cropping season, the increase in organic carbon content (Fig. 10) compared to the initial value was higher with higher rate of fertilizer application (48 and 44 per cent with and without micronutrients, respectively) than the corresponding increase with lower rate of fertilization (41 and 38 per cent, respectively). The amount of organic matter formed in the soil depends upon the rate of crop residue added and its humification coefficient (the fraction of organic carbon left after one year of decomposition). The higher organic carbon content recorded with higher rates of

fertilization is attributed to the increased crop residue addition. With increase in soil organic matter content, the buffering and nutrient supplying capacity of the soil might have increased. The quinones formed during the decomposition of organic matter might have inactivated the urease, the enzyme responsible for decomposition of urea, and thus prevented losses of urea N and increased its availability. The organic matter might have formed stable complexes with Al and Fe present in the iron and aluminium phosphates and thus increased the P availability. The organic matter in combination with clay minerals might have formed stable complexes with Zn^{2+} , Cu^{2+} and Mn^{2+} and other polyvalent cations and thereby enhanced the availability of micronutrients.

Application of FYM increased the soil organic matter content to a greater extent. This presumably occurred because in addition to its nutrient value, the FYM itself represented an additional source of organic matter. Application of FYM increased the easily decomposable fractions of soil organic matter which served as an immediate source of nutrients for plant growth. The beneficial effect of FYM application in increasing the soil available K status is due to the greater capacity of organic colloids present in the FYM to hold K in the exchange sites. The FYM application increased the cation exchange capacity of the soil and hence the availability of P and Fe.

Available nitrogen content was higher (Fig. 11) under higher rate of fertilization (150% NPK) compared to the lower rate (100% NPK) in all the three cropping cycles but the increase was only marginal. The crop residue addition increased invariably under both the fertilizer rates which equally increased the available nitrogen in the soil at both fertilizer rates. Application of FYM and higher rate of fertilizers and crop residues

increased the available nitrogen content of the soil (12 and 10 per cent) at higher (150% NPK) and lower (100% NPK) rate of fertilization with micronutrients in the cropping cycle III compared to the initial value of 218 kg ha⁻¹).

With repeated incorporation of crop residues, the N mineralization encompassed the accumulated effect of all previous season's additions, which in turn increased the available N content (Thomson, 1992). The cowpea residues contained easily decomposable carbohydrates, proteins and other substances which contributed to the increased N mineralization (Mishra *et al.*, 2001). Application of higher rate of fertilizer N along with crop residues reduced the half time (time required to mineralize half of the potentially mineralizable N), *i.e.*, $t_{1/2}$ values and increased the mineral N content within a short period of time (Tripathi and Misra, 2000). Even if residue decomposes quickly, nutrients contained in it are not subjected to the same rapid loss as that which occurs with fertilization. Continuous application of crop residues to the soil involves a substantial input of carbonaceous material and thus may result in immobilization of some inorganic N already present in the soil atleast temporarily. However the balance between immobilization and mineralization changes with time and, in the long run, increasingly favours mineralization.

Available phosphorus (Fig. 12) and potassium (Fig. 13) also increased marginally at higher rate of fertilization (150% NPK) compared to the lower rate (100% NPK) in all the three cropping cycles. At both fertilizer rates considerable build up in available P was noticed due to application of FYM and crop residues along with fertilizers (13 and 12 per cent at higher (150% NPK) and lower (100% NPK) rate of fertilization with

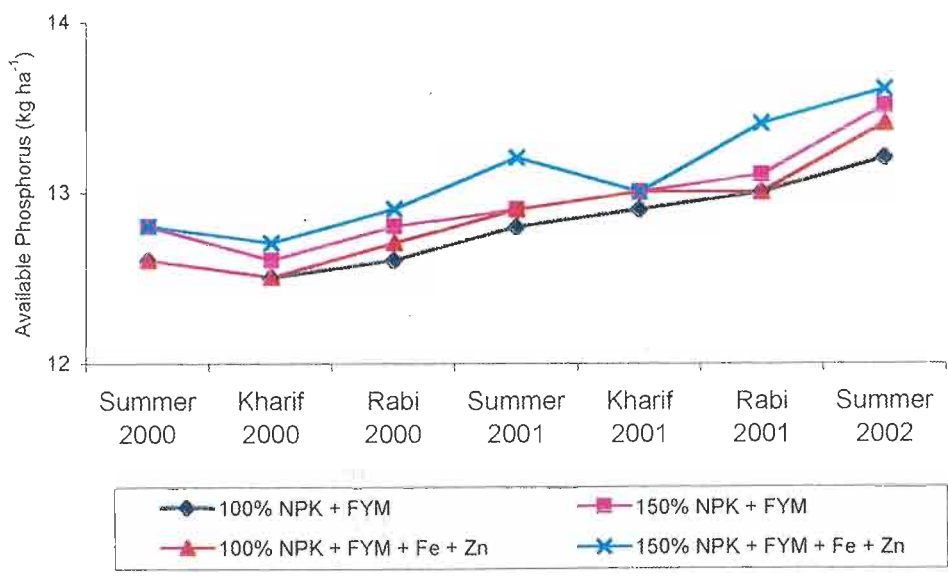
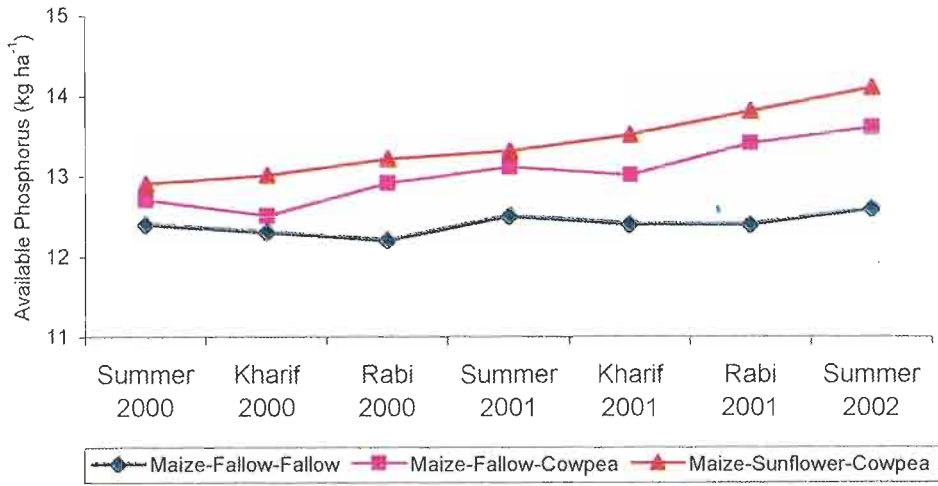


Fig 12. Available phosphorus content under different cropping systems and integrated nutrient management practices

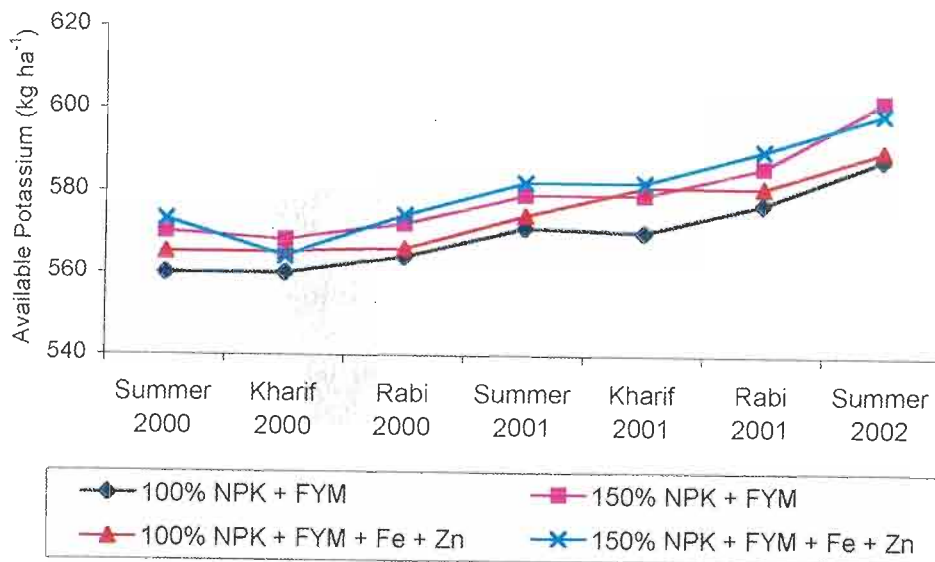
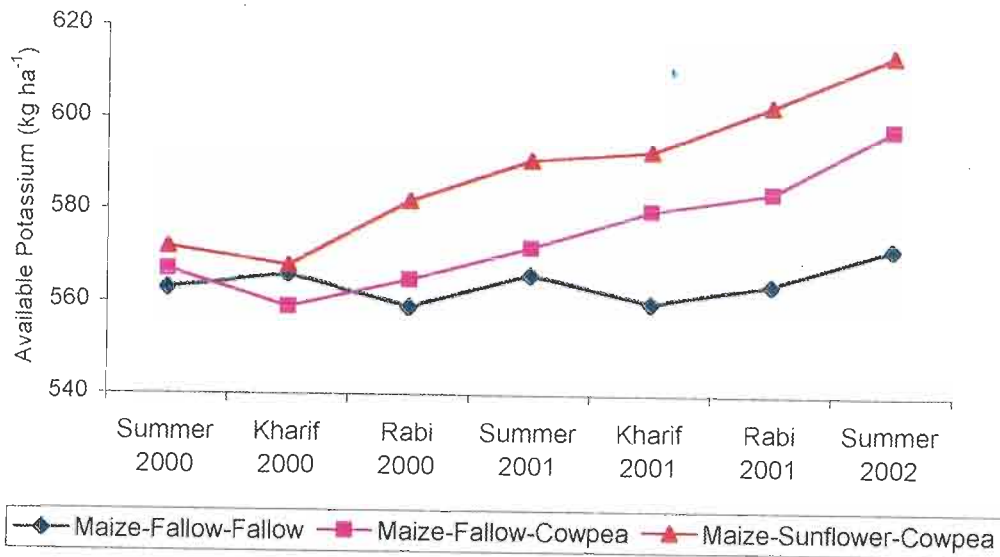


Fig 13. Available potassium content under different cropping systems and integrated nutrient management practices

micronutrients respectively in the cropping cycle III) compared to the initial value of 12 kg ha⁻¹. The corresponding build up in available potassium was seven and six per cent respectively compared to the initial value of 558 kg ha⁻¹. Incorporation of residues increased the available P because there was less soil contact of organic P in crop residues and hence less P fixation. An increase in phosphatase enzyme activity during crop residue decomposition might have been responsible for an increase in available P. Combined application of fertilizers, crop residues and FYM might have had a buffering effect on pH and favoured the P availability.

In general the N fertilization stimulates the mineralization of native soil organic N and its uptake (Powelson *et al.*, 1992). This phenomenon is referred to as priming effect or added N interaction. The priming effect of chemical fertilizer N may largely be a result of biological interchange between fertilizer N and soil N. Stimulation of microorganisms, increased metabolism and greater soil exploration by expanding root systems may contribute to the higher levels of soil N in fertilized plants. The FYM has a positive priming effect on the mineralization of soil N, *i.e.*, the amount of soil N mineralized is much less than the N entering the soil through FYM. This indicates that the priming effect on the mineralization of soil N will not lead to a lowering of N supplying capacity of the soil over a long time. The residual N from FYM helps to maintain or even increase the N supplying capacity of the soil.

Integrated nutrient management practices increased the population of bacteria, fungi and actinomycetes (211×10^6 , 121×10^4 , 192×10^5 CFU g⁻¹ of soil respectively under higher rate of fertilization (150% NPK) + micronutrients in the cropping cycle III)

in the soil which in turn had favourable influence on available nutrients. Changes in total as well as available nutrients depend largely on microbial activity. Hence the increased available nutrient content under different integrated nutrient management practices is partly attributed to the hastened decomposition and release of nutrients from FYM and crop residues by microorganisms.

5.6. Effect of cropping systems and integrated nutrient management practices on nutrient uptake by maize, sunflower and cowpea

The nitrogen uptake by maize was higher under the legume based rotations (S_3 and S_2) by 23 and 10 per cent respectively in cropping cycle III compared to the rotation with two seasons of fallowing (S_1). The phosphorus and potassium uptake was also higher by 21 and nine and 24 and 10 per cent under S_3 and S_2 , respectively in the cropping cycle III. The nitrogen uptake by cowpea was higher by eight per cent under the system with continuous cropping (S_3) compared to the system with one season of fallowing (S_2) in the cropping cycle II. The corresponding phosphorus and potassium uptake values were also higher (both seven per cent) under S_3 compared to S_2 in the cropping cycle II. Inclusion of cowpea in the rotation contributed much to the nutrient uptake by the following crops through N effect as well as rotation effects. It is found that N recoveries from leguminous residues are about one-half of that from various forms of N fertilizers. But only one eighth of non-leguminous crop residue N is recovered by the succeeding crops. The nitrogen content of the soil under the S_3 and S_2 rotations which included cowpea was higher because more legume N than fertilizer N was retained in the soil and entered the organic N pool which in turn increased the N availability and N uptake.

The S₃ and S₂ systems returned greater amounts of crop residues to the soil and thereby built up soil organic matter content which ensured an adequate nutrient supply to the plants. The incorporated residues supplied energy continuously to the microorganisms and increased the microbial population which had favourable effect on nutrient availability. The degree of availability of nutrients depends on mineralization and immobilization rates. The rates of these processes are regulated by microorganisms. The higher population of bacteria, fungi and actinomycetes (211×10^6 , 121×10^4 , 192×10^5 CFU g⁻¹ of soil, respectively, under the system with continuous cropping (S₃) in cropping cycle III) favoured these processes which are responsible for nutrient release which in turn increased the nutrient uptake.

The nitrogen uptake by maize was higher at higher rate of fertilization by 13 and 11 per cent with and without micronutrients, respectively, compared to the lower rate (100% NPK) in the cropping cycle III. The phosphorus and potassium uptake were also higher at higher rate of fertilization + micronutrient application by nine and 13 per cent respectively compared to the corresponding values at lower rate of fertilization (100% NPK). Nutrient uptake by sunflower and cowpea also exhibited the similar trend. Integrated nutrient management practices improved soil physical properties, organic matter and available nutrients content and thereby enhanced the nutrient uptake. Soil organic matter contains a major proportion of the soil N, P, S and other nutrients and 50 to 80 per cent of the N even in fertilized crops comes from mineralization of soil organic matter.

Higher rates of fertilizer application (150% NPK) improved the growth of plants and their root activity and thus enabled the plants to absorb nutrients to a greater extent. It is reported that humic substances present in organic matter promote root hair formation and root elongation and thereby accelerate nutrient uptake. The active roots can absorb nutrients from the whole rhizosphere soil and protect the leaves from early senescence, probably by the translocation of phytohormones. Plants supporting a large and deep root system receive sufficient N from the soil even under low available N conditions (Hamid and Ahmad, 1994). In addition, moderation of hydrothermal regime with the application of FYM and crop residues might have improved the root growth especially in the surface layers and uptake of nutrients. The cumulative effect of successive additions of FYM, crop residues and fertilizers contributed considerably to the increase in DMP and nutrient uptake over the cropping seasons. Addition of cowpea residues having low C/N ratio increased the available nutrients more than maize and sunflower residues which in turn improved the nutrient uptake by succeeding maize crop. It is found that the efficiency of uptake of nutrients from legume residues is similar to that of fertilizers but for crop residues with high C/N ratio, it is slightly lower (Bremner and Van Kessel, 1992).

5.7. Effect of cropping systems and integrated nutrient management practices on soil microbial population

At the end of the second cropping cycle, the increase in population of bacteria under the systems with three (S_3) and two (S_2) crops in an annual cycle was 117 and 94 per cent, respectively compared with the rotation with two seasons of fallowing (S_1). The corresponding increase in the population of fungi under S_3 and S_2 systems were 151 and

102 per cent and actinomycetes were 111 and 95 per cent respectively compared to the system without a legume crop (S_1). The legume based S_3 and S_2 systems increased the quantity of crop residues added to the soil which in turn enhanced the population of microorganisms. In addition, the quality of the cowpea residues was relatively higher in terms of higher labile organic N content which served as an easily decomposable substrate and supported higher microbial population (Dinesh and Dubey, 1998).

The population of bacteria, fungi and actinomycetes increased at higher rate of fertilization (150% NPK) with micronutrient application by 11, 27 and 12 per cent respectively compared to the corresponding values at lower rate (100% NPK) in the cropping cycle III. At higher fertilizer rates (150% NPK), crop residues added to the soil increased which in turn enhanced the microbial population. Integrated nutrient management practices significantly increased the microbial population in the soil owing to their influence on soil organic matter content. Soil microbial biomass and their activity are closely related to soil organic matter content. The FYM might have stimulated microbial activity in the soil and the humic substances present in FYM increased the efficiency of N fixing organisms like *Rhizobium* and *Azotobacter*. The systems with three (S_3) and two (S_2) crops in an annual cycle increased the amount of crop residues added to the soil (11981 and 15063 kg ha⁻¹, respectively in the second cropping cycle) which increased the supply of substrates for both phototrophic and heterotrophic N fixing microorganisms and in turn increased their population (Thompson, 1992; Srivastava and Lal, 1994). Microbial activity is strongly influenced by variations in soil water content during the growing season. Increased crop residue incorporation under the S_3 and S_2

N. Concurrent with the release of N from soil microbial biomass, there will also be direct release of N from fresh residues and native soil organic matter (Thomson, 1992).

5.8. Nutrient Balance

There was no marked difference in net gain in available nitrogen under the systems with two (S_2) and three (S_3) crops in an annual cycle during the period of cropping cycle I and the net gain under the system with two seasons of fallowing (S_1) was much less than the S_2 and S_3 systems. Under the S_1 system there was less addition of N during the *kharif* 2000 fallow period from the previous season's maize residues and during the *rabi* 2000 fallow period there was no addition of N. Hence the net gain under the S_1 system during the cropping cycle I was very less. Even though the system with two crops in an annual cycle comprised a fallow period during *kharif* 2000 season, the net gain in available nitrogen under the S_2 system showed no marked difference from the system with three crops in an annual cycle. But the net gain in available N under the system with three crops (S_3) during the period of cropping cycles II and III put together was slightly higher than the system with two crops in an annual cycle (S_2). The overall net gain under the system with two seasons of fallowing (S_1) was very less indicating the unfavourable effect of fallowing on soil available nitrogen under tropical conditions. Fallowing for one season (S_2) had not resulted in considerable reduction in available N indicating the cumulative effect of application of crop residues, FYM and fertilizer. Despite the additions exceeding the removal, there was only a marginal net gain in available nitrogen under the system with continuous cropping (S_3) and one season of fallowing (S_2) indicating that there might have been losses of N under both the systems.

The overall net gain under the system with three crops in an annual cycle was slightly higher than the S_2 system and this might have resulted from increased amount of crop residues added under the S_3 system.

The soil available phosphorus under the system with two seasons of fallowing (S_1) maintained its initial level without any increase during the cropping cycle I indicating that continuous addition of phosphorus was essential to buildup the available P status. Even though the addition of P was high compared to the removal, the marginal net gain in S_2 and S_3 systems indicated that the added fertilizer P might be lost or fixed in the soil. The positive P balance under the systems with two and three crops indicated that large addition of crop residues, FYM and fertilizers was essential to buildup the available P status in the soil.

The net gain in available potassium was only marginal under the system with one season (S_2) and two seasons (S_1) of fallowing during the cropping cycle I but during the cropping cycles II and III put together there was considerable net gain ($13-35 \text{ kg K ha}^{-1}$) under the S_2 and S_1 systems. Even though the total addition of potassium was far less than the removal, there was no depletion of soil available potassium in all the cropping cycles and there was appreciable overall net gain ($44 \text{ to } 51 \text{ kg K ha}^{-1}$) especially under the system with three (S_3) crops in an annual cycle due to the cumulative effect of addition of FYM and crop residues in all the three seasons.

5.9. Economics of cropping systems and integrated nutrient management practices (Fig. 14 and 15)

Rotations with three (S_3) and two (S_2) crops in an annual cycle registered higher the net return compared to the rotation with two seasons of fallowing (S_1). Rotations with three (S_3) and two (S_2) crops in an annual cycle had increased the yield of the crops and thereby net returns (Rs. 40464 and 29311 $\text{ha}^{-1} \text{year}^{-1}$ respectively at higher rate (150% NPK) of fertilization + micronutrients in the second cropping cycle). The lower maize grain yield and two seasons of fallowing are attributed to the lower net return under the S_1 system (Rs. 22476 $\text{ha}^{-1} \text{year}^{-1}$) in cropping cycle II. Higher rate of fertilization (150% NPK) increased the yield of the crops in all the three systems and thereby increased the net return. The increase in net return under the rotations with three (S_3), two (S_2) and one (S_1) crop(s) in an annual cycle at higher rate of fertilization (150% NPK) + micronutrients was Rs. 2958, 1778 and 2542 $\text{ha}^{-1} \text{year}^{-1}$ respectively in the cropping cycle II. The increase in net return due to micronutrient application was minimum (Rs. 2662 $\text{ha}^{-1} \text{yr}^{-1}$ at higher rate of fertilization in the cropping cycle II) owing to the marginal increase in yield due to micronutrient application.

The increased B/C ratio (2.87) under the system with two seasons of fallowing (S_1) at higher rate (150% NPK) of fertilization + micronutrients in the second cropping cycle is attributed to the lower cost of cultivation compared to the systems with three (S_3) and two (S_2) crops in an annual cycle. The cost incurred for labour and fertilizers was higher under the system with three crops (111 and 73 per cent, respectively) and two crops (54 and 42 per cent respectively) compared to the system with one crop in an annual cycle. Higher cost incurred for labour and fertilizers under the systems with three

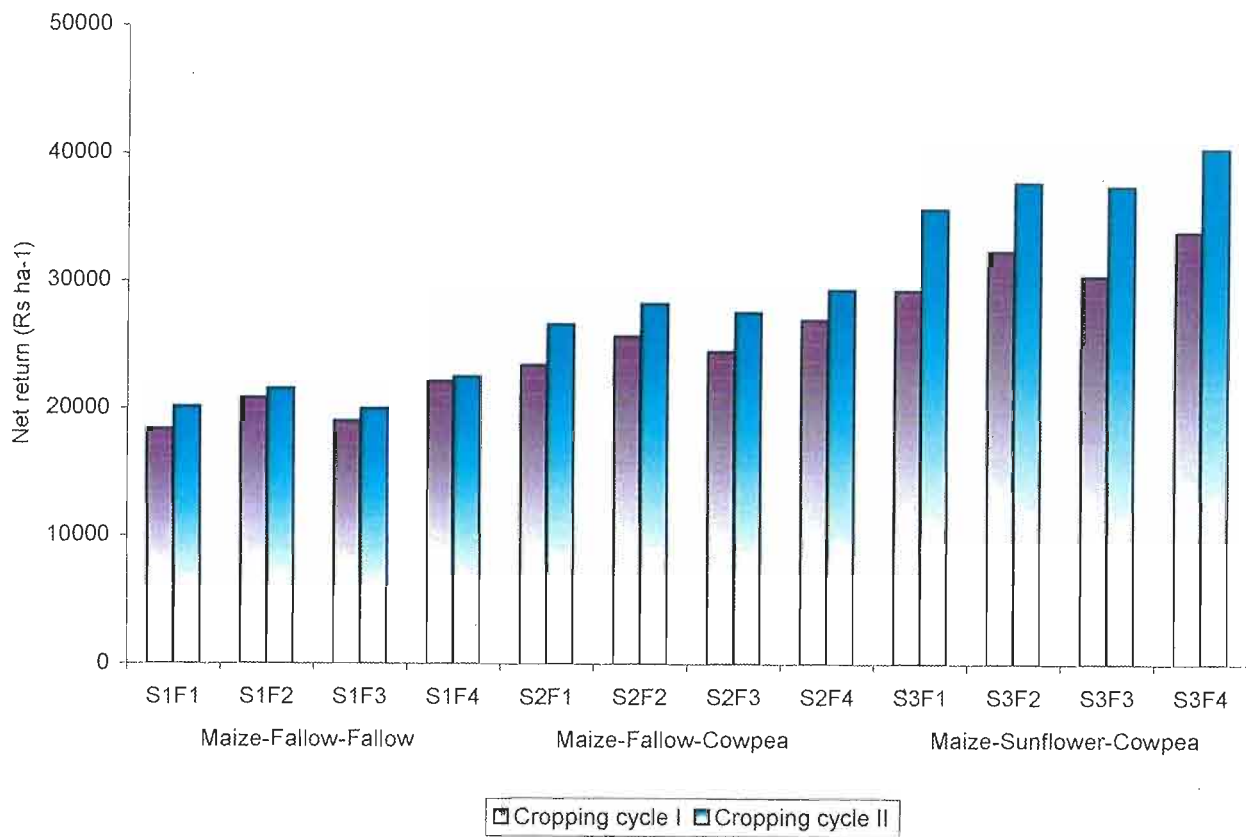


Fig 14. Net returns under different cropping systems and integrated nutrient management practices

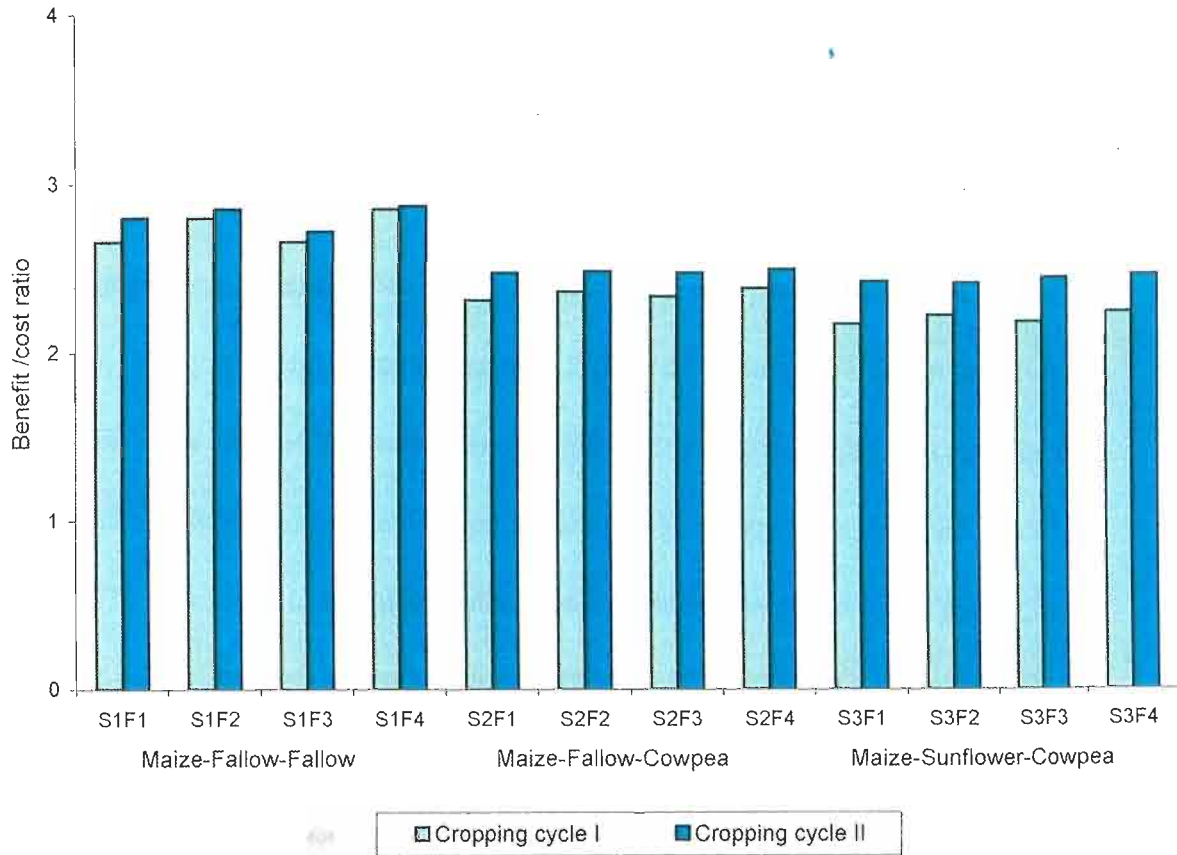


Fig 14. Benefit cost ratio under different cropping systems and integrated nutrient management practices

(S₃) and two (S₂) crops in an annual cycle increased the total cost of cultivation and thus decreased the B/C ratio (2.46 and 2.40, respectively at higher rate of fertilization (150% NPK) + micronutrient application in the cropping cycle II).

From the study it is concluded that in general cropping systems and integrated nutrient management practices improved the soil physical, chemical and biological properties and thereby the yield of the component crops and economic return of cropping systems. Among the cropping systems, maize-sunflower-cowpea was better in improving soil quality, crop yields and economic returns followed by maize-fallow-cowpea system. Leaving the land fallow for two seasons did not improve much the soil quality characteristics as well as crop yields. Application of 150% recommended NPK with 12.5 t ha⁻¹ of FYM was found to be the best integrated nutrient management practice for better soil quality, higher crop yields and economic returns. Micronutrient application (Zn and Fe) has resulted in only marginal improvement in soil quality and crop yields. Maize-sunflower-cowpea and maize-fallow-cowpea systems with 150% recommended NPK and FYM enhanced the soil available NPK status considerably.

CHAPTER VI

SUMMARY AND CONCLUSION

Field experiments were conducted at Tamil Nadu Agricultural University over seven cropping seasons, from summer 2000 to summer 2002 to study the effect of maize based cropping systems and integrated nutrient management practices in relation to physical, chemical and biological properties of soil and productivity of the component crops. The experiment was laid out in split plot design with three replications. The cropping systems, *viz.*, maize-fallow-fallow (S_1), maize-fallow-cowpea (S_2) and maize-sunflower-cowpea (S_3) were included as main plot treatments and the integrated nutrient management practices, *viz.*, 100% recommended NPK + FYM (F_1), 150% recommended NPK + FYM (F_2), 100% recommended NPK + FYM + Zn + Fe (F_3) and 150% recommended NPK + FYM + Zn + Fe (F_4) formed the subplot treatments. The growth and yield of the component crops, nutrient uptake and soil physical, chemical and biological properties were studied in all the seasons and nutrient balance and economics were computed. The results obtained were summarized in this chapter.

The dry matter production, root dry weight, grain yield and stover yield of the component crops of maize and sunflower were higher in the maize-sunflower-cowpea (S_3) system in all the seasons followed by the maize-fallow-cowpea (S_2) system. Cropping systems had no significant influence on the growth and yield of the component crop cowpea. The maize-fallow-fallow (S_1) system registered the least increase in maize yield.

The dry matter production, root dry weight, grain yield and stover yield of maize, sunflower and cowpea were significantly higher at 150% NPK + FYM (F_2) and 150% NPK + FYM + Zn + Fe (F_4) than the 100% NPK + FYM (F_1) and 100% NPK + FYM +

Zn + Fe (F₃) treatments. Application of micronutrients marginally improved the growth and yield of the crops.

The maize-sunflower-cowpea (S₃) system with 150% NPK + FYM (F₂) and 150% NPK + FYM + Zn + Fe (F₄) recorded increased dry matter production, root dry weights, grain yields and stover yields of the component crops followed by the maize-fallow-cowpea system (S₂).

Cropping systems had no significant influence on soil bulk density during the first four seasons, *viz.*, summer 2000, *kharif* 2000, *rabi* 2000 and summer 2001. In the latter three seasons, the effect of cropping systems on bulk density was significant. The maize-sunflower-cowpea (S₃) system had lowered the soil bulk density followed by the maize-fallow-cowpea (S₂) system.

The integrated nutrient management practices did not influence the bulk density of the soil significantly.

The maize-sunflower-cowpea system (S₃) significantly increased the non-capillary porosity followed by the maize-fallow-cowpea (S₂) system. Non-capillary porosity was higher with application of 150% NPK + FYM (F₂) and 15% NPK + FYM + Zn + Fe (F₄).

Cropping systems did not alter the capillary porosity significantly. The effect of integrated nutrient management practices on capillary porosity was also non-significant except for summer 2000.

The maize-sunflower-cowpea (S₃) system increased the total porosity of the soil significantly followed by the maize-fallow-cowpea (S₂) system. The effect of integrated nutrient management practices on total porosity was non-significant except during *rabi* 2000 and *kharif* 2001, wherein the total porosity was significantly higher at 150% NPK + FYM (F₂) and 150% NPK + FYM + Zn + Fe (F₄).

Cropping systems did not influence the hydraulic conductivity significantly during the first two seasons, viz., summer 2000 and *kharif* 2000. In the other seasons, higher values for hydraulic conductivity were recorded under the maize-sunflower-cowpea (S₃) system which was closely followed by the maize-fallow-cowpea system (S₂). Integrated nutrient management practices had no significant influence on the hydraulic conductivity.

Percentage of water stable aggregates was significantly higher under the maize-sunflower-cowpea (S₃) system followed by the maize-fallow-cowpea (S₂) system. Integrated nutrient management practices had not significantly influenced the percentage of water stable aggregates except during summer 2001 wherein 150% NPK + FYM + Zn + Fe (F₄) recorded significantly higher percentage of water stable aggregates.

Moisture content at field capacity was higher under the maize-sunflower-cowpea (S₃) system followed by maize-fallow-cowpea (S₂) system. The 150% NPK + FYM (F₂), 150% NPK + FYM + Zn + Fe (F₄) and 100% NPK + FYM + Zn + Fe (F₃) increased the moisture contents at field capacity.

Moisture content at permanent wilting point was significantly higher under the maize-sunflower-cowpea (S₃) system followed by maize-fallow-cowpea (S₂) system. The integrated nutrient management practices did not influence the moisture content at permanent wilting point significantly in summer 2000, *rabi* 2000 and *kharif* 2001. In other seasons, the treatments 150% NPK + FYM + Zn + Fe (F₄), 150% NPK + FYM (F₂) and 150% NPK + FYM + Fe + Zn (F₃) had higher moisture content at permanent wilting point.

The available soil moisture was higher under the maize-sunflower-cowpea (S₃) than the maize-fallow-cowpea (S₂) systems. Integrated nutrient management practices had no significant influence on the available soil moisture during *kharif* 2000, *kharif* 2001

and summer 2002. In the rest of the seasons, 150% NPK + FYM + Zn + Fe (F₄) and 150% NPK + FYM (F₂) treatments increased the available soil moisture content.

The maize-fallow-fallow system (S₁) recorded higher bulk density and lower porosity, hydraulic conductivity, percentage of water stable aggregates and available soil moisture.

The maize-sunflower-cowpea (S₃) system with 150% NPK + FYM + Zn + Fe (F₄) and 150% NPK + FYM (F₂) recorded lower bulk density and higher porosity, hydraulic conductivity, percentage of water stable aggregates and available soil moisture.

Soil organic carbon content was significantly higher under the maize-sunflower-cowpea (S₃) system. The 150% NPK + FYM + Zn + Fe (F₄) and 150% NPK + FYM (F₂) recorded higher soil organic carbon content compared to the other treatments.

Available nitrogen content in the soil was significantly higher under the maize-sunflower-cowpea (S₃) and maize-fallow-cowpea (S₂) systems. Integrated nutrient management practices had no significant influence on the available nitrogen content of the soil.

Cropping systems did not influence the available phosphorus content of the soil significantly in summer 2000, summer 2001 and *kharif* 2001. In the remaining seasons, the maize-sunflower-cowpea (S₃) and maize-fallow-cowpea (S₂) systems registered higher available phosphorus content. The soil available phosphorus content was not significantly influenced by integrated nutrient management practices.

Cropping systems and integrated nutrient management practices did not influence the available potassium content of the soil significantly in all the seasons of study.

The organic carbon, available nitrogen, phosphorus and potassium contents were lower under the maize-fallow-fallow (S₁) system. The maize-sunflower-cowpea system

(S₃) with 150% NPK + FYM + Zn + Fe (F₄) and 150% NPK + FYM (F₂) recorded higher organic carbon, available nitrogen, phosphorus and potassium contents.

Population of bacteria, fungi and actinomycetes were higher under the maize-sunflower-cowpea system (S₃) followed by the maize-fallow-cowpea system (S₂). The effect of integrated nutrient management practices on microbial population was not consistent. In general, 150% NPK + FYM + Zn + Fe (F₄) and 150% NPK + FYM (F₂) had recorded higher microbial population.

The nitrogen, phosphorus and potassium uptake values by maize and cowpea were higher under the maize-sunflower-cowpea system (S₃) followed by maize-fallow-cowpea system (S₂). The 150% NPK + FYM + Fe + Zn (F₄) and 150% NPK + FYM (F₂) increased the nutrient uptake by maize, sunflower and cowpea.

The maize-sunflower-cowpea (S₃) system with 150% recommended NPK + FYM + Zn + Fe (F₄) improved the soil available NPK status considerably followed by maize-fallow-cowpea system.

The maize-sunflower-cowpea (S₃) system with 150% NPK + FYM + Fe + Zn (F₄) produced higher net returns. However the B/C ratio was higher under the maize-fallow-fallow system (S₁) with 150% NPK + FYM + Zn + Fe (F₄).

From the study, it is concluded that both cropping systems and integrated nutrient management practices improved the soil physical, chemical and biological properties, yield of component crops, net returns and B/C ratio considerably. Among the cropping systems, maize-sunflower-cowpea performed better in improving the soil fertility status through improvement in soil organic carbon content, better NPK balance, higher crop yields and economic returns, followed by maize-fallow-sunflower system. The maize-fallow-fallow system neither altered the soil quality nor increased the crop yields and economics appreciably.

Application of 150% NPK + FYM + Zn + Fe was the better integrated nutrient management system for improving the soil fertility as well as for higher crop yields and economic returns. However the response of crops to micronutrient application was only marginal.

REFERENCES

- Alok Kumar and Yadav, D.S. 1995. Use of organic manure and fertilizer in rice (*Oryza sativa*) – wheat (*Triticum aestivum*) cropping system for sustainability. **Indian Journal of Agricultural Sciences**, 65(10): 703-707.
- Anderson, T.H., Domsch, K.H. 1989. Ratios of microbial biomass carbon to total organic carbon in arable soils. **Soil Biol. Biochem.**, 21: 471-479.
- Annadurai, K and Palaniappan, SP. 1994. Effect of potassium on yield, oil content and nutrient uptake of sunflower. **Madras Agricultural Journal**, 81(10): 568-569.
- Annadurai, K., Seshadri, P. and Palaniappan, S. 1994. Response of soybean (*Glycine max*) to phosphorus and residual potassium. **Indian Journal of Agronomy**, 32(2): 320-322.
- Aoyama, M., Angers, D.A. and N'Dayegamiye, A. 1999. Particular and mineral-associated organic matter in water-stable aggregates as affected by mineral fertilizer and manure applications. **Can. J. Soil Sci.**, 79: 295-302.
- Arunachalam, L. and Habeebullah, B. 1993. Integrated nutrient management in gardenland cropping system. **Madras Agricultural Journal**, 80(8): 460-468.
- Azad, A.S., Manchanda, J.S. and Gill, A.S. 1992. Differential response and economics of nitrogen application to field pea (*Pisum sativum*) in soil of variable organic carbon status. **Indian Journal of Agronomy**, 37(2): 377-378.
- Badanur, V.P., Poleshi, C.M. and Naik, B.K. 1990. Effect of organic matter on crop yield and physical and chemical properties of a Vertisol. **Journal of the Indian Society of Soil Science**, 38(3): 426-429.
- Bahl, G.S. and Pasricha, N.S. 2000. N-utilization by maize (*Zea mays* L.) as influenced by crop rotation and field pea (*Pisum sativum* L.) residue management. **Soil Use and Management**, 16: 230-231.
- Balubane, M. 1996. Turnover of clay-associated organic nitrogen in the different aggregate-size classes of a cultivated silty loam. **Eur. J. Soil Sci.**, 47: 285-291.
- Bansal, K.N. 1992. Potassium balance in multiple cropping system in a Vertisol at Jabalpur. **Journal of Potassium Research**, 8(1): 52-58.

- Barrios, E., Buresh, R.J. and Sprent, J.I. 1996. Organic matter in soil particle size and density fractions from maize and legume cropping systems. **Soil Biol. Biochem.**, **28**: 185-193.
- Belanger, G., Richards, J.E. and Angers, D.A. 1999. Long-term fertilization effects on soil carbon under permanent swards. **Can. J. Soil Sci.**, **79**: 99-102.
- Bellakki, M.A. and Badanur, V.P. 1994. Effect of crop residue incorporation on physical and chemical properties of a Vertisol and yield of sorghum. **Journal of the Indian Society of Soil Science**, **42**(4): 533-535.
- Benbi, D.K., Biswas, C.R., Bawa, S.S. and Kumar, K. 1998. Influence of farm yard manure, inorganic fertilizers and weed control practices on some soil physical properties in a long-term experiment. **Soil Use and Management**, **14**: 52-54.
- Beri, V., Sidhu, B.S., Bahi, G.S. and Bhat, A.K. 1995. Nitrogen and phosphorus transformations as affected by crop residue management practices and their influence on crop yield. **Soil Use and Management**, **11**(2): 51-54.
- Beri, V., Sidu, B.S., Bhat, A.K., Bhujinderpal Singh and Singh, B. 1992. Nutrient balance and soil properties as affected by management of crop residues. **Proceedings of the International Symposium on Nutrient Management for Sustained Productivity: Volume 2**: 133-135.
- Bhagat, R.M. and Verma, T.S. 1991. Impact of rice straw management on soil physical properties and wheat yield. **Soil Science**, **152**(2): 108-115.
- Bharadwaj, V. and Omanwar, P.K. 1992. Impact of long-term fertility treatments on bulk density, water contents and microbial population of soil. **Journal of the Indian Society of Soil Science**, **40**(3): 553-555.
- Bhore, A.V., Kadam, S.B., Gaikwad, C.B., Patil, J.D. and Kale, S.P. 1994. Double cropping of kharif fodder crops with safflower/chickpea under dryland conditions of Maharashtra. **Journal of Maharashtra Agricultural Universities**, **19**(2): 318-319.
- Campbell, C.A., Biederbeck, V.O., Wen, G., Zentner, R.P., Schoenau, J. and Hahn, D. 1999. Seasonal trends in selected soil biochemical attributes: Effects of crop rotations in the semi-arid prairie. **Can. J. Soil Sci.**, **79**: 73-84.
- Campbell, C.A., Biederbeck, V.O., Zentner, R.P. and Lafond, G.P. 1991. Effect of crop rotations and cultural practices on soil organic matter, microbial biomass and respiration in a thin Black Chernozem. **Can. J. Soil Sci.**, **71**: 363-378.
- Caporali, F. and Onnis, A. 1992. Validity of rotation as an effective agroecological principle for a sustainable agriculture. **Agric. Ecosystems Environ.**, **41**: 101-113.

- CGIAR, 1990. Sustainable agricultural production. Final report of the CGIAR Committee. MT/90/18. Presented at the CGIAR Meeting, The Hague, Netherlands, 21-25, May 1990.
- Chan, K.Y. 1997. Consequences of changes in particulate organic carbon in Vertisols under pasture and cropping. **Soil Science Society of America Journal**, **61**: 1376-1382.
- Chan, K.Y., Heenan, D.P. and Ashley, R. 1994. Seasonal changes in surface aggregate stability under different tillage and crops. **Soil & Tillage Research**, **28**: 301-314.
- Chandrashekhara, C.P., Patil, V.C. and Sreenivasa, M.N. 1995. VA-mycorrhiza mediated P effect on growth and yield of sunflower (*Helianthus annuus* L.) at different P levels. **Plant and Soil**, **176**(2): 325-328.
- Channabasavanna, A.S. and Setty, R.A. 1993. Effect of nitrogen, ferrous sulphate and zinc sulphate on ground nut (*Arachis hypogaea*) yield in deep black soils. **Indian Journal of Agronomy**, **38**(2): 329-330.
- Chaudhary, M.L. and Kumar, N. 1992. Residual effect of phosphorus and zinc applied to maize on the dry matter yield of wheat, P uptake and its availability in the soil. **Haryana Journal of Agronomy**, **8**(1): 19-24.
- Christensen, B.T. and Olesen, J.E. 1998. Nitrogen mineralization potential of organomineral size separates from soils with annual straw incorporation. **European Journal of Soil Science**, **49**: 25-36.
- Collings, C.H. and M.P.Lyne. 1968. Microbiological methods. 5th Edition, Butterworth, London.
- Cook, R.J. 1984. Root health: Importance and relationship to farm practices. In **Organic Farming: Current Technology and Its Role in a Sustainable Agriculture**. Eds. D.F. Bezdicsek and J.F. Powell. Am. Soc. Agron. Special Publ. 46. Am. Soc. Agronomy, Madison, WI. Pp.111-127.
- Cook, R.J. 1988. Biological control and holistic plant-health care in agriculture. **Am. J. Alter. Agric.**, **3**: 51-62.
- Dakshinamurti, C. and Gupta, R.P. 1967. Practicals in Soil Physics, IARI, New Delhi.
- Darwish, O.H., Persaud, N. and Martens, D.C. 1995. Effect of long-term application of animal manure on physical properties of three soils. **Plant and Soil**, **176**: 289-295.
- Das, A.C. and Mukherjee, D. 1990. Microbiological changes during decomposition of wheat straw and neem cake in soil. **Environment and Ecology**, **8**(3): 1012-1015.

Das, S.K. and Rao, A.C.S. 1986. Effect of preceding crops on nitrogen management for rainfed sorghum in black soil. **Journal of the Indian Society of Soil Science**, **34** (3): 510-513.

Das, S.K., Reddy, S.G., Vittal, K.P.R., Venkateswarlu, B., Reddy, M.N. and Reddy, Y.V.R. 1993. Prediction of nitrogen availability in soil after crops residue incorporation. **Fertilizer Research**, **34**(3): 209-215.

4 Deepak Kher. 1991. Soil properties as influenced by continuous liming, manuring and cropping in an Alfisol. **Crop Research (Hisar)**, **4**(2): 346-349.

4 Dev, S.P. and Bharadwaj, K.K.R. 1995. Effect of crop wastes and nitrogen levels on biomass production and nitrogen uptake in wheat-maize sequence. **Annals of Agricultural Research**, **16**(2): 264-267.

Devarajan, R., Kumerasan, K.R., Ramanathan, G. and Pachanathan, R.M. 1989. Response of sunflower to micronutrients. **Madras Agricultural Journal**, **75**(11-12): 401-404.

Dick, R.P. 1992. A review: Long-term effect of agricultural systems on soil biochemical and microbial parameters. **Agric. Ecosystems Environ.**, **40**: 25-36.

4 Dinesh Badiyala and Verma, S.P. 1990. Effect of supplemental sources and fertilizer nitrogen on physico-chemical properties of acid soils of Himachal Pradesh. **Indian Journal of Agronomy**, **35**(2): 144-149.

Dinesh, R. and Dubey, R.P. 1998. Nitrogen mineralization rates and kinetics in soils freshly amended with green manures. **J. Agronomy & Crop Science**, **181**: 49-53.

Dormaar, J.F. and Carefoot, J.M. 1998. Effect of straw management and nitrogen fertilizer on selected soil properties as potential soil quality indicators of an irrigated Dark Brown Chernozemic soils. **Can. J. Soil Sci.**, **78**: 511-517.

Ekwe, E.I. 1992. Effect of organic and fertilizer treatments on soil physical properties and erodibility. **Soil & Tillage Research**, **22**: 199-209.

Franzluebbers, A.J., Hons, F.M. and Zuberer, D.A. 1995. Tillage and crop effects on seasonal soil carbon and nitrogen dynamics. **Soil Sci. Soc. Am. J.**, **59**: 1618-1624.

Fyson, A. and Oaks, A. 1990. Growth promotion of maize by legume soils. **Plant and Soil**, **122**: 259-266.

Gangwar, K.S. and Singh, N.P. 1991. Growth and development behaviour of lentil (*Lens culinaris* Medic.) in relation to zinc fertilization. **Indian Journal of Agricultural Research**, **25**(1): 38-42.

Gaonker, S.B.N., Sreenivasa, S.B. and Alagawadi, A.R. 1993. Rhizosphere microflora, growth and yield of wheat as influenced by inoculation of *Glomus fasciculatum* in conjunction with organic amendments. **Karnataka Journal of Agricultural Sciences**, 6(4): 371-377.

X Ghosh, P.K. and Singh, N.P. 1995. Residual effect of summer legumes on succeeding maize: A study on nitrogen concentration and its uptake. 1995. **Indian Agriculturist**, 39(1): 31-35.

Ghoshal, N. and Singh, K.P. 1995. Effects of farmyard manure and inorganic fertilizer on the dynamics of soil microbial biomass in a tropical dryland agroecosystem. **Biology and Fertility of Soils**, 19(2/3): 231-238.

Gill, H.S. and Meelu, O.P. 1982. Management of fertilizer phosphorus in a rice-wheat rotation. **International Rice Research Newsletter**, 7(5): 23.

Golchin, A., Oades, J.M., Skjemstad, J.O. and Clarke, P. 1994. Soil structure and carbon cycling. **Australian Journal of Soil Research**, 29: 829-867.

Gomez, K.A. and Gomez, A.A. 1984. Statistical procedure for Agricultural Research. An International Rice Research Institute Book. A Wiley-Interscience Publication, John Wiley and Sons, Inc.

Gregorich, E.G., Ellert, B.H., Drury, C.F. and Liang, B.C. 1996. Fertilization effects on soil organic matter turnover and corn residue C storage. **Soil Sci. Soc. Am. J.**, 60: 472-476.

Grewal, H.S., Kolar, J.S. and Kang, J.S. 1992. Effect of combined use of green-manure and nitrogen on the productivity of maize (*Zea mays*)-wheat (*Triticum aestivum*) system. **Indian Journal of Agronomy**, 37(4): 635-638.

X Guldekar, V.D., Patil, R.T., Durge, D.V. and Chavan, P.N. 1992. Effect of organic and inorganic sources of nitrogen on uptake and yield of jowar (CSH-9). **Bioved**, 3(1): 111-112.

Gupta, A.P., Narwal, R.P., Antil, R.S. and Dev, S. 1992. Sustaining soil fertility with organic-C, N, P and K by using farmyard manure and fertilizer-N in a semi arid zone: A long-term study. **Arid-Soil Research and Rehabilitation**, 6(3): 243-251.

Gupta, V.K. 1995. Zinc research and agricultural production. **Micronutrient Research and Agricultural Production**. 131-164.

Gupta, V.K. and Potalia, B.S. 1991. Influence of N carriers and Zn levels on Cu, Mn and Fe nutrition on maize (*Zea mays* L.). **Indian Journal of Agricultural Research**, 25(1): 1-6.

- Gurung, G.B. and Sherchan, D.P. 1993. Study on the effects of long-term application of compost and chemical fertilizers on crop yields and physiochemical properties of soil on rice-wheat cropping pattern. **PAC Working Paper Pakbribas Agricultural Centre, 87: 6.**
- Hamid, A. and Ahmad, M. 1994. Effect of ^{15}N -labelled ammonium nitrate and urea on soil nitrogen during growth of wheat (*Triticum aestivum* L.) under field conditions. **Biol Fertil. Soils, 17: 232-236.**
- Harjit Singh, Sharma, K.N. and Arora, B.S. 1995. Influence of continuous fertilization to a maize wheat system on the changes in soil fertility.
- Harris, G.H. and Hesterman, O.B. 1990. Quantifying the nitrogen contribution from alfalfa to soil and two succeeding crops using nitrogen-15. **Agron. J., 82: 129-134.**
- Hassink, J. and Whitemore, A.P. 1997. A model of the physical protection of organic matter in soils. **Soil Sci. Soc. Am. J., 61: 131-139.**
- Haynes, R.J. and Beare, M.H. 1996. Aggregation and organic matter storage in mesothermal, humid soils. In: *Advances in Soil Science: Structure and organic matter in agricultural soils*, eds M. Carter and B.A. Stewart, C.R.C. Lewis Press Inc.
- Hegde, B.R., Havanagi, G.V., Reddy, N.M., Venugopal, N., Vishwanatha, A.P. and Satyanarayanan, T. 1982. Studies on the incorporation of maize residue on soil properties and yield of maize under rainfed conditions.
- Hegde, D.M. 1996. Long-term sustainability of productivity in an irrigated sorghum-wheat system through integrated nutrient supply. **Field Crops Res., 48: 167-175.**
- Hema Singh. 1995. Nitrogen mineralization, microbial biomass and crop yield as affected by wheat residue placement and fertilizer in a semi-arid tropical soil with minimum tillage. **Journal of Applied Ecology, 32(3): 588-595.**
- Hoflich, G., Tauschke, M., Kuhn, G. and Rogasik, J. 2000. Influence of agricultural crops and fertilization on microbial activity and microorganisms in the rhizosphere. **J. Agronomy & Crop science, 184: 49-54.**
- Houghton, R.A. and J.L.Hackler. 1994. The net flux of carbon from deforestation and degradation in south and southeast Asia. IN: Dale, V. (Ed.) *Effects of Land-Use Change on Atmospheric CO₂ concentrations: South and Southeast Asia as a Case Study*, Springer-Verlag, New York, pp.301-327.
- Humphries, E.C. 1956. Mineral components and ash analysis. In: *Modern Method of Plant Analysis*, Springer-Verlag, Berlin, 1: 468-502.

- Hundal, H.S., Arora, B.R., Dhillon, K.S. and Dhillon, S.K. 1990. Phosphorus utilization by maize from [³²P] P labeled plant material of cowpea. **Journal of Nuclear Agriculture and Biology**, **19**(3): 157-161.
- Jackson, M.L. 1973. Soil chemical Analysis. Printice Hall of India Pvt. Ltd., New Delhi.
- Jansen, H.H., Bole, J.B., Biederbeck, V.O. and Slinkard, A.E. 1990. Fate of N applied as green manure or ammonium fertilizer to soil subsequently cropped with spring wheat at three sites in western Canada. **Can. J. Soil Sci.**, **70**: 313-322.
- Jawson, M.D., Franzluebbers, A.J., Galusha, D.K. and Aiken, R.M. 1983. Soil fumigation within monoculture and rotations: Response of corn and mycorrhizae. **Agron. J.**, **85**: 1174-1180.
- Jaya Niranjane, Puranik, R.B., Somani, R.B., Guhe, Y.S. and Deshmukh, S.D. 1993. Microbial population as influenced by incorporation of wheat straw in a Typic Ustorthent. **Journal of the Indian Society of Soil Science**, **41**(2): 368-369.
- Karlen, D.L. (Chair), Allan, D.L., Adriano, D.C., Bezdicsek, D.F., Cline, R.G., Coleman, D.C., Doran, J.W., Haberer, J., Harris, R.F., Tuo, A.S.R., Mausbach, M.J., Peterson, G.A., Schum, G.E. and Singer, J.J. 1995. SSSA Statement on Soil Quality. P.7. **Agron. News**. June 1995.
- Karlen, D.L., Varvel, G.E., Bullock, D.G. and Cruse, R.M. 1994. Crop rotations for the 21st Century. **Advances in Agronomy**, **53**: 1-45.
- Ken Knight, G. and Muncie, J.H. 1939. Isolation of phytopathogenic actinomycetes. **Phytopath.**, **29**: 1000-1001.
- Kesavan, S.P., Sharma, N.K., Khadikar, P.V. and Verma, G.P. 1995. Effect of long-term input and intensive cropping on aggregation of a black clay soil. **Crop Research (Hisar)**, **9**(2): 258-265.
- Kharwara, P.C. and Pathania, P.K. 1994. Analysis of maize based cropping system. **Himachal Journal of Agricultural Research**, **20**(1/2): 12-15.
- Khokhani, M.G., Ahlawat, R.P.S. and Trivedi, S.J. 1993. Effect of nitrogen and phosphorus fertilizers on yield and nutrient uptake in sunflower (*Helianthus annuus*). **Indian Journal of Agronomy**, **38**(2): 330-332.
- Kler, D.S., Sarbjeet Singh, Dhillon, M.S. and Brar, S.S. 1993. Influence of legumes and nitrogen on the grain yield in maize-wheat system. **Environment and Ecology**, **11**(3): 693-695.
- Kuo, S., Sainju, U.M. and Jellum, E. 1996. Winter cover crop influence on nitrogen mineralization. Presidedress soil nitrate test, and corn yields. **Biol. Fertil. Soils**, **22**: 310-317.

- Kurual, A. and Tripathi, R.P. 1990. Effect of continuous use of manures and fertilizers on physical properties of soil under paddy-wheat-cowpea cropping system. **Crop Research**, 3(1): 7-12.
- Lal, R. 1994. Methods and guidelines for assessing sustainable use of soil and water resources in the tropics. SMMS Technical Monograph No. 21, Washington, DC.
- Lal, R. and Muller, F.P. 1993. Soil quality and its management in humid subtropical and tropical environment. Proc. XVII International Grassland Congress, Massey University, New Zealand.
- Lal, R. and Stewart, B.A. 1995. Need for long-term experiments in sustainable use of soil resources. In: R. Lal and B.A. Stewart (eds) "Soil Management: Experimental Basis for Sustainability and environmental Quality". Lewis Publishers, Boca Raton, FL: pp.537-545.
- Lekha Sreekantan and Palaniappan, S.P. 1989. Integrated P management in rice-rice-green gram cropping system. **Indian J. Agron.**, 34(1): 27-29.
- Liang, B.C., Gregorich, E.G., MacKenzie, A.F., Schnitzer, M., Voroney, R.P., Monreal, C.M. and Beyaert, R.P. 1998. Retention and turnover of corn residue carbon in some eastern Canadian soils. **Soil Sci. Soc. Am. J.**, 62: 1361-1366.
- Lomte, M.H., Ateeque, M., Bharambe, P.R. and Kwarkhe, P.K. 1993. Influence of sorghum-legume association on physico-chemical properties of soil. **Journal of Maharashtra Agricultural Universities**, 18(3): 388-390.
- Lupwayi, N.Z., Rice, W.A. and Clayton, G.W. 1999. Soil microbial biomass and carbon dioxide flux under wheat as influenced by tillage and crop rotation. **Can. J. Soil Sci.**, 79: 273-280.
- Mahajan, M.S. and Nikam, S.M. 1992. Nitrogen requirement for safflower based double-cropping sequence under rainfed condition. **Biovigyanam**, 18(2): 73-77.
- Mahapatra, B.S. and Sharma, G.L. 1988. Effect of integrated nitrogen management in rice on soil organic carbon and on succeeding wheat crop yield. **International Rice Research Newsletter**, 13(1): 21-22.
- Malhi, S.S., Nybord, M. and Solberg, E.D. 1989. Recovery of ¹⁵N-labelled urea as influenced by straw addition and method of placement. **Can. J. Soil Sci.**, 69: 543-550.
- Mandal, B.C., Roy, A.B., Saha, M.N. and Mandal, A.K. 1984. Wheat yield and soil nutrient status as influenced by continuous cropping and manuring in a jute-rice-wheat rotation. **Journal of the Indian Society of Soil Science**, 32(2): 696-700.
- Martin, J.P. 1950. Use of acid, rose Bengal and streptomycin in the plate method for estimating soil fungi. **Soil Sci.**, 69: 215-233.

- Martyn Silgram and Mark A. Shepherd. 1999. The effects of cultivation on soil nitrogen mineralization. **Advances in Agronomy**, **65**: 267-311.
- McGill, W.B., Dormaar, J.F. and Reind-Dwyer, E. 1998. New perspectives on soil organic matter quality, quantity and dynamics on the Canadian Prairies. **In Land Degradation and Conservation Tillage**. Proc. 34th Annual CSSS/AIC meeting, Calgary, Alberta. Pp.30-48.
- Mishra, R.K. 1994. Effect of various pigeon pea cultivars and spacings on yield and their residual fertility effect on succeeding wheat. **Bharatiya Krishi Anusandhan Patrika**, **9(4)**: 253-258.
- Mishra, S.S., Gulati, J.M.L., Nanda, S.S., Garnayak, L.M. and Jena, S.N. 1989. Micro nutrient studies in wheat. **Orissa Journal of Agricultural Research**, **2(2)**: 94-96.
- Mishra, B., Sharma, P.K. and Bronson, K.F. 2001. Decomposition of rice straw and mineralization of carbon, nitrogen, phosphorus and potassium in wheat field soil in western Uttar Pradesh. **Journal of the Indian Society of Soil Science**, **49(3)**: 419-424.
- Misra, A.K., Daniel, H., Till, R. and Blair, G.J. 1999. Effect of long-term crop rotations and rewetting on soil on stability. **Soil Use and Management**, **15**: 254-255.
- Mohan Singh and Tilak, K.V.B.R. 1992. Inoculation of sorghum (*Sorghum biocolor*) with *Glomus versiforme* under field conditions. **Tropical Agriculture**, **69(4)**: 323-326.
- Morel, R., Lasnier, T., Bourgeois, S. 1984. Les essais de fertilization de longue duree de la station agronomique de Grignon: Dispositif Deherain et des 36 parcelles. INRA, Paris.
- Nagasundaram, N., Savithri, P., Manickam, T.S. and Kothandaraman, G.V. 1986. Comparative efficacies of FYM addition, soil and foliar application of ferrous sulphate to sorghum (CSH.5) in ameliorating chlorosis and increasing yield.
- Nagre, K.T. and Chandrasekhar, A. 1988. Effect of summer legumes on nitrogen economy and yield of succeeding sorghum. **PKV Research Journal**, **12 (2)**: 102-106.
- Nambiar, K.K.M. and Abrol, I.P. 1989. Long-term fertilizer experiments in India – An overview. **Fert. News**, **34**: 11-20, 26.
- Nandita Ghoshal and Singh, K.P. 1994. The influence of soil amendments on the proportion of organic carbon and nitrogen in the microbial biomass in a dryland agroecosystem. **Tropical Ecology**, **35(2)**: 309-319.

- Nuttall, W.F., Bowren, K.E. and Campbell, C.A. 1986. Crop residue management practices, and N and P fertilizer effects on crop response and on some physical and chemical properties of a Black Chernozem over 25 years in a continuous wheat rotation. **Can. J. Soil Sci.**, **66**: 159-171.
- Oades, J.M. and Waters, A.G. 1991. Aggregate hierarchy in soils. **Australian Journal of Soil Research**, **29**: 815-828.
- Ocio, J.A., Brookes, P.C., Jenkinson, D.S. 1991. Field incorporation of straw and its effects on soil microbial biomass and soil inorganic N. **Soil Biol. Biochem.**, **23**: 171-176.
- Olsen, S.R., Cole, C.V., Watanabe, F.S. and Dean, L.A. 1954. Estimation of available phosphorus in soils by extraction with sodium bicarbonate. USDA Circ. No. 939.
- Omay, A.B., Rice, C.W., Maddux, L.D. and Gordon, W.B. 1997. Changes in soil microbial and chemical properties under long-term crop rotation and fertilization. **Soil Sci. Soc. Am. J.**, **61**: 1672-1678.
- Omay, A.B., Rice, C.W., Maddux, L.D. and Gordon, W.B. 1998. Corn yield and nitrogen uptake in monoculture and in rotation with soybean. **Soil Sci. Soc. Am. J.**, **62**: 1596-1603.
- Pandurangi, R.B., Wankhade, S.G. and Patil, D.B. 1989. Response of hybrid sorghum to P and Zn application. **PKV Research Journal**, **13**(2): 158-160.
- Patel, M.L., Gami, R.C. and Patel, P.V. 1993a. Effect of farmyard manure and NPK fertilizers on bulk density of deep black soil under rice-wheat green gram rotation. **Gujarat Agricultural University Research Journal**, **18**(2): 109-111.
- Patel, M.S., Suthar, D.M. and Kanzaria, M.V. 1993b. Effect of foliar application of iron and sulphur in curing chlorosis in groundnut. **Journal of the Indian Society of Soil Science**, **41**(1): 103-105.
- Patil, M.N., Zade, K.B., Naphade, K.T. and Kharkar, P.T. 1993. Decomposition of organic materials in soil in relation to nutrient mineralization. **Journal of Maharashtra Agricultural Universities**, **18**(3): 348-351.
- Patra, D.D., Schdev, M.S. and Subbian, B.V. 1990. Effect of cowpea and maize +m cowpea intercropping on N uptake by succeeding maize and wheat crops. **Journal of Nuclear Agriculture and Biology**, **19**(2): 71-75.
- Patwary, S.U., Haque-Q and Badruddin, M. 1989. Role of legume on nitrogen balance and A-value of soil under different sequential cropping systems. **Thai Journal of Agricultural Science**, **22**(3): 213-221.
- Paul, E.A., Clark, F.E. 1989. Soil microbiology and biochemistry. Academic Press, San Diego.

- Paustian, K., Collins, H.P. and Paul, E.A. 1997. Management controls on soil carbon. Pages 15-49 in E.A.Paul, E.T.Elliot, K.Paustian and C.V.Cole, eds. Soil organic matter in temperate agroecosystems. CRC Press, Boca Raton, FL.
- Paustian, K., Parton, W.J., Persson, J. 1992. Modeling soil organic matter in organic amended and nitrogen-fertilized long-term plots. **Soil Sci. Soc. Am. J.**, **56**: 476-488.
- Pawar, K.P. and Jadhav, A.S. 1995. Nutrient balance in legume sorghum (*Sorghum bicolor*) cropping sequence. **Indian Journal of Agricultural Sciences**, **65**(7): 515-518.
- Peterson, T.A. and Varvel, G.E. 1989. Crop yield as affected by crop rotation and N rate. III. Corn. **Agron. J.**, **81**: 735-738.
- Poonguzhalan, R., Nanjappa, H.V. and Ramachandrappa, B.K. 1996. Effect of fertilizer levels and weed control methods on NPK uptake by sunflower and weeds. **Annals of Agricultural Research**, **17**(1): 107-110.
- Powlson, D.S., Brookes, P.C., Christensen, B.T. 1987. Measurement of soil microbial biomass provides an early indication of changes in total soil organic matter due to straw incorporation. **Soil Biol. Biochem.**, **19**: 159-164.
- Powlson, D.S., Hart, P.B.S., Poulten, P.R., Johnstone, A.E. and Jenkinson, D.S. 1992. Influence of soil type, crop management and weather on the recovery of ¹⁵N-labelled fertilizer applied to winter wheat in spring. **J. Agric. Sci.**, **118**: 83-100.
- Prasad, B. and Singh, A.P. 1980. Changes in soil properties with long-term use of fertilizer, lime and farm yard manure. **Journal of the Indian Society of Soil Science**, **28**(4): 465-468.
- Prasad, B. and Umar, S.M. 1993. Direct and residual effect of soil application of zinc sulphate on yield and zinc uptake in a rice-wheat rotation. **Journal of the Indian Society of Soil Science**, **41**(1): 192-194.
- Prasad, R. and Power, J.F. 1991. Crop residue management. **Advances in Soil Science**, **5**: 205-251.
- Raina, J.N. and Goswami, K.P. 1988. Effect of added ¹⁴C-labeled organic materials on the decomposition of native soil organic matter. **Journal of the Indian Society of Soil Science**, **36**(4): 646-651.
- Raju, R.S. and Iruthayaraj, M.R. 1995. Effect of irrigation methods of irrigation and nitrogen levels on nutrient uptake by maize (*Zea mays*). **Madras Agricultural Journal**, **82**(3): 215-216.
- Ram Newaj and Yadav, D.S. 1994. Change in physico-chemical properties of soil under intensive cropping systems. **Indian Journal of Agronomy**, **39**(3): 373-378.

- ✓ Ramaswami, P.P., Raj, D. and Selvaraj, K.V. 1979. Effect of continuous application of manures and fertilizers on some of the physico-chemical and microbiological properties of soil under irrigated condition. **Mysore Journal of Agricultural Sciences**, 13(2): 167-170.
- Rao, A.V., Tarafdar, J.C., Sharma, S.K., Praveen Kumar and Aggarwal, R.K. 1995. Influence of cropping systems on soil biochemical properties in an arid rain-fed environment. **Journal of Arid Environments**, 31(2): 237-244.
- Rao, K.J. and Dakhore, R.C. 1994. Nutrient changes in a Vertisol under sorghum wheat rotation for five years. **Journal of Soils and Crops**, 4(2): 108-112.
- Rasmussen, P.E. and Collins, H.P. 1991. Long-term impacts of tillage, fertilizer, and crop residue on soil organic matter in temperate semiarid regions. **Adv. Agron.**, 45: 93-134.
- Rathore, P.S. and Maliwal, P.L. 1990. Response of mustard to soil and foliar application of sulphur. **Haryana Journal of Agronomy**, 6(1): 96-97.
- Reeves, D.W. 1994. Cover Crops and Rotations. In: J.L.Hatfield and B.A. Stewart (eds) *Advances in Soil Sciences – Crop Residue Management*. Lewis Publishers, CRC Press, Boca Raton, FL: pp. 125-172.
- Rego, T.J. and Burford, J.R. 1992. Sustaining crop productivity and rainfed Vertisols through grain legumes. In **Agronomy Abstract 1992**. Annual Meetings American Society of Agronomy. P.285. Crop Sci. Soc. Am., Soil Sci. Soc. Am., Clay Minerals Soc., Minneapolis, Minnesota.
- Robinson, C.H., Dighton, J., Frankland, J.C. and Roberts J.D. 1994. Fungal communities on decaying wheat straw of different resource qualities. **Soil Biology and Biochemistry**, 26: 1053-1058.
- Rochette, P. and Gregorich, E.G. 1998. Dynamics of soil microbial biomass C, soluble organic C and CO₂ evolution after three years of manure application. **Can. J. Soil Sci.**, 78: 283-290.
- Roder, W., Mason, S.C., Clegg, M.D., and Kniep. 1989. Yield soil water relationships in sorghum-soybean cropping systems with different fertilizer regimes. **Agron. J.**, 81: 470-475.
- Sabine Houot and Chaussod. 1995. Impact of agricultural practices on the size and activity of the microbial biomass in a long-term field experiment. **Biol. Fertil. Soils**, 19: 309-316.
- Sachan, S.S. and Bhas, S. 1986. Effect of cropping systems, fertility levels and moisture conservation practices on the performance of mustard and safflower under dryland conditions. **Farm Science Journal**, 1 (1-2): 70-76.

- Sadanandan, N. and Mahapatra, I.C. 1973. Studies on multiple cropping – Balance sheet of total and available phosphorus in various cropping patterns. Central Rice Research Institute, Cuttack.
- Sawasha, S.G. and Patil, P.L. 1985. Residual effects of legumes and sorghum on microbial count and yield of wheat. **Journal of Maharashtra Agricultural Universities**, **10**(3): 302-304.
- Sekhon, N.K., Sidhu, A.S. and Sur, H.S. 1992. Physiological response of summer mung (*Vigna radiata* L. Wilczek) to wheat straw management techniques. **Indian Journal of Plant Physiology**, **35**(1): 30-37.
- Sharma, H.L., Modgal, S.C. and Singh, M.P. 1985. Effect of applied organic manure, crop residues and nitrogen in rice-wheat cropping system in North Western Himalayas. **Himachal Journal of Agricultural Research**, **11**(1): 63-68.
- Sharma, H.L., Singh, C.M. and Modgal, S.C. 1987. Use of organic in rice-wheat crop sequence. **Indian Journal of Agricultural Sciences**, **57**(3): 163-168.
- Sharma, M.L., Bharadwaj, G.S. and Chauhan, Y.S. 1992. Studies on mustard based cropping sequences under irrigated conditions of north M.P. **Haryana Journal of Agronomy**, **8**(2): 112-115.
- Sharma, P.K., Verma, T.S. and Bhagat, R.M. 1995. Soil structural improvements with the addition of Lantana camara biomass in rice wheat cropping. **Soil Use and Management**, **11**(4): 199-203.
- Sharma, S.N., Prasad, R. and Singh, S. 1996. Residual effects of growing mung bean and urid bean on the yield and nitrogen uptake of a succeeding wheat crop. **Fertilizer Research**, **44**(3): 163-168.
- Shivaramu, H.S., Shivashankar, K. and Siddaramappa, R. 1994. Organic and lime amendments on physico-chemical and biological properties of soil. **Mysore Journal of Agricultural Sciences**, **28**(1): 39-44.
- Sidhu, A.S. and Sur, R.S. 1993. Effect of incorporation of legume straw on soil properties and crop yield in a maize-wheat sequence. **Tropical Agriculture**, **70**(3): 226-229.
- Sidhu, B.S. and Beri, V. 1989. Effect of crop residue management on the yields of different crops and on soil properties. **Biological Wastes**, **27**(1): 15-27.
- Sidhu, M.S., Sharma, B.M. and Dhillon, N.S. 1992. Prediction of nitrogen requirements of wheat (*Triticum aestivum*) after summer and rainy season fodder crops. **Journal of Research, Punjab Agricultural University**, **29**(4): 431-437.
- Singaram, P. and Kothandaraman, G.V. 1994. Studies on residual, direct and cumulative effect of phosphorus sources on the availability, content and uptake of phosphorus and yield of maize. **Madras Agricultural Journal**, **81**(8): 425-429.

- Singh, A.L., Joshi, Y.C. and Chaudhari, V. 1990. Effect of different sources of iron and sulphur on nutrient concentration and uptake by groundnut. **Fertilizer Research**, **24**(2): 97-103.
- Singh, R.D. and Yadav, U.V. 1986. Transformation of N, P and organic matter during paddy straw decomposition with and without rock phosphate. **Agricultural Wastes**, **18**(3): 247-252.
- Singh, S.P. and Nayyar, V.K. 1993. Effect of volume of soil treated with zinc and its rate on the yield of maize. **Journal of Research, Punjab Agricultural University**, **30**(1/2): 24-26.
- Singh, T., Tewari, K.N. and Pathak, A.N. 1988. Effect of zinc on seed yield and nutrient content of pea (*Pisum sativum* L.). **Indian Journal of Plant Physiology**, **31**(3): 312-315.
- Singh, V.P.N. and Uttam, S.K. 1994. Feasibility of double cropping under rainfed condition of central Uttar Pradesh. **Bhartiya Krishi Anusandhan Patrika**, **9**(1): 49-55.
- Singh, Y., Bijay Singh, Maskina, M.S. and Meelu, O.P. 1988. Effect of organic manures, crop residues and green manure (*Sesbania aculeate*) on nitrogen and phosphorus transformations in a sandy loam at field capacity and under waterlogged conditions. **Biology and Fertility of Soils**, **6**(2): 183-187.
- Sinha, M.N. and Rai, R.K. 1994. Cowpea as green manure for productivity of wheat and oat. **Annals of Agricultural Research**, **15**(1): 95-96.
- Six, J., Elliott, E.T., Paustian, K. and Doran, J.W. 1998. Aggregation and soil organic matter accumulation in cultivated and native grassland soils. **Soil Sci. Soc. Am. J.**, **62**: 1367-1377.
- Smith, J.L. and Paul, E.A. 1990. The significance of soil microbial mass estimations. **Soil Biochem.**, **6**: 35-396.
- Smith, J.L. and Elliott, L.F. 1990. Tillage and residue management effects on soil organic matter dynamics in Semi-arid Regions. **Advances in Soil Science**, **13**: 69-88.
- Soon, Y.K. 1998. Crop residue and fertilizer management effects on some biological and chemical properties of a Dark Grey Solod. **Can. JU. Soil Sci.**, **78**: 707-713.
- ✓ ~~✓~~ Soon, Y.K. 1999. Crop residue and fertilizer management effect on nutrient use and barley production. **Can. J. Soil Sci.**, **79**: 389-394.
- Srinivasan, K., Shantha, R. and Ramasamy, M. 1991. Effect of summer pulses on the growth and productivity of succeeding *kharif* maize. **Indian Journal of Pulses Research**, **4**(1): 51-55.
- ✓ ~~✓~~ Sriramachandrasekharan, M.V., Muthusamy, P. and Ravichandran, M. 1995. Long-term effects of fertilizers on microflora and soil properties in irrigated inceptisol. **Annals of Agriculture Research**, **16**(2): 195-200.

- Srivastava, G.P. and Srivastava, V.C. 1993. Nitrogen economy and productivity of wheat (*Triticum aestivum*) succeeding grain legumes. **Indian Journal of Agricultural Sciences**, **63**(11): 694-698.
- Srivastava, S.C. and Lal, J.P. 1994. Effects of crop growth and soil treatments on microbial C, N, and P in dry tropical arable land. **Biol. Fertil. Soil.**, **17**: 108-114.
- Srivastava, S.C. and Singh, J.S. 1991. Microbial C, N and P in dry tropical forest soils: Effects of alternate land-users and nutrient flux. **Soil Biol. Biochem.**, **23**: 117-124.
- Standley, J., Hunter, H.M., Thomas, G.A., Blight, G.W. and Webb, A.A. 1990. Tillage and crop residue management affect vertisol properties and grain sorghum growth over seven years in the semi-arid sub-tropics. 2. Changes in soil properties. **Soil & Tillage Research**, **18**: 367-388.
- Stanford, G. and English, I. 1949. Use of flame photometer in rapid soil test for K and Ca. **Agrol. J.**, **41**: 446-447.
- Steiner, R.A. 1995. Long-term experiments and their choice for the research study. *Agricultural Sustainability: Economic, Environmental and Statistical Considerations* (V.Barnett, R. Pagne, and R. Steiner, eds.), pp. 15-22. Wiley & Sons, Chichester, England.
- Stott, D.E., Elliott, L.F., Papendick, R.I., and Campbell, G.S. 1986. Low temperature or low water potential effects on the microbial decomposition of wheat residues. **Soil Biol. Biochem.**, **18**: 577-582.
- Subbaiah, B.V. and G.I. Asija. 1956. Rapid procedure for estimation of available nitrogen in soils. **Curr. Sci.**, **25**: 259-260.
- Subbian, P. 1989. Studies on the production potential of high intensity cropping systems under gardenland conditions. Ph.D. thesis submitted to the Tamil Nadu Agricultural University, Coimbatore.
- Subbian, P., Lal, R. and Akala, V. 2000. Long-term effects of cropping systems and fertilizers on soil physical properties. **Journal of Sustainable Agriculture**, **16**(2): 89-100.
- Subbian, P. and Palaniappan, S.P. 1992. Effect of integrated management practices on the yield and economics of crops under high intensity multiple cropping systems. **Indian J. Agron.**, **37**: 1-5.
- Subramanian, K.S. and Kumaraswamy, K. 1989. Effects of continuous cropping and fertilization on chemical properties of soil. **J. Indian Soc. Soil Sci.**, **37**: 171-173.

- Sundara, B. 1993. Nutrient dynamics in sugarcane-based cropping systems in red soils. **Red and Lateric Soils of India Resource Appraisal and Management**: 239-247. NBSS Publication No. 37.
- Sudarsan, S. and Ramaswami, P.P. 1993. Micronutrient nutrition in groundnut-blackgram cropping system. **Fertilizer News**, **38**(2): 51, 53, 55, 57.
- Susanne Aref and Wander, M. 1998. Long-term trends of corn yield and soil organic matter in different crop sequences and soil fertility treatments on the morrow plots. **Advances in Agronomy**, **62**: 153-197.
- Telang, R.S., Lakhdive, B.A. and Tamgade, D.B. 1992. Effect of soil incorporation of sorghum and legume residues on wheat yield and soil properties. **Annals of Plant Physiology** **6**(2): 258-261.
- Thind, S.S., Hundal, H.S. and Vig, A.C. 1993. Phosphate utilization by moong and cowpea under differential P fertility. **Journal of Nuclear Agriculture and Biology**, **22**(2): 89-93.
- Thompson, J.P. 1992. Soil biotic and biochemical factors in a long-term tillage and stubble management experiment on a vertisol. 2. Nitrogen deficiency with zero tillage and stubble retention. **Soil & Tillage Research**, **22**: 339-361.
- Thomsen, I.K. and Jensen, E.S. 1994. Recovery of nitrogen by spring barley following incorporation of ¹⁵N-labelled straw and catch crop material. **Agriculture, Ecosystems and Environment**, **49**: 115-122.
- Tomar, R.K.S., Raghuwanshi, R.S., Pathak, K.N., Tiwari, K.P. and Ali, S.A. 1994. Productivity and profitability of mustard under different cropping sequences of farmers' fields. **Crop Research (Hisar)**, **8**(3): 453-456.
- Tomar, R.K.S., Raghuwanshi, R.S., Tiwari, K.P. and Raghu, J.S. 1993. Production potential and economic returns of chickpea in different cropping sequences on farmers' fields. **International Chickpea Newsletter**, **29**: 32-33.
- Tomar, S.S. and Gautam, D.S. 1992. Study on production potential and economic evaluation of different cropping sequences under northern India. **Bhartiya Krishi Anusandhan Patrika**, **7**(4): 235-242.
- Tripathi, K.P. and Mishra, B. 2000. Kinetics of N mineralization during rice straw decomposition in the soils. **Journal of the Indian Society of Soil Science**, **49**(1): 56-59.
- Turco, R.F., Bischoff, M., Breakwell, D.P. and Griffith, D.R. 1990. Contribution of soil-borne bacteria to the rotation effect in corn. **Plant and Soil**, **122**: 115-120.

- Tyagi, V.V. and Venkatesh Bharadwaj. 1994. Effect of continuous cropping and fertilization on the status of available nitrogen, phosphorus and potassium in a Mollisol. **Journal of Potassium Research**, 10(4): 384-391.
- Unkovich, M.J.U., Pate, J.S. and Sanford, P. 1997. Nitrogen fixation by annual legumes in Australian Mediterranean agriculture. **Aust. J. Agric. Res.**, 48: 267-293.
- Vaidya, V.B., Varshneya, M.C. and Bote, N.L. 1994. Effects of legume cultivation in Kharif season on the yield of subsequent Rabi sorghum. **Journal of Maharashtra Agricultural Universities**, 19(3): 469-470.
- Velayudham, K. and Seth, J. 1987. Effect of plant residue management in kharif on the yield and quality of wheat. **Indian Journal of Agronomy**, 34(4): 341-346.
- Velayutham, M., Pal, D.K. and Bhattacharyya, T. 2000. Organic carbon stock in soils of India. In: Lal, R., Kimble, J.M. and Stewart, B.A. (eds.) Global climate change and tropical ecosystems. **Advances in Soil Science**. CRC Press, Boca Ratan, pp.71-95.
- Venkateswarlu, J. 1987. Cowpea and pearl millet response to organic amendments in semi arid alfisols of Telengana, Andhra Pradesh, India. **Arid Soil Research and Rehabilitation**, 1(1): 47-54.
- Venugopal, N. and Shivashankar, K. 1989. Direct and cumulative effect of maize stover residue incorporation in conjunction with nitrogen on maize. **Indian Journal of Dryland Agricultural Research and Development**, 4(2): 107-116.
- ✓ Verma, T.S. and Bhagat, R.M. 1992. Impact of rice straw management practices on yield, nitrogen uptake and soil properties in a wheat-rice rotation in northern India. **Fertilizer Research**, 33(2): 97-106.
- Viswanathan, J. and Doddamani, V.S. 1994. Forms of phosphorus contributing to the P uptake by maize in Vertisol of Malanrabba Command Area. **Journal of Maharashtra Agricultural Universities**, 19(1): 1-3.
- Vyas, M.D., Rupendra Khandwe and Saran, R.N. 1995. Performance of various cropping systems for production potential and economic feasibility in Vertisol of Vindhyan plateau of Madhya Pradesh under rainfed conditions. **Indian Journal of Agricultural Sciences**, 65(7): 474-477.
- Walia, S.S., Brar, S.S. and Kler, D.S. 1995. Effect of management of crop residues on soil properties in rice-wheat cropping system. **Environment and Ecology**, 13(3): 503-507.

APPENDIX-1

Weather parameters prevailed during the crop growing seasons

Std. Weeks	Temperature (°C)		Relative humidity (%)		Rainfall (mm)	Evaporation (mm)	Sunshine hours
	Max.	Min.	7.22 Hrs	14.22 Hrs			
1. Summer '00 (21.1.2000 - 12.5.2000; Maize)							
3	30.5	18.1	91	39	0.0	4.1	9.2
4	31.6	16.9	90	35	0.0	4.7	9.5
5	31.0	18.3	89	40	0.0	4.4	6.7
6	32.0	21.9	89	48	0.0	3.5	7.4
7	32.2	19.9	88	37	0.0	4.9	9.2
8	32.7	20.9	91	52	0.0	4.0	5.7
9	30.5	19.6	90	45	18.9	3.6	8.0
10	33.4	19.8	86	35	0.0	4.6	9.4
11	35.0	21.9	86	33	0.0	4.9	9.3
12	35.0	21.9	85	33	0.0	6.4	8.4
13	35.3	22.3	87	38	0.0	6.8	7.0
14	34.6	23.1	85	43	2.5	5.5	8.0
15	35.9	22.9	86	44	7.0	6.8	9.5
16	34.6	20.2	87	41	10.4	5.9	8.0
17	35.5	23.7	83	42	0.0	5.8	9.6
18	35.8	23.6	82	44	7.0	7.4	9.8
19	35.4	23.3	82	35	6.5	6.1	8.5
2. Kharif '00 (9.6.2000 - 30.8.2000; Sunflower)							
23	30.5	22.8	74	59	16.4	6.3	2.6
24	32.0	22.9	80	48	3.4	7	4.9
25	32.2	23.1	79	51	2.0	6.7	5.6
26	32.5	22.4	76	50	2.3	6.6	4.5
27	30.5	22.2	78	51	25.0	5.6	2.1
28	30.8	24.2	64	51	12.0	10.1	6.1
29	32.2	22.5	77	47	0.0	7.8	7.5
30	32.8	21.9	88	50	0.0	6.3	7.7
31	32.8	22.6	92	53	41.4	5.6	7.8
32	30.2	22.8	75	55	6.2	6.5	4.5
33	31.6	22.1	88	56	89.0	4.8	5.9
34	28.4	22.8	75	70	22.9	4.9	0.8
35	29.8	21.8	86	54	4.1	5.2	6.3
3. Rabi '00 (22.9.2000 - 11.12.2000; Cowpea)							
38	31.9	22.5	89	60	89.6	3.8	5.2
39	29.6	22.3	92	70	117.2	3.2	4.5
40	29.3	21.4	91	65	10.3	4.5	3.5

- Walkley, A. and Black, J.A. 1934. An estimation of the Degtjareff method for determining soil organic matter and a proposed modification of chromic acid titration method. **Soil Sci.**, **37**: 93-101.
- Wani, S.P., McGill, W.B., Hauugen-Kozyra, K.L. and Juma, N.G. 1994. Increased proportion of active soil N in Breton loam under cropping systems with forages and green manures. **Can. J. Soil Sci.**, **74**: 67-74.
- Wani, S.P., McGill, W.B. and Robertson, J.A. 1991. Soil N dynamics and N yield of barley grown on Breton loam using N from biological fixation or fertilizer. **Biology and Fertility of Soils**, **12**(1): 10-18.
- Wani, S.P., Rego, T.J., Rajeswari, S. and Lee, K.K. 1995. Effect of legume-based cropping system on nitrogen mineralization potential of Vertisol. **Plant and Soil**, **175**(2): 265-274.
- Warkentin, B.P. 1995. The changing concept of soil quality. **J. Soil Water Conserv.**, **50**: 226-228.
- Watts, C.W., Whalley, W.R., Longstaff, D.J., White, R.P., Brooke, P.C. and Whitmore, A.P. 2001. Aggregation of a soil with different cropping histories following the addition of organic materials. **Soil Use and Management**, **17**: 263-268.
- Weigand, Auerswald, K. and Beck, T. 1995. Microbial biomass in agricultural top soils after 6 years of bare fallow. **Biol. Fertil. Soils**, **19**: 129-134.
- Weill, A.N., Mehuys, G.R. and McKyes, E. 1990. Effect of tillage reduction and fertilizer type on soil properties during corn (*Zea mays* L.) production. **Soil & Tillage Research**, **17**: 63-76.
- Wilson, T.C., Paul, E.A. and Harwood, R.R. 2001. Biologically active soil organic matter fraction in sustainable cropping systems. **Applied Soil Ecology**, **16**: 63-76.
- Yadav, D.S. 1990. Studies of nitrogen economy through mung bean and urd bean legumes in legume-cereal (wheat) cropping system. **Legume Research**, **13**(2): 65-68.
- Yadav, D.V., Singh, T. and Srivastava, A.K. 1987. Recycling of nutrients in trash with N for higher cane yield. **Biological Wastes**, **20**(2): 133-141.
- Yadav, R.L. and Verma, R.P. 1995. Crop residue management to conserve soil organic matter content in sugarcane based crop rotations. **Bioresource Technology**, **51**(2-3): 241-245.

Std. Weeks	Temperature (°C)		Relative humidity (%)		Rainfall (mm)	Evaporation (mm)	Sunshine hours
	Max.	Min.	7.22 Hrs	14.22 Hrs			
41	30.9	21.6	90	60	11.3	4.1	5.7
42	31.1	21.7	93	63	10	3.9	4.7
43	31.7	19.4	91	46	5.2	4.5	7.3
44	30.8	21.2	89	54	0.0	3.3	7.0
45	31	21.5	89	48	0.0	4.5	7.9
46	30	21.4	87	49	1.2	4.3	5.7
47	28.2	21.8	93	66	52.1	2.4	3.2
48	29	18.0	92	50	30.2	3.7	6.5
49	28.9	19.1	88	50	0.0	3.5	7.8
50	28.5	15.2	88	35	0.0	4.2	10.5
4. Summer '01 (22.12.2000 - 10.4.2001; Maize)							
51	27.4	19.9	88	41	0.0	4.2	8.8
52	28	20.6	87	53	14.4	5.3	5.3
1	29.3	19.9	91	48	0.0	3.7	6.3
2	29.7	19.1	88	43	0.0	4.3	7.4
3	30.1	17.0	90	40	0.0	4.5	7.9
4	31.7	21.0	81	44	0.0	4.8	5.0
5	29.7	20.0	86	50	0.0	3.7	3.0
6	29.8	21.0	84	32	0.0	4.6	9.1
7	32.2	20.2	88	33	0.0	6.1	9.1
8	33.2	17.6	87	37	0.0	6.3	9.0
9	34.6	19.0	87	33	0.0	7.1	9.6
10	35.1	19.4	74	34	0.0	5.9	7.7
11	35.3	21.7	78	33	0.0	6.5	9.1
12	34.6	22.1	84	38	0.0	6.9	8.4
13	35.3	24.0	83	38	0.0	7.8	8.7
14	35.5	23.3	79	36	0.0	6.4	7.2
15	36.1	24.2	88	50	77.7	5.5	5.8
5. Kharif '01 (8.6.2001 - 5.9.2001; Sunflower)							
23	30.5	23.0	80	53	2.5	7.2	4.6
24	29	22.5	80	63	34.1	5.6	2.7
25	31.2	23.3	72	48	0.5	7.3	7.2
26	32.6	23.2	73	45	0.0	8	5.1
27	31.1	23.9	69	52	4.4	9.5	4.8
28	30.4	22.7	81	56	5.5	6.2	4.3
29	31.6	22.1	81	51	0.5	5.8	6.9
30	31.5	21.3	87	55	9.5	6.1	6.7
31	28.7	22.0	85	67	11.5	3.4	2.2

Std. Weeks	Temperature (°C)		Relative humidity (%)		Rainfall (mm)	Evaporation (mm)	Sunshine hours
	Max.	Min.	7.22 Hrs	14.22 Hrs			
32	31.9	22.1	85	50	0.0	6.9	7.3
33	32.2	23.0	81	49	0.7	7.2	6.1
34	32.1	22.2	85	51	4.0	6.4	6.0
35	32.2	21.3	90	49	10.6	5.8	7.1
36	33.5	21.2	86	44	0.0	5.8	10.1
Rabi '01 (11.9.2001 - 30.11.2001; Cowpea)							
37	33.6	22.9	90	49	48.6	3.9	7.1
38	32.9	23.2	87	50	6.5	4.2	5.4
39	30.9	22.2	92	59	41.5	5.3	4.1
40	31.1	22.4	87	58	2.0	4.5	4.7
41	31.4	22.7	88	61	0.0	4.8	4.8
42	31.7	21.7	93	60	152.3	4.3	6.3
43	30.3	19.3	92	63	130.4	3.5	5.4
44	30.3	21.7	91	60	17.6	4.3	6.3
45	30.4	22.2	93	66	30.9	4	5.3
46	29.6	22.1	91	71	48.5	3.5	4.7
47	28.3	20.9	92	65	34.1	3.8	7.6
48	28.7	20.9	91	56	8.3	3.3	6.9
mer '02 (21.12.2001 - 12.4.2002; Maize)							
51	27.4	19.9	90	70	14.3	2.8	2.0
52	28	20.6	90	57	0.5	3.1	6.0
1	29.3	19.9	86	50	0.0	4.4	7.6
2	29.7	19.1	88	45	0.0	3.5	8.3
3	30.1	17.0	90	49	0.0	3.7	9.1
4	31.7	21.0	89	54	0.0	3.7	4.4
5	29.7	20.0	87	56	0.0	3.5	3.8
6	29.8	21.0	86	53	0.0	3.5	4.6
7	32.2	20.2	87	35	0.0	5	9.0
8	33.2	17.6	84	21	0.0	6.7	10.2
9	34.6	19.00	82	27	0.0	7	10.3
0	35.1	19.4	78	23	0.0	7.8	10.6
1	35.3	21.7	84	34	28	7.1	9.5
2	34.6	22.1	88	42	4.0	6.8	8.7
3	35.3	24.0	86	42	37.2	6.6	8.4
4	35.5	23.3	83	42	1.5	6.1	9.2
5	36.1	24.2	78	36	1.5	6.5	9.2