



ज्यांनी तळहाताचा पाळणा आणि नेत्रांचा दिवा केला.
त्या माझ्या माता-पितांच्या आशिर्वादाने,
अर्धांगिनीच्या अलोट प्रेम व सहकायाने,
गुरूजनांच्या मार्गदर्शनाने फलस्वरूपास आलेला
सरस्वती मातेच्या मंदीरातील अंतीम कक्षीचा हा प्रबंध.

॥ आई बुळगाभवाणी आणि श्री स्वामी समर्थान्विता
दृश्या विनम्रपणे समर्पित ॥

INTEGRATED NUTRIENT MANAGEMENT IN SUGARCANE GROWN ON SALINE SODIC SOIL

A Thesis submitted to the
MAHATMA PHULE KRISHI VIDYAPEETH,
RAHURI - 413 722, DIST. AHMEDNAGAR
MAHARASHTRA, INDIA

C 821

in partial fulfilment of the requirements for the degree

of

DOCTOR OF PHILOSOPHY (AGRICULTURE)

in

SOIL SCIENCE

by

Pramod Bhimrao Jagtap

(Reg.No. 99010)

DEPARTMENT OF AGRICULTURAL CHEMISTRY
AND SOIL SCIENCE

**POST GRADUATE INSTITUTE
MAHATMA PHULE KRISHI VIDYAPEETH,
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**DEPARTMENT OF AGRICULTURAL CHEMISTRY AND
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RAHURI - 413 722, DIST. AHMEDNAGAR,
MAHARASHTRA, INDIA**

2002

CANDIDATE'S DECLARATION

*I hereby declare that this thesis or part
there of has not been submitted
by me or other person to any
other University or Institute
for a Degree or
Diploma*

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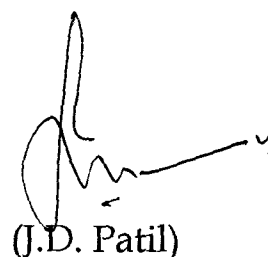
CERTIFICATE

This is to certify that the thesis entitled, "**INTEGRATED NUTRIENT MANAGEMENT IN SUGARCANE GROWN ON SALINE SODIC SOIL**", submitted to the Mahatma Phule Krishi Vidyapeeth, Rahuri for the award of the degree of **DOCTOR OF PHILOSOPHY (AGRICULTURE) in SOIL SCIENCE**, embodies the results of a *bona fide* research carried out by **Mr. PRAMOD BHIMRAO JAGTAP** under my guidance and supervision and that no part of the thesis has been submitted for any other Degree or Diploma.

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

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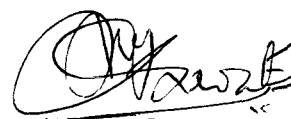
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ACKNOWLEDGEMENTS

Mahatma Phule Krishi Vidyapeeth, Rahuri is the land of meditation where the Gangaes river of knowledge flows and where many stalwart, versatile scientists monks preach the disciples. One such amongst those is my research guide my Guru Dr. J.D. Patil Sir, Head, Department of Agricultural Chemistry and Soil Science, Mahatma Phule Krishi Vidyapeeth, Rahuri who with his hard-gained treasure of knowledge and scholastic expertise and efficient power to transform one into a scientist philosopher guided me for my Ph.D. research work. Its with his generous whole hearted guidance, that I learnt not only science and technology, but much more to be perfectly humane. Hence, its beyond my capacity to express my indebtedness to him.

On the path of search for knowledge, one needs the complementary guidance and this task was performed by the members of my advisory committee Dr. A.S. Patil, Soil Chemist, STCR Project, Dr. A.D. Kadlag and Dr. Y.M. Patil, Asstt. Professor to whom I express my deepest sense of gratitude for their valuable suggestions and guidance during the tenure of my Ph.D. studies.

Supporting encouragement and guidance always has to be appreciated and I sincerely acknowledge the same received from Dr. R.N. Adsule, Professor, Agricultural Chemistry and Soil Science, Dr. A.L. Pharande, Dr. V.M. Amrutsagar, Associate Professor, Dr. V.K. Kharche, Analytical Chemist, Micronutrient Research Project, Dr. V.S. Pawar, Chief Scientist, Dr. K.M. Pol, Associate Professor, Plant Physiology for their constant encouragement and inspiration during my research work.

The blessings and valuable help received from staff of the 'Sugarcane Pandhari' the CSRS, Padegaon amongst whom are Prof. A.M. Pawar, the then Sugarcane Specialist, Dr. M.B. Jadhav, Soil Physicist, Dr. R.Y. Jadhav, the then Asstt. Cotton Breeder, Dr. R.M. Naik, Biochemistry, Dr. B.S. Kadam, Senior Research Assistant, Dr. D.B. Shinde, Asstt. Professor, A.C. Pune, Dr. S.M. Pawar, Sugarcane Physiologist and all other staff therefrom, Dr. A.R. Bangar, ADR, Solapur, Dr. A.N. Deshpande, Soil Physicist, DLA, Solapur. I acknowledge this with sincere thanks.

What is appropriately coined as the "life line" or the friends indeed in need", I am fortunate enough to have such a company of colleagues who always genuinely pushed me ahead on the path of progress to whom I owe a great deal of thanks include Dr. Anil Nimbalkar, Pediatricion, Shri. Datta Chavan (Aaba), Director, Someshwar, SSK and member, Hon, Pune Z.P., Shri. Dilip Pharande (Dada), Chairman, Samata

Patsanstha, Nira, Shri. Ashok Mane, Shri. Shrinivas Prabhune, Shri. Prakash Narute, Mohan Mane, Pravin Mane, Maruti Wabale and all others.

Unforgettably, I must keep on my record of sincere thanks the well wishes and encouragement received from Prof. S.P. Surve, Prof. H.L. Ghadge, Shri. Nitin Konde, Shri. Satish Jadhav and Shri. Pankaj Patil.

My research task would not have been superfine and superfinshed without the assistance and co-operation extended by Dr. Popat Kadu, Dr. Anil Durgude, Shri. Vikrant Bhalerao, Shri. Girish Ahire, Shri. Sonawane, Shri. Jagdhani, Shri. Game, Shri. Dhamale, Shri. Pendharkar, Shri. Yadav, Shri. Buchude, Shri. Dhonde, Shri. Pawar, Shri. Chaudhari to whom I whole heartedly thank.

The greatness of parents to their offsprings is obscure even for the God and Godesses and so is for me too to express my overwhelming feelings for their all kinds of sacrifices and blessings conferred upon me by revered Appa and Aai and its lifelong idebtedness to them for which not to thank but to serve them devotedly is the only way. I am equally thankful and indebted to my father in-law, Dada, mother in-law, Mami, brother, Praphulla, Pradip, sister Pratibha, Sou. Seema vahini, Rajendra and Sanjay brother in laws for their constant and instant loving support and encouragement.

I also thank to Shri. Viswhanath Z. Kadam 'Suyog Computers' who helped and extended co-operation for neat typing of the present manuscript within the time.

Last but not the least and who is my life-long partner in all my happiness and misery all alike, my beloved wife Mrs. Pradnya who all the while stood beside me to make my progress path tolerable and pleasant. It is my privilege to thank her and equally to my sweet kids, son master Pranav and daughter Pravita, which is the very vital fragrance of our eternal life.

Place : M.P.K.V., Rahuri


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Dated : 2 / 5 / 2002

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ABBREVIATIONS

$^{\circ}\text{C}$	: Degree celsius
Ca	: Calcium
CD	: Critical difference
CEC	: Cation exchange capacity
Cl	: Chloride
cm	: Centimetre
dSm^{-1}	: Desisiemens per meter
DTPA	: Diethylene triamine pentaacetic acid
EC	: Electrical conductivity
ECe	: Electrical conductivity of saturation extract
ESP	: Exchangeable sodium percentage
et al.	: And others
Fe	: iron
Fig.	: Figure
FYM	: Farm yard manure
g pot^{-1}	: Gram per pot
g	: Gram
ha	: Hectare
INM	: Integrated nutrient management
K	: Potassium
kg	: Kilogram
L	: Litre

m	: Meter
me L ⁻¹	: Miliequivalent per litre
mg kg ⁻¹	: Milligram per kilogram
mg pot ⁻¹	: Milligram per pot
Mg	: Magnesium
Mn	: Manganese
MOP	: Muriate of potash
N	: Nitrogen
Na	: Sodium
NH ₄ -N	: Ammonical nitrogen
NO ₃ -N	: Nitrate nitrogen
NS	: Non-significant
P	: Phosphorus
pHe	: pH of saturation extract
RDF	: Recommended dose of fertilizers
RSC	: Residual sodium carbonate
S.E.	: Standard error
SAR	: Sodium adsorption ratio
SSP	: Single superphosphate
Zn	: Zinc
%	: Per cent

ABSTRACT

XIX

INTEGRATED NUTRIENT MANAGEMENT IN SUGARCANE GROWN ON SALINE SODIC SOIL

By

Pramod Bhimrao Jagtap

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Rahuri - 413 722

2002

Research Guide : Dr. J.D. Patil

Department : Agril. Chemistry and Soil Science

The periodical release of nutrients in saline sodic soil under integrated nutrient management was studied in incubation studies at ambient conditions in the laboratory. The pot culture experiment with sugarcane crop was conducted during 2000-2001 in wire house at Department of Agril. Chemistry and Soil Science, M.P.K.V., Rahuri in factorial completely randomised block design with three replications. The soil used for incubation and pot culture experiment was of Sawargaon soil series (*Vertic Ustrophepts*). There were four sets of incubation tried for nutrient release pattern studies in saline sodic soil.

The conjoint use of urea, FYM and *Azotobacter* was effective in lowering the soil pH. The ammonical nitrogen was increased up to 20 days of an incubation. The nitrate nitrogen, available phosphorus, DTPA Fe and Zn were increased with progress of time during incubation period.

The conjoint use of single superphosphate, FYM and phosphate solubilizers was helpful to reduce the soil pH, increased the

ammonical and nitrate nitrogen and DTPA-Zn and Fe in saline sodic soil. The release of phosphorus in saline sodic soil was more by the use of FYM and phosphate solubilizers.

The combined application of FeSO_4 , ZnSO_4 and FYM decreased the soil pH and increased the electrical conductivity. The phosphorus availability in saline sodic soil was increased by micronutrient application along with FYM and *Thiobacillus ferrooxidans*. Ammonical and nitrate nitrogen and DTPA-Zn and Fe were increased significantly.

The integrated nutrient management in saline sodic soil as urea, single superphosphate, $\text{FeSO}_4 + \text{ZnSO}_4$, FYM and biofertilizers (*Azotobacter*, phosphate solubilizers and *Thiobacillus ferrooxidans*) significantly decreased the soil pH, increased electrical conductivity, available phosphorus and DTPA-Zn and Fe. This integration increased the ammonical nitrogen upto 20 days and nitrate nitrogen after 30 days of incubation.

The integrated use of urea, single superphosphate, micronutrient (ZnSO_4 and FeSO_4) and biofertilizers was beneficial for shoot and root dry matter in saline sodic soil. It was also significant for increasing the uptake of nitrogen, phosphorus, potassium, iron and zinc by sugarcane in saline sodic soil. The conjoint use of organic and inorganic fertilizers enhanced the nutrient use efficiency in saline sodic soil.

Chapter Opener Page

INTRODUCTION

1. INTRODUCTION

The problem of salinity and alkalinity is one of the most important soil conditions which may turn an otherwise fertile land into a very low productive or barren land. The problem was initially and inherently limited to arid and semiarid climates and also to sea coast and delta region of many countries of the world including India. But due to the advent of irrigation projects coupled with faulty water management, blocking of natural drainage systems, over lifting of under ground water and many other anthropic activities accentuated the salinity and alkalinity problem. As a result, many fertile lands are gradually turning into unproductive or low productive lands.

The introduction of canal irrigation and seepage resulted in rise of water table to the crucial 1 to 1.5 meters depth on large areas. Every rise of water table is accompanied by an increase in the mineralization and dissolution of salts from the upper salt rich horizons which are ultimately drawn upto the surface by evaporation. Under perennial irrigation some soils developed salt problems according to the nature and concentration of various salts particularly the chlorides, sulfates and bicarbonates of sodium. The black clayey soils are being deteriorated at a very fast rate. The introduction of irrigation canals soon thereafter the salt problem began to loom prominently. The adverse effects being suppressed

initially by the large amount of manures, fertilizers and irrigation water. Chemical deterioration is the deterioration of land through development of salinity and alkalinity which are mainly restricted to the command areas under major and minor irrigation projects, where water is used indiscriminately for irrigation during cultivation of crops throughout the year either through canal or lift irrigation systems. Varade *et al.* (1985) reported that approximately 10 per cent of the irrigable vertisols area in each irrigation project of Maharashtra is adversely affected due to the salts and water lodging problem.

According to some world estimate India shares about 23.8 M ha of salt affected soils (23.2 M ha saline and 0.6 M ha alkali soil) out of 950 M ha of salt affected soils (Bandopadhyay *et al.*, 2000). India has about 12.0 M ha salt affected soils (Sharma and Gupta, 1986). Among the different categories of salt affected soils in India, the vertisols region is one of the important groups which comprises another important groups where secondary salinization has claimed large areas in Western and Southern India. In Maharashtra about 0.54 M ha of black soils were initially reported to be salt affected (Abhange *et al.*, 1986) which have been increased to 1.06 M ha i.e. 3.4 per cent of the total geographical area (Gaikwad and Challa, 1996).

The problematic soils are either deficient in their nutrient status or the nutrient availability is inhibited by the antagonistic effect of the nutrient element present in excessive amount as soluble or exchangeable ions or both. The production potential of a particular

crop can be better achieved if the nutrients essential for the physiological and metabolic activities of the plant are made available to them through application of fertilizers in proper form and required amount. The availability and uptake of nutrients and water to crop plants are becoming constraints due to excess cations/anions (salts) in root zone under saline and alkali conditions of soil. The rhizosphere environment becomes unfavourable and inhospitable for healthy growth of plants although there may be sufficient amounts of water and nutrients in saline sodic soils, are different from those of normal soils and their management needs special attentions.

The salt affected soils are generally poor in fertility. They are deficient in nitrogen and organic carbon. The availability and supply of phosphorus, manganese, copper, zinc and iron are the major constraints in plant nutrition (Biswas *et al.*, 1985). Yeresheemi *et al.* (1989) studied the macro and micronutrient status of some salt affected vertisols of upper Krishna command and reported low available N (46 to 162 kg ha⁻¹), low to medium phosphorus (2 to 13 kg ha⁻¹) and adequate potassium (161 to 454 kg ha⁻¹). Among the micronutrients cations Cu, Mn, Fe were adequate while the soils were deficient in zinc supply.

The soil salinity adversely affect many micro-organisms as is the case with plant growth. It is evident that the soils do not become productive immediately after the removal of alkali but

gradually as the favourable microorganisms were given time to multiply.

The basic problems of fertilizer use in salt affected soils arise due to the interactive effects of salts of exchangeable sodium with fertilizer nutrients which are mainly governed by the various factors which includes nature and degree of salinity and sodicity. Chemical reactivity and solubility of added fertilizers, nutrient requirement of the crop, their availability in the soil and tolerance behaviour of the crop.

Majority of the salt affected soils of India fall in the reclaimable category. The methods of reclamation may however, vary and may often be location specific depending upon the soil characteristics, climatic conditions and resource availability with the cultivators. Complete reclamation of alkali soils is generally a capital intensive proposition and often availability of appropriate outlets for disposal of the drain water and inadequacy of regional drainage system pose serious problems.

The adverse effects of salts on crop growth can be mitigated to some extent by adopting a package of soil management practices which could minimize the sodium and salinity hazards in soil during the crop growth and safe-guard the soil from further deterioration.

To mitigate the adverse effect of excessive salts or exchangeable sodium there is a need to increase the fertility status of

these salts affected soils through judicious use of fertilizers. The quantities of fertilizers to be applied could correctly be assessed based on nutrient supplying power of the soil and nutrient requirement of the crop to be grown.

Sugarcane (*Saccharum officinarum* L.) is grown under diverse socioeconomic situations in India. It covers nearly 4 million hectares of land to the extent of 2.2 per cent of the total gross cropped in area. It is an important cash crop of India in general and Maharashtra particular and occupies pivotal position in the agricultural economy of the country for it sustains the second largest agro-industry, next only to the textile industry. The maximum sugarcane production in India, has been achieved 282 million tonnes during 1995-96 on 4.14 million hectares area. The sugar production obtained was 16.45 million tonnes. The corresponding figures for Maharashtra state were 46.66 million tonnes of cane production and 5.39 million tonnes of sugar production on 0.58 million hectares of area under cultivation.

The average cane yield of Maharashtra during 1999-2000 was 89.81 t ha⁻¹ against 70.8 t ha⁻¹ for India with per cent recovery of 11.50 and 10.20 respectively indicating that Maharashtra is one of the important states in India in respect of cane yield and recovery (Anonymous, 2000 and 2001).

The National Commission on Agriculture estimated the expected population of India by 2010 A.D. will be 1160 million. They

will require 27.2 million tonnes of sugar and 14.6 million tonnes of Jaggery and Khandsari. To meet this requirement it is estimated that 383 million tonnes of sugarcane with its 65 per cent of drawal for crushing in sugar factories having 10.75 per cent sugar recovery will be required by the sugar industry (Yadav, 2000).

Sugarcane responds well to better management practices. Hence, better agrotechniques such as use of high yielding and fertilizer responsive varieties, judicious irrigation management and adequate supply of nutrients, proper mode of application of different types and forms of fertilizers need to be developed. In Maharashtra, however, the major area affected due to salinity and/or alkalinity fall in sugarcane growing tract. The problem of declined cane yield in the state during last two decades is always ascribed to saline sodic soils. Being an important cash crop the farmers in this area will continue to grow sugarcane even in salt affected soils. Under such circumstances integrated nutrient management of sugarcane crop will be the only alternative for sugarcane growers which will help in sustaining the sugarcane productivity.

Fertilizers are powerful crop management tools and can make effective contribution to crop production provided all other production factors are in reasonable balance and receive appropriate attention. Over the past 100 years, the yield of crops in the highly developed agricultural system have shown more than 60 per cent increase due to the use of mineral fertilizers. The efficient use of

fertilizers has proved highly advantageous to the economy of the various countries as well as to individual farmers. Thus, fertilization is one of the most important components of crop management that materially affect cane and sugar yields. The extensive and intensive use of fertilizers in judicious manner is one of the surest ways for increasing the cane production.

Looking to the fertility status of saline alkali soils there is a need for identification of viable cost effective and efficient integrated nutrient management technology involving farm wastes, biofertilizers and mineral fertilizers to sustain high productivity of crops and soils on a long term basis for sugarcane.

Keeping this in view the investigation was carried out to study the integrated nutrient management of sugarcane grown on saline sodic soil with the following objectives.

- i. To study the release pattern of nitrogen, phosphorus, zinc and iron in saline sodic soils.
- ii. To study the interaction of N, P, Zn and Fe in saline sodic soil.
- iii. To assess the efficiency of applied inorganic fertilizers in conjunction with organics.
- iv. To study the effect of organic and inorganic fertilizers on growth and dry matter yield of sugarcane at earthing up and
- v. To study the uptake of nutrients by sugarcane.

Chapter Opener Page

REVIEW OF LITERATURE

2. REVIEW OF LITERATURE

The soils cultivated intensively for short and long duration crops in command areas of Western Maharashtra are dwindling in their productivity. The situation was much more aggravated in last 2-3 decades. The aggravation of constraints in fertility and productivity of soil either by improper crop management, excessive use of irrigation water, nutrient imbalance, use of only inorganic fertilizers, no consideration for organics or an inherent soil properties was attended. As a results such soils either became sick or problematic. With a view of these consideration efforts are made in this chapter to review the work done in the past.

2.1 Nutrient status

The plant growth depression on salt affected soils is due to high osmotic pressure, nutrient imbalance and presence of some ions in toxic quantities. Salt affected soils pose a serious problems in many parts of the country. Therefore, proper nutrient management in these soils is necessary for higher production and productivity (Biswas *et al.*, 1985).

The high soil pH and high levels of exchangeable sodium significantly alter the nutrient management of alkali soils by enhancing the solubility of phosphorus compounds, higher losses of applied nitrogen fertilizers and reduced availability of certain micronutrients (Abrol, 1990).

2.1.1 Nitrogen

Nitrogen is mostly deficient in salt affected soils. The extent of loss of applied nitrogen could be as high as 87 per cent in an upland berbor soil (pH 10.5) of North Sudan (Jewitt, 1942). The reduced hydrolysis of urea in sodic soils can be attributed to the possible effect of high pH on the activity of enzyme urease or the direct effect of carbonate ions on the forward reaction resulting in the formation of ammonium carbonate (Chapman and Liebig, 1952 and Williamson and Willey, 1964). The high soil pH affected the enzymatic activity of *Nitrosomonas* spp. oxidizing ammonia to nitrate to a lesser extent than that of *Nitrobacter* spp. carrying out oxidation to nitrite to a lesser extent than that of *Nitrobacter* spp. carrying out oxidation to nitrite to nitrate. As a result phytotoxic accumulation of nitrite was often observed in high pH soils (Martin *et al.*, 1942; Chapman and Liebig, 1952 and Williamson and Willey, 1964). The reduced availability of nitrogen in soil is associated with low mineralization and enhanced volatilization of nitrogen with an increased salinity and sodicity (Patric and Wyatt, 1964).

The higher concentration of calcium carbonate was found beneficial for nitrogen fixation with alkali salts whereas, other salts were proved to toxic beyond certain limit (Pathak and Tripathi, 1964). Fenn and Kissel (1973) observed that in normal soils loss of ammonia through volatilization was in significant but the magnitude of such losses increased directly with increasing soil reaction.

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The organic matter and nitrogen content of salt affected soil was generally found in deficient quantity. These deficiencies were associated with low vegetative growth and less root biomass in soil (Agarwal and Gupta, 1968). Baligar and Patil (1968) studied volatile losses of ammonia as influenced by rate and methods of urea application to soils. They reported that the urea on application to soils was converted to ammonia. The portion of ammonia thus, formed is likely to be lost due to volatilization depending upon the factors such as texture, pH, moisture content of soil, the placement and its method and quantity of fertilizer applied. The negative correlation with soil pH and available nitrogen was reported by Sharma *et al.* (1969) in alkali soils with soil organic matter.

The increased pH and soil salinity adversely influenced the nitrification process (Nitant, 1974, Bandopadhyay and Bandopadhyay, 1983). The hydrolysis of urea was inhibited in presence of excess salts and high pH of the soils. Nitrite accumulation and its persistence for longer period had been observed in sodic soils (Nitant and Bhumbra, 1974).

The dynamics of fertilizer nitrogen in Indian soils showed that the hydrolysis of urea fertilizer to ammonium form is completed within 1-3 weeks. The application of urea in higher doses retards their transformation. The urea nitrogen content in soil to the extent of 200-800 mg kg⁻¹ enhanced the transformation in laterite soils followed by red and alkaline black soils of Karnataka state. Whereas, the

nitrification process was faster in sodic soils as compared to non-sodic soils of Karnataka (Tandon, 1974). The nitrogen losses amongst the various sources were in the order of urea $\text{CO}(\text{NH}_2)_2$ > ammonium sulphate $[(\text{NH}_4)_2\text{SO}_4]$ > ammonium nitrate (NH_4NO_3) > calcium nitrate (CaNO_3) under saline sodic conditions (Gandhi and Paliwal, 1975). Basdeo and Gangwar (1976) conducted studies on losses of ammonia by volatilization from nitrogenous fertilizers applied to soils and reported that volatilization losses of ammonia were found to increase with the increased levels of fertilizer application, temperature and soil pH but decreased with the depth of placement. Among the N carriers the nitrogen loss was maximum with urea followed by ammonium sulphate and ammonium nitrate, respectively.

Gandhi and Paliwal (1976) studied the mineralization and gaseous losses of nitrogen from urea and ammonium sulphate in salt affected soils. They observed that the mineralization of nitrogen was increased with time and decreased with the increase of salinity. It was more in ammonium sulphate than urea. The gaseous losses of $\text{NH}_4\text{-N}$ were increased with the salinity. Salinity and pH both were negatively correlated with the N-mineralization and positively with the gaseous losses of ammonia in salt affected soils. The excessive accumulation of $\text{NO}_2\text{-N}$ in saline, saline sodic and sodic soils may be due to the reduced activity of *Nitrobacter* (Sharma and Chauhan, 1994).

Sahrawat (1979) reviewed the nitrogen losses in rice soils. He observed that a part of NH_4^+ or NH_4^+ forming fertilizers could be lost through volatilization from a soil water system if the pH of soil or flood water is high. Fertilizers like urea can provide their own alkalinity for this mechanism of loss due to its hydrolysis to $(\text{NH}_4)_2\text{CO}_3$ by soil urease activity. He further, reported that the potential of loss due to ammonia volatilization will be significant if the pH of the system is higher than 7.0 and may be considerable if the pH is above 8.0. The loss of applied nitrogen may range between 30 and 65 per cent depending on the level of applied nitrogen and the prevalent soil moisture of alkali soils (Bhardwaj and Abrol, 1978; Rao and Batra, 1983). Fenn and Hosnner (1985) studied the ammonia volatilization from ammonium or ammonium forming nitrogenous fertilizers. He reported that an alkaline environment will occur if the soils are calcareous and/or contain a certain degree of saturation. The N fertilizer that react with CaCO_3 like $(\text{NH}_4)_2\text{HPO}_4$ will create additional alkalinity thereby increasing and intensifying NH_3 losses.

Singh and Bajwa (1986) studied urea hydrolysis in salt affected soils. Urea hydrolysis was considerably delayed with increase in soil pH. The time required for complete hydrolysis to occur varied from 3 to 14 days.

Vinod Kumar *et al.* (1988) studied the effects of urea rates, farmyard manure, CaCO_3 , salinity and alkalinity levels on urea hydrolysis and nitrification in soils. They reported that the hydrolysis

rate of urea was not proportional to the amount of urea added. The inhibition of urea hydrolysis was associated with increased levels of soil CaCO_3 , pH and EC. The NH_4^+ concentration increased upto 6 days and then decreased upto 24 days with a corresponding increasing NO_3^- concentration. However, accumulation of NO_2^- continued upto 24 days at higher CaCO_3 , EC and pH levels. The rate of nitrification was decreased with increased levels of urea. However, it was fast in the presence of farm yard manure and slower at the higher CaCO_3 , pH and EC levels.

When urea was applied to moist soil, it hydrolysed to ammonical-N ($\text{NH}_4\text{-N}$) which was oxidised to nitrite-N ($\text{NO}_2\text{-N}$) and later to nitrate-N ($\text{NO}_3\text{-N}$). pH of the soil solution in the vicinity of urea prills was about 8 and in soils having pH 7 or above, a part of the ammonium loss by ammonia volatilization and loss was more when urea was broadcasted on the soil surface (Prasad *et al.*, 1990).

The application of urea phosphate to calcareous and alkaline soils reduced the volatilization losses of nitrogen by forming the orthophosphoric acid on dissolution with irrigation water. Similarly, orthophosphoric acid also retards the urea hydrolysis which leads to delayed dissolution of urea (Abdul Mehdi *et al.*, 1991).

The recovery of added nitrogen fertilizers in salt affected soils was low. The lowest recovery of nitrogen fertilizers might be due to higher rate of loss in initial stage (Patra *et al.*, 1992). Sahrawat (1992) studied the transformation of surface applied urea in three

soils of varying pH. The net changes in the content of urea-N, NH_4^+ -N and NO_3^- -N indicated that the hydrolysis of urea was complete in one day in the vertisol (pH 8.35) by two days in the alfisols (pH 6.20).

Sharma *et al.* (1992) reviewed the work on nutrient transformation in soil due to addition of organic manure and growing crops. They reported that bio-slurry which was the product obtained from anaerobically digested (methanised) farm yard manure (FYM), an efficient source of organic manure with capability to supply nutrients particularly organic N fractions as affected by application of bio-slurry and fertilizer N in a maize (*Zea mays*) mustard (*Brassica campestris*) crop sequence. The application of bio-slurry increased the nitrogen content of soil in the form of NO_3^- , NH_4^+ , hexosamine-N, hydrolyzable- NH_4^+ and total hydrolyzable nitrogen irrespective of addition of inorganic fertilizers.

Singh and Prasad (1992) conducted an experiment to study the volatilization loss of ammonia as influenced by integrated nutrient management in calcareous soils. They observed that the cumulative volatilization loss of ammonia was decreased with increase in soil water content and addition of organic matter. Whereas, it was increased with application of blue green algae and higher rate of nitrogen application. The degree of cumulative volatilization losses of NH_3 was in the order of control > blue green algae > farm yard manure > blue green algae + FYM. The peaks of

ammonia volatilization were the highest at the 12th day, thereafter, these declined and become zero after the 15th day. The magnitude of nitrogen loss was increased with increased soil reaction, temperature and concentration of applied ammonium salt. Whereas, presence of sufficient moisture, organic matter and placement of fertilizer below the surface minimized the nitrogen losses (Somani and Totawat, 1993).

Lal *et al.* (1993) reported that the saline soils contain more microorganisms which were antagonistic to *Azotobacter* as results the addition of atmospheric nitrogen was less which leads to low nitrogen fertility in soil. The percentage of anti *Azotobacter* activity microorganisms increased with increasing salinity thereby decreasing the atmospheric nitrogen fixation in these soils. The rate of nitrification was also low in such soils.

Sharma and Chauhan (1994) studied urea transformation in saline and sodic soils of semi-arid region of Agra. They found that the increasing levels of nitrogen gradually enhanced the $\text{NH}_4^+\text{-N}$ content in soil over control. The effects of sodicity were more prominent in the retardation of urea hydrolysis than that of salinity. Saline sodic soil showed the highest $\text{NO}_2\text{-N}$ content. The concentration of $\text{NO}_3\text{-N}$ increased upto 28 days of incubation and it was decreased thereafter. The salt affected soils were deficient in nitrogen content (Somani and Totawat, 1993).

Patra *et al.* (1996) studied the nitrogen transformation in salt affected soils. They studied the nitrogen transformation in normal, saline, saline sodic and sodic soils and concluded that the salinity and sodicity together had an additive adverse effect on N-transformation and recovery in soil. Both ammonification and nitrification processes were significantly low in saline sodic soil as compared to normal, saline and sodic soils. Dinesh and Dubey (1999) studied the nitrogen mineralization rates and kinetics in soils amended with organic manures. They concluded that net N mineralization was significantly higher in soils amended with organic manures compared to the unamended control.

Dinesh Kumar *et al.* (2000) reported that the urea was hydrolysed enzymatically by soil urease with the formation of ammonium and rise in soil pH. The increase in soil pH lead to several problems like damage to germinating seeds and young plants, nitrite toxicity and volatilization of urea-N as ammonia. These problems were accentuated in alkali soils when the high soil pH can induce appreciable ammonia volatilization losses. The soil type, organic matter, pH, salinity and alkalinity, CaCO_3 , amount of added nitrogen, heavy metals and some organic compounds have been reported to affect the hydrolysis of urea in soils.

Singh and Ram (2000) studied the effects of organic sources on NH_4^+ -N and NO_3^- -N dynamics in calcareous salt affected soils. They reported that most of urea-N added to soil was converted

to available form as $\text{NH}_4^+\text{-N}$ and $\text{NO}_3^-\text{-N}$ in consecutive three days from the time of application. Traceable amount of $\text{NH}_4^+\text{-N}$ and $\text{NO}_3^-\text{-N}$ released from urea was identified even after 14 days. However, poultry manure showed maximum mineralization of organic nitrogen for longer times and lowest from compost. The conjoint use of urea and poultry manure release maximum amount of $\text{NH}_4^+\text{-N}$ and $\text{NO}_3^-\text{-N}$ to soil. Yaduvanshi (2001) conducted a field experiment to study the volatilization losses of nitrogen from integrated nutrient management of rice field of alkali soils of Karnal. The volatilization loss was decreased significantly by conjoint use of urea with FYM or green manuring as compare to urea alone.

2.1.2 Phosphorus

The availability of phosphorus is one of the major constraints in almost all soil types. The fixation of phosphorus is the major phenomena resulted with the soil reaction, organic matter, CaCO_3 , clay content and amount of cations present in soils. The availability of phosphorus in salt affected soils is the major limitation in their production potential. The solubility of phosphorus is minimum in alkaline calcareous soil with the pH range between 7.6 – 8.5 and increased on either side. The soil is expected to contain high exchangeable and soluble sodium percentage. The orthophosphate ions combined with sodium and form more soluble compound than that of HPO_4^- with calcium. Therefore, the phosphate

is more soluble in the pH range of 8.5 to 9.0 than in the range of 7.5 to 8.5 (McGeorge, 1939).

The increased solubility of phosphorus with increasing level of exchangeable and soluble sodium was also reported by Lewis *et al.* (1952). Rogers *et al.* (1953) reported that the ammonium phosphates was quite good for their use on alkaline or calcareous soils due to their higher solubility. In the absence of availability of above two fertilizers super phosphate may be applied. The solubility of phosphorus is more above pH 8.5, however, its availability to plants is low (Thompson, 1957). Black (1968) also mentioned that the phosphorus uptake generally decreased with an increase in pH of the soil.

Lindsay *et al.* (1962) in his studies on identification of reaction products from phosphate fertilizers in soils observed that the fertilizer P, such as concentrated superphosphate (CSP) reacts with soil to produce variety of crystalline and amorphous forms of P with differing solubilities. Initial reactions at granular site are important and these product dominate the environment in their immediate vicinity. The initial product change with time and cropping to less soluble forms but they provide an important source of P for plant roots. With the length of time, these initial products exists in the soil becomes an important factor in their utilization. Soil properties, especially pH and texture plays a significant role in the rate of transformation. Prabhakar *et al.* (1972) conducted an incubation

studies and observed that the addition of organic manure in the form of compost and *Glyricidia maculata* increased the availability of native phosphorus by 46 and 37 per cent in red sandy loam, 35 and 26 per cent in black clay loam and 42 and 27 per cent in alluvial paddy soil respectively. The use of organic manures like compost and green manure increased the available phosphorus content by 24 and 17 per cent in red sandy loam, 25 and 17 per cent in black clay loam and 24 and 13 per cent in alluvial paddy soils respectively.

Singhania *et al.* (1973) studied the transformation of applied phosphorus in neutral to alkaline alluvial and red soils. They observed that the conversion of added phosphorus to calcium phosphate was more in alkaline soils. Fulky (1978) studied the available phosphorus content of soil affected by P fertilization and its change in time. The super phosphate was applied as a source of P and he found that the rate of increase of available phosphorus was primarily influenced by the presence of CaCO_3 and its close correlation with the pH as well as silt + clay content. There was also difference between the rate of increase of NaHCO_3 soluble phosphorus content in calcareous and non calcareous soils. In calcareous soils 60-70 per cent, whereas, in non calcareous soils 30-40 per cent of added phosphorus can be extracted by NaHCO_3 .

The barren sodic soils of Indo-Gangetic plains were reported to contain very high amount of Olsen's extractable phosphorus (upto 67 ppm). It was highly correlated with the

electrical conductivity of the surface soil (0-15 cm). The high solubility of phosphorus was probably be due to higher concentration of Na_2CO_3 in these soils which react with the native calcium phosphate to form more soluble sodium phosphate (Chhabra *et al.*, 1980).

Dhillon and Dev (1986) reported that there was increase in the content of different inorganic fractions due to mineralization of P from farmyard manure. The organic matter might complexed calcium of thus might have increased P in solution from some of calcium phosphates present in soil. Singh and Sarkar (1986) studied effect of fertilizer phosphorus and farmyard manure on inorganic phosphorus transformation and concluded that addition of phosphate, enhanced the saloid bound P, Al-P, Fe-P and Ca-P of soil. Addition of FYM enhanced the solubility of phosphate probably by interfering some way with formation of less soluble octacalcium form from dicalcium phosphate. Phosphorus might have released through the acidifying effect of CO_2 and action of organic chelates produced by microbial decomposition.

Plants absorb most of their phosphorus as primary orthophosphate ion, H_2PO_4^- and in small amount as secondary orthophosphate ion, $\text{HPO}_4^{=}$. There are ten times more absorption sites on plant roots for their H_2PO_4^- ion than for the $\text{HPO}_4^{=}$ ion for its absorption by the plant roots. This explains the poor absorption of P

in alkali situation in spite of increased solubility of P as sodium phosphate (Somani and Totawat, 1993).

Superphosphate applied to the coarse loamy sand soils over a period of 12 years largely influenced the form of Ca-P, followed by Fe-P and Al-P (Dhargave *et al.*, 1991). Lal *et al.* (1993) reviewed the use of phosphatic fertilizers in alkali soils which will cause a reduction in pH in localised areas. This may increase the absorption of phosphorus and decrease its conversion to less soluble forms. Therefore, mono and diammonium phosphates should be used for phosphorus fertilization in alkali soils.

The recovery of added P as Olsen's P increased by 9.3 per cent with one per cent increase in organic carbon (Tekchand and Tomar, 1993).

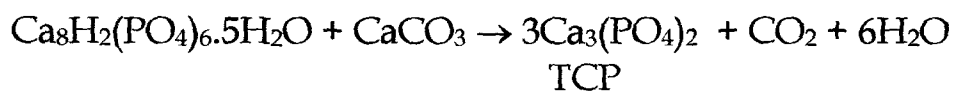
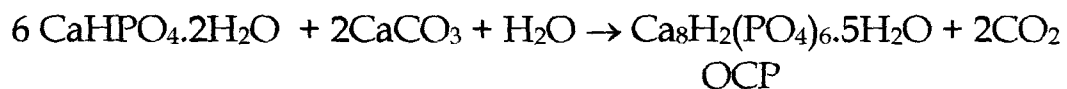
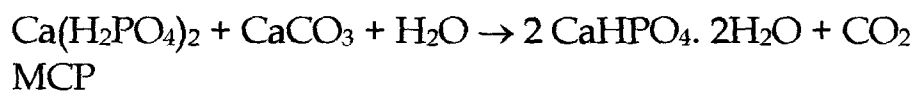
Somani and Totawat (1993) reviewed the fertilizer management in salt affected soils. They reported that the orthophosphates are most important phosphatic fertilizers amongst the various sources. In alkaline and calcareous soils the rock phosphate as such is a little value owing to its low solubility. In general, single superphosphate and ammonium phosphate are quite satisfactory and are better than the meta and tricalcium phosphate. Ammonium phosphates are superior owing to their high P content, more solubility and low cost. However, single superphosphate particularly when applied as localised placement or line drilled

would also prove better in sodic soils owing to its calcium and sulphur content (15 and 11 per cent, respectively).

The solubility and availability of soil phosphorus was more complex in excessively saline sodic soils than in normal soils due to the following main factors.

- i. Nature and amount of soluble salts.
- ii. Higher degree of sodium saturation.
- iii. High pH in addition to presence of calcium carbonate in calcareous salt affected soils.
- iv. Immobilization of P through added gypsum in reclamation of sodic soils.

Availability of P in alkaline soil is determined by solubility of Ca compounds wherein, P is fixed. If H_2PO_4^- containing fertilizer such as single superphosphate is added to a soil having pH 8.0, the H_2PO_4^- quickly reacts to form less soluble compounds.



A series of reaction occurs when monocalcium phosphate is added to the soil. $\text{Ca}(\text{H}_2\text{PO}_4)_2 \cdot \text{H}_2\text{O} + \text{H}_2\text{O} \rightarrow \text{CaHPO}_4 \cdot 2\text{H}_2\text{O} + \text{H}_3\text{PO}_4$. The H_3PO_4 laden solution having pH 1.4 creates quite acidic conditions in the microzones dissolving Fe^{++} , Al^{+++} , Mn^{++} and Ca^{++} .

Thus, iron and aluminum hydroxy phosphates formed in acidic range and tricalcium phosphate formed in alkaline range makes the phosphate ion unavailable to plants due to the high Fe^{+++} and Al^{+++} activity at low microlyte pH ($\text{pH} < 5.5$) and Ca^{++} activity at high pH ($\text{pH} > 6.5$) (Somani and Totawat, 1993).

Tek Chand *et al.* (1994) studied the reaction products of monocalcium phosphate in alkaline calcareous and acid soils. They revealed that the efficiency of added P, among other factors also depends upon the solubility and availability of reaction products formed as a result of the interaction of P fertilizer. Phosphorus fixation is affected by clay, organic matter, pH and CaCO_3 in alkaline calcareous soils. Of the added P 39.35 to 84.25 per cent in alkaline calcareous soil was fixed within five minutes.

Yash Pal and Milap Chand (1999) reported that amending of calcareous soil with green manure increased labile inorganic P, Fe and saloid P fractions and enhanced availability of P in soils. Basak (2000) studied the fates of phosphorus fertilizers in soils and he found that when single superphosphate added to neutral or alkaline soils, monocalcium phosphate is converted to apatite, decreased the contents of exchangeable calcium and/or calcium carbonate and formed hydrogen ions which decreased soil pH. The sparingly soluble gypsum, $\text{CaSO}_4 \cdot 2\text{H}_2\text{O}$ present in large amount in the fertilizer very slowly dissolved to some extent to yield calcium and sulphate ions, subjected to various reactions in soil or absorbed

by plants. The addition of single superphosphate in soil decreased the soil pH due to Ca from CaSO_4 present in single superphosphate by precipitating carbonates and also forming a complex calcium salt with ammonium hydroxide which might have prevented ammonia loss from the soil (Kundu *et al.*, 2000).

Patel and Patel (2000) studied dynamics of phosphorus and zinc in calcareous salt affected soils of Bhal region as influenced by natural drying, levels of phosphorus sources and FYM. They found that the application of FYM (13.5 t ha^{-1}) significantly increased (more than double) the Olsen's P in the soil at all levels of moisture. Similarly the phosphorus content was significantly increased (59 %) even with only FYM application. Further, more Olsen's P in the soil was significantly higher (24 %) when P was applied through DAP than MCP in presence of FYM.

Tomar (2000) reviewed dynamics of phosphorus in soils and reported that when the soil was increased with organic matter, the amounts of native saloid-P and available P were relatively much higher than in organic matter untreated soils. He further reported that mineralization of organic phosphorus in soil was largely due to combined activity of soil microorganisms and free enzyme "phosphatases" present in the soil. Organic matter increases the availability of phosphate by chelating the phosphate fixing cations (Al^{3+} , Fe^{3+} , Ca^{2+}) exchange of adsorbed PO_4^{3-} by organic anions protective actions and decrease in pH of the soils.

2.1.3 Potassium

It has been reported by many workers that saline sodic soils are rich in available potassium. However, when crops like sugarcane having relatively high requirement for potassium grown in such soils, it becomes imperative to search for review of literature on this topic.

Pal and Mandal (1980) conducted field studies in semi reclaimed sodic soil and pot culture in sodic soil with different crops indicated no response to K. This might have happened due to substantial of potassium in the available forms from potassium bearing minerals under sodic soil conditions.

Chhabra (1985) conducted field experiments on crop responses to phosphorus and potassium fertilization of a sodic soil. He concluded that rice and wheat grown in sodic soils of the Indo-Gangatic plains did not respond to dressing of P and K fertilizers and therefore, their application can be deferred for the initial six year of reclamation. After six year only application of P fertilizer be made to the rice crop in a rice-wheat cropping sequence. Tewatia *et al.* (1989) reported that salt affected soils having pH range 8.0 - 9.2 and high soluble salts, low organic matter are medium to high in available K and have large total K reserves. In these soils, illite clays predominant with kaolinite, mixed layer materials smectite and chlorite.



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Bandopadhyay and Maji (1993) studied long term effect of NPK fertilizers in coastal saline soil under rice-fallow cropping system. They concluded that nitrogen is the most required fertilizer in this soil. Phosphorus application may not render any immediate benefit in terms of crop yield. Potassium fertilizer may not be useful for the soil.

Gaikwad (1995) studied potassium release behaviour of swell shrink soils and influenced by organic and inorganic amendments. She concluded that the application of 60 kg K₂O through fertilizer and FYM, application of higher levels increased different forms of K i.e. step K and constant rate K. Therefore, the increasing utilization efficiency of added K fertilizer in combination with organic sources was possible.

Bhalerao (1998) studied potassium fixation and release in salt affected soils of Central Research Farm, M.P.K.V., Rahuri and reported the highest K fixation in sodic soils, followed by saline soils and least in saline sodic soils. The step K release was moderate in these soils indicating the moderate pool of available non-exchangeable K under long term intensive cropping.

Bandopadhyaya *et al.* (2000) reviewed nutrient management in saline and alkali soils and reported that the salt affected soils both in alluvial and black soil region in India are generally rich in available potassium. The availability of potassium in salt affected soils depends primarily on the parent materials,

weathering conditions and type and amount of clay minerals. It also depends on the nature and amount of salts present in the soil since the soluble salts contain a considerable amount of clay and it influences fixation, release in soil and response to K. Potassium availability in alkali soils generally has been reported as adequate. Predominance of micaceous minerals in soils of many arid and semiarid regions were reported. Na-K exchange in biotite and dissolution of muscovite structural units released large amounts of K in alkaline sodium soils environments. They suggested that most of the saline and alkali soils can be cultivated without K fertilizers which may not have any adverse effect on soil fertility and crop yield.

2.1.4 Micronutrients

2.1.4.1 Zinc

Zinc deficiencies are usually observed on soils with pH greater than 6.0. Nair and Mehta (1959) reported a significant correlation coefficient value of $r = 0.402$ between pH and 0.1 N HCl soluble zinc content of Gujarat soils. The use of organic matter may promote the availability of zinc presumably by complexing the substances which fix zinc. They observed positive significant relationship ($r = 0.358$) between organic matter and acid soluble zinc.

Agarwala (1964) observed that the increase in ESP in the range of 1-13 was associated with a rise in water soluble zinc and in soils of higher ESP it decreased. A highly significant negative

correlation was observed between extractable Zn, pH and CaCO_3 content of the soil (Kanwar and Randhawa, 1974 and Misra and Pandey, 1976). Chatterjee and Das (1964) also found that there was more ammonium acetate extractable zinc in soils with pH below 6.0 and its content decreased as pH rose above 7.0. Eswarappa *et al.* (1969) found a positive significant correlation between organic matter content and available Zn in red laterite and black soil types in Mysore. According to Randhawa *et al.* (1969) the reduced soil pH increases the recovery of zinc.

Lindsay (1972) reported that the solubility of Zn was highly dependant on pH and a 100 fold decrease in solubility occurred with each unit increase in pH. The application of zinc fertilizers to alkali soils was found to improve the tolerance of crops to sodic environment which reflects in increasing the crop yields (Shukla and Prasad, 1974). The solubility of Zn in sodic soils is governed by the solubility of $\text{Zn}(\text{OH})_2$ and ZnCO_3 , which are the immediate reaction products (Dhillon *et al.*, 1975).

The results of pot culture study indicated that the maximum pool of available zinc in black soils of Tamilnadu was from the organic fractions as chelated zinc, zinc bound in humic fractions and zinc in the organic residues (Daulat Ram *et al.*, 1976). The crops grown in sodic soils were adversely affected due an inadequate availability of Zinc (Takkar and Randhawa, 1978 and Takkar and Nayyar, 1981).

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Chavan *et al.* (1980) studied Zn, Mn, B and Mo distribution in soil profiles of different agroclimatic zones of Maharashtra. They were observed that the rainfall and organic matter were associated positively with available zinc. The deficiency of zinc in sodic soils are generally associated with their low organic matter, high pH and CaCO₃ content (Katyal *et al.*, 1980). Chand Milap *et al.* (1980) reported that the application of fulvic acid to a saline sodic soil augmented the solubility of Zn by > 1000 fold.

The ameliorative role of zinc was observed on the growth of corn under sodic situation which was attributed to the alleviation of zinc deficiency and changes in chemical composition of plants, widening of Ca/Na and K/Na ratios as also enhanced absorption of Ca, K and Zn (Shukla and Prasad, 1974 and Shukla and Mukhi, 1980). The use of single superphosphate for Zn deficient soils may be preferred because of its impurities especially its Zn content (Dev and Shukla, 1981). Chand Milap *et al.* (1981) studied the effectiveness of zinc chelates in zinc nutrition of green house rice crop in a saline sodic soil. They concluded that uptake and utilization of zinc from applied sources, decreased in the following order Zn-DTPA > Zn-fulvate > Zn-EDTA > ZnSO₄.

Jadhav *et al.* (1981) conducted laboratory experiment to study the kinetics of zinc availability under varied levels of organic matter and phosphorus in black soil. They revealed that the zinc availability was enhanced with increased levels of zinc in soil. They

observed that there was positive relationship between organic carbon and available zinc in soil. The application of organic matter increases the availability of zinc. The concentration of available zinc was increased with soil pH and decreased with exchangeable sodium in strongly alkali soils (Takkar and Nayyar, 1981). Although the solubility of zincate ions increases with rise in pH (NaOH) but the interaction with Ca in between pH 6 to 8 results in the minimum zinc solubility product and thereby Zn deficiency. The problems of zinc deficiency is more aggravated in calcareous soil wherein CaCO_3 act as a strong absorbent of zinc.

Srivastava and Sethi (1981) studied the contribution of farm yard manure (FYM) on the buildup of available zinc in aridisol. They revealed that the farm yard manure contributes to the buildup of DTPA Zn in soil. Similarly, it was linearly correlated with the organic carbon content of soil. The regression equation gives an increase of 0.2 ppm DTPA Zn with 0.1 per cent increase of organic carbon in aridisol. The addition of fifteen ton FYM ha^{-1} resulted in an increase of 0.18 ppm DTPA Zn in soil.

The concentration of available zinc in strongly alkali soils was increased with pH and vis-a-vis with exchangeable sodium (Takkar and Nayyar, 1981). The kind and amount of amendment used for reclamation of alkali soil also influenced the Zn concentration in soil solution, apparently due to the differential ability to reduce soil pH.

Singh *et al.* (1982) observed that application of zinc and compost increased the zinc content and uptake in the rice crop significantly over control.

In alkaline range ($\text{pH} > 8.0$) zinc forms negatively charged ions called ZINCATE ion (ZnO_2). The solubility of zincate ion increases with rise in pH but the interaction with Ca in between pH 6 to 8 results in the minimum zinc solubility product and thereby Zn deficiency. The problem of Zn solubility is more aggravated in calcareous soil wherein, CaCO_3 acts as strong absorbant of zinc (Somani and Totawat, 1993). The zinc content of submerged sodic soils was increased with addition of FYM and rice husk (Swarup, 1982).

The use of ZnSO_4 along with organic manure has been found better for various crops grown on saline sodic soils (Singh *et al.*, 1983, Takkar and Nayyar, 1981).

Rahmatullah (1984) conducted incubation experiment to study the effect of farm yard manure on the availability of zinc sulphate in two different textured soils. In alkaline calcareous soils, premixing of ZnSO_4 with FYM for about twelve hours before its incorporation into the soil had little effect on Zn availability in loamy sand soil. On loamy clay soil it was increased the Zn availability in comparison with ZnSO_4 added alone at 25 ppm Zn. More than 50 to 70 per cent of the applied Zn could not be extended by 0.005 $\underline{\text{N}}$ DTPA in the loamy sand and loamy clay soils respectively after four weeks.

Swarup (1986) observed that Zn might have formed stable complexes of different stability with organic ligands which decreased the susceptibility to adsorption, fixation or precipitation reactions in soil. The application of FYM might have resulted in the formation of such metallo-organic complexes of higher extractability.

Calcareous soils having an inherent pH around 8.0 are known for their responsiveness in Zn application although they contain sufficient total Zn. The difference between the effective and ineffective amounts of zinc seems to vary widely, depending on the chemical nature and pH of salt affected soils. Calcareous soils having an inherent pH around 8.0 are known for their responsiveness to Zinc application although they contain sufficient total Zn (Singh and Abrol, 1986). Sharma and Deb (1988) studied the effect of organic manuring on zinc diffusion in soils of varying texture and revealed that application of manures enhances the diffusion rate of zinc in all the soils. Prasad *et al.* (1990) conducted field experiments to study the zinc fractions and availability of applied zinc in calcareous soil treated with organic materials and they observed that most of Zn fractions were correlated positively and significantly with DTPA Zn. The organic complexed Zn was major source of available Zn in organic materials amended calcareous soil. The calcareous sodic soils are reported deficient in micro nutrients particularly zinc (Somani and Totawat, 1993).

2.1.4.2 Iron

The iron play a vital role in the metabolic activities of crop plants. However, the iron is the most deficient nutrient cation in sodic soils. The use of ferrous sulphate in alkali soils removes the exchangeable sodium to safe limit. These reduce the pH of the soil. It is an acid forming amendment. The following reactions are taking place on the application of ferrous sulphate in calcareous soil (Richards, 1954).

- i. $\text{FeSO}_4 + \text{H}_2\text{O} \leftrightarrow \text{H}_2\text{SO}_4 + \text{FeO}$
- ii. $\text{H}_2\text{SO}_4 + \text{CaCO}_3 \leftrightarrow \text{CaSO}_4 + \text{CO}_2 \uparrow + \text{H}_2\text{O}$
- iii. $2\text{NaX} + \text{CaSO}_4 \leftrightarrow \text{CaX}_2 + \text{Na}_2\text{SO}_4$

Singh *et al.* (1969) observed a negative significant correlation between reducible iron and CaCO_3 content. Takkar (1982) also observed significant positive correlation between CaCO_3 and exchangeable iron ($r = 0.637$) and between CaCO_3 and extractable iron ($r = 0.670$). These relationship indicated that the factors affecting solubility and precipitation of CaCO_3 and iron are similar. The use of iron containing salt as a source of iron in conjunction with organic matter increased their use efficiency. The availability of iron in calcareous soil is the major constraint in exploiting the production potential of crop plants.

The available iron or potentially available forms of iron in soil has been found to depend on organic matter content. He further, reported that the exchangeable extractable and free iron contents of

soils depends on organic matter in calcareous soils of Punjab. Similarly, the significant positive correlation was observed between exchangeable and extractable iron with organic carbon.

The low content of reducible iron in soil was associated with the lower amount of organic matter. However, in non calcareous soils, the relationship between exchangeable and extractable iron and organic carbon content failed to reach the level of significance.

Next to zinc, iron is the most deficient nutrient cation in sodic soils. It is not the total but available iron which is the limiting factor, because of high pH and CaCO_3 content Fe deficiency has often been noticed in rice seedlings grown on raised seed beds in calcareous sodic soils (Singh and Singh, 1966; Takkar and Randhawa, 1978; Katyal and Sharma, 1980).

In the incubation study of medium black clay calcareous soil with the application of iron ($\text{FeSO}_4 \cdot 7\text{H}_2\text{O}$) FYM and elemental sulphur at various moisture regimes showed that FYM @ 10 t ha^{-1} , S @ 80 mg kg^{-1} and Fe @ 10 mg kg^{-1} significantly increased the availability of iron. The effect was more pronounced as incubation period increased upto 42 days (Babaria and Patel, 1980).

The correction of iron deficiency with an application of ferrous sulphate was not useful unless the conjoint use of ferrous sulphate with organic matter in prolonged submerged soils (Katyal and Sharma, 1980).

Swarup (1980) showed a marked increase in the extractable Fe and Mn status of sodic soil upon submergence upto 60 days. The increase was more when organic materials like rice husk or farm yard manure were incorporated in the soil. The use of chelated form of Fe (Fe EDTA, PACA, DTPA, HEEDTA) or that of iron citrate and iron tartarate has been found beneficial in alleviating the iron deficiency in sodic soils.

Elgala and Amberger (1982) in their experiment on effect of pH, organic matter and plant growth on the movement of iron in soils found that an increase in extractable Fe from FeSO_4 treatment of alkaline soil was evident only when the soil was enriched with organic matter and incubated for three months.

Pendias and Pendias (1984) reported that the soil horizons rich in organic matter, iron appeared in chelated form. Organic matter had significant influence on the formation of iron oxides soil Fe exhibited a great affinity to form mobile organic complexes and chelates. These compounds were largely responsible for Fe migration between soil horizons, iron leaching from soil profiles and also were important in the supply of iron to plant roots.

Sakal *et al.* (1986) reported that the 6 mg kg^{-1} DTPA-Fe is considered as critical. They further reported that the availability of iron was negatively correlated with organic carbon, available phosphorus and potassium.

Rajkumar *et al.* (1990) studied the distribution of available micronutrients cations in some dominant soil series in different physiographic units of Bundelkhand region of Madhya Pradesh. They found that available Fe did not show any regular pattern with depth in vertisols. Organic carbon and pH were dominant factors controlling availability of micronutrients. Available Fe was largely controlled by organic carbon. Similarly, Lindsay (1991) studied the iron solubilization by organic matter and its effect on iron availability. He observed that the most important influence of organic matter on the solubilization of Fe was through reduction.

Verma *et al.* (1992) reported that soil application of FYM, dhaincha, ferrous sulphate and super digested ferrous sulphate with FYM increased the cane yield comparable with foliar sprays of ferrous sulphate. Yerriswamy *et al.* (1994) reported that application of ferrous sulphate with or without manure significantly increased the dry matter yield. The Fe concentration increased by nine times due to application of 30 kg FeSO₄ with 10 t manure ha⁻¹ over control. It might be due to formation of organo-metal complexation in soil and thereby higher utilization by plants.

2.2 Organic matter

2.2.1 Farmyard manure

The use of organic manures along with superphosphate was advocated for maintenance of soil fertility. Application of

compost augmented the soil organic carbon level, total nitrogen, CEC and decreased the exchangeable bases of the soil (Gaur, 1982).

The availability of native phosphorus as well as added phosphorus sources were increased by the application of organic matter @ 1 per cent (Vyas and Motiramani, 1971). Organic matter accelerated the release of iron and manganese in red and black soils of Karnataka (Gaur, 1982). Paliwal (1972) concluded that the fertilizers showed better response in the presence of FYM.

The use of cereal residues in combination with chemical fertilizers or non edible cakes were found to accelerate the mineralization of nutrients except nitrogen. However, mineralisation of humified FYM or compost was a slow and steady and acts as slow release fertilizers (Gaur, 1982).

The paddy straw with C : N ratio 80:1 - 90:1 was found to show adverse effect on the $\text{NH}_4^+\text{-N}$ and $\text{NO}_3^-\text{-N}$ status of soil even upto 14 weeks. Whereas, the C : N ratio 30:1 - 40:1 maintained a higher level of $\text{NH}_4^+\text{-N}$ and $\text{NO}_3^-\text{-N}$ (Hajra and Nandi, 1974). The available nitrogen and phosphorus in the soil were appreciably enhanced during the biodegradation of the added organic manures (Shantaram *et al.*, 1975).

The phosphorus solubilizing bacteria were stimulated by FYM (Dey *et al.*, 1976). The maintenance of flooded condition for 15-30 days following incorporation of FYM reduced ESP to a greater extent by minimizing the escape of CO_2 released during fast initial

decomposition besides facilitating leaching of sodium replaced from the exchange complex (Swarup, 1980. Srivastava and Sethi (1981) and Swarup (1982) reported that the application of FYM improve markedly the zinc, iron and phosphorus status of soil.

Somani and Saxena (1981) observed limited amelioration when FYM and gypsum were used singly. However, their combined use brought much faster reclamation due to a greater part of organic matter and got hydrolysed when FYM was used alone. Soil incubation studies have shown that in the absence of addition of organic manures there was loss of 7 to 31 per cent of native soil carbon from various types of soil in about 6 months. The soil organic carbon and available plant nutrients were increased with an addition of FYM or compost or crop residues (Gaur, 1982). The highly alkaline soil can be reclaimed by using the 20-25 t of FYM ha⁻¹ for first year and half the quantity during second and third year followed by rice cultivation (Leather, 1983).

Gaffar *et al.* (1992) conducted field experiment to study the effect of farmyard manure and sand on the performance of sorghum and sodicity of soils. They observed that FYM helped in decreasing sodicity of soil. It might be due to the increased rate of decomposition of organic matter, and formation of carbonic acid. The decrease in pH, increase of CO₂ partial pressure might have increased the available phosphorus by increasing the solubility of fixed phosphorus. Patel *et al.* (1992) reported the solubilizing effect of

certain organic acids released during decomposition of organic matter by an ion exchange or replacement. Singh *et al.* (1992) reported that transformation of micronutrients were influenced by organic matter additions through changes in oxidation reduction regimes and through chelation capacity.

More (1994) conducted a field experiment for three years to study the effect of farm wastes and organic manures on soil properties, nutrient availability and yield of rice and wheat on sodic vertisols. He concluded that the application of FYM @ 50 t ha⁻¹ have shown highest infiltration rate, indicating the improvement in water permeability of the soil. He further reported that addition of FYM in sodic soil, the exchange surface was coated with FYM due to which adsorption of calcium from the soil solution party in exchange of sodium was observed. The decrease in soil pH and increase in availability of P and K was also observed.

2.2.2 Microflora and salinity

Thiobacillus thiooxidans and *thiobacillus ferrooxidans* were mainly responsible for oxidation of sulphur and pyrites producing acid which reacts with CaCO₃ and replaces sodium from exchange complex. Possibility of existence of salt tolerant species of *Thiobacillus* has been indicated by several workers (Somani and Totawat, 1993 and Bajpai and Gupta, 1979).

The availability of essential plant nutrients in soil is solely depends on microflora of soil in normal as well as problematic soils.

The soil metabolic activities mainly governed by the microflora. Gupta and Bajpai (1974) reported that the *Azotobacter* population to be mainly dependent on soil pH. Tanatin (1954) reported the decrease in microbial population with salts and alkalinity.

Bajpai and Gupta (1979) studied the effect of salinity and alkalinity of soil on important microbial activities and reported that the ammonifying power in normal soil was the highest (50.8 %) and the lowest in saline alkali (43.4 %) soils. The nitrifying power was considerably low in salt affected soils as compared to normal soils, which might be due to low population and low activity of nitrifiers in the environment of high salinity/alkalinity. Plant growth might be affected positively and or negatively by soil microflora. Salinity adversely affected many microorganisms as it was doing with plant growth (Gaur and Kumar, 1993).

2.3 Nutrient management of sugarcane

2.3.1 Nitrogen

The sugarcane crop is grown in almost all the districts of Maharashtra and different parts of the country. It is cultivated on various types of soil inspite of their chemical and physical potential for sugarcane production. The main reason behind is that sugarcane crop is accepted by the cultivator as a cash crop. The intensive cultivation of sugarcane in command areas bound to affect the phenomenon of nutrient availability. It is therefore, necessary to

formulate the integrated nutrient management system for sugarcane to increase per hectare production and their sustainability.

Thakur *et al.* (1979) conducted field experiment to study the response of sugarcane to nitrogen and phosphate in saline, alkali and normal calcareous soils of North Bihar. They applied nitrogen in three levels (0, 150 and 200 kg N ha⁻¹) and four levels of phosphate (0, 60, 100 and 150 kg P₂O₅ ha⁻¹). They revealed that the sugarcane responded significantly to nitrogen upto 200 kg ha⁻¹ (maximum dose) in both the soils. But effect of phosphate was significant upto 100 kg P₂O₅ ha⁻¹ in normal calcareous soil and 50 kg P₂O₅ ha⁻¹ in saline alkali soils. The interactions were positive and significant. They further, reported that the nitrogen without phosphate had lower efficiency and phosphate without nitrogen had very poor and uneconomic response even at the lowest dose.

Zende and Kibe (1983) studied the release of nitrate nitrogen in the soil as influenced by organic matter, phosphate and manganese and its effect on sugarcane yield. The studies revealed that Mn and phosphate (preferably as superphosphate) had beneficial effects on the mineralization and oxidation of organic matter resulting in the higher levels of nitrate in the soil. Gypsum and rock phosphate as a source of calcium also increased the supply of nitrate in soil. The field trial showed that the cane yield was considerably increased by nitrate N level particularly at earthing up and the grand growth phases. It also maintained 20 ppm nitrate-N in the soil

throughout the crop and its absorption by the cane as reflected in obtaining higher yields.

Nema *et al.* (1995) conducted field experiments to investigate the effect of nitrogen (0, 150, 225 and 300 kg N ha⁻¹) and organic manures (no manure, FYM @ 4 t ha⁻¹ and PMC @ 4 t ha⁻¹) on yield and quality of sugarcane grown in black calcareous soils of Madhya Pradesh. They revealed that the growth and yield parameters of sugarcane improved significantly with the application of nitrogen and organic manures. The level of 300 kg N ha⁻¹ produced significantly the highest cane and sugar yield. The juice quality decreased with increasing levels of nitrogen. Use of organic manures either FYM or PMC was helpful in increasing the yield and quality of sugarcane. The application of PMC @ 4 t ha⁻¹ was better than FYM at the same level.

2.3.2 Phosphorus

The application of phosphorus @ 50 and 100 kg P₂O₅ ha⁻¹ in a calcareous saline-sodic soil of low available phosphate but having a high P fixation capacity increased cane yields significantly. While it was not affecting the sucrose content. The P and K contents in the cane increased with increased N and P dosage (Prasad *et al.*, 1982). The conjoint use of phosphorus to sugarcane @ 30, 75 and 100 kg P₂O₅ ha⁻¹ with 25 and 50 kg ZnSO₄ ha⁻¹ were found to slight increase in cane yield whereas, sugar yield remain unaffected (Pannu *et al.*, 1989).

2.3.3 Potassium

Nutrient removals by crops like sugarcane are reported to be substantial under normal soil and climatic conditions. Especially sugarcane crops requires 2-3 kg potassium for production of 1 tonne yield.

The NPK fertilization and high levels of soil test values and improvement in uptake due to FYM application resulted in more nutrient uptake and sugarcane crop production (Hagin and Tucker, 1982). Similarly, Kadu (1998) reported that there was an increase in K uptake with increase in levels of K fertilizers and FYM application which contributed to increase in uptake of K and thereby increasing cane yields of seasonal sugarcane.

Prasad *et al.* (1996) reported that the response of sugarcane to major nutrients (N and P) has been intensively investigated so far K is concerned, potassium is recommended only as maintenance dose without considering the requirement of crop. Sonar *et al.* (1984) also reported the highest yield of seasonal sugarcane and adsali at 300 kg ha⁻¹ K level with 400 kg N and 200 kg P ha⁻¹. Khera *et al.* (1990) however, reported that scanty use of organic manures and lower use of potassium than that of N may lead to widespread deficiency of potassium in agricultural lands.

2.3.4 Zinc

Juang *et al.* (1977) studied the effect of zinc application on yield and nutrient uptake of sugarcane. Trials were conducted with

application of 25 and 50 kg Zn per hectare as ZnSO_4 to four cane soils for autumn planted cane and to two of the soils for a ratoon crop. Two of the soils showed a significant response in the plant crop for both cane and sugar yields while, application to the other two soils increased ratoon cane and sugar yields. The cane and sugar yield showed significant relationship with soil Zn.

The cane and sugar yield of sugarcane grown on Zn deficient soil was increased by the application of 44 kg $\text{ZnSO}_4 \text{ ha}^{-1}$ before planting or upto 10 kg ha^{-1} elemental zinc (Benson, 1991). Patel *et al.* (1991) reported that the supplement of Zn alone or the mixed micronutrients along with growth regulators applied into soil or foliage under recommended practices of fertilization significantly increased the CCS per cent but did not affect the cane yield per unit area.

2.3.5 Iron

The iron has multidimensional role in metabolic activities of sugarcane which reflects in commercial cane sugar and cane yield. The availability of iron is mainly governed by the soil properties. Therefore, availability of iron in soil is the major constraints in sugarcane production. Because of this the iron has important consideration in nutrient management of sugarcane.

Patil and Somawanshi (1983) studied the correlation of iron chlorosis in sugarcane on saline calcareous soil and reported that the application of FeSO_4 alone or in combination with gypsum

increased the chlorophyll content of sugarcane leaves. The increase in leaf chlorophyll was strongly correlated with increase in leaf Fe^{++} , soil DTPA-Fe and dry matter production.

Haghihara^{and Boshart} (1984) revealed that the growth of sugarcane was significantly increased and foliar symptoms of Fe deficiency were eliminated when Fe - DTPA was applied to a slightly clay loam soil.

Low available iron in subsurface soils with high pH and excess lime were found associated with iron deficiency in plants. Foliar sprays of ferrous sulphate increased the cane yield. Soil application of FYM, dhaincha, ferrous sulphate and super digested ferrous sulphate with FYM also increased the cane yield comparable with foliar sprays of ferrous sulphate.

Naik (1988) reported that the sugarcane displays iron chlorosis when grown in calcareous alkali soils (pH 7.8 to 8.6) of South India resulting in decline in cane productivity. Several foliar sprays of different iron materials were resulted in greening of the leaves but the effect was temporary.

Palanivet (1990) concluded that the basal applications of 100 kg and 200 kg FeSO_4 ha^{-1} with 25 tonne FYM ha^{-1} to sugarcane were less effective in comparison to foliar spray of FeSO_4 alone in calcareous soil. Yadav and Yaduvanshi (1989) observed the similar effects of FeSO_4 to sugarcane chlorosis.

2.3.6 Biofertilizers

The soaking of sugarcane setts in 1.0 per cent of *Azospirillum* bacterial culture along with 300 kg N ha⁻¹ gave higher values of growth parameter, cane and CCS yield (Gholve *et al.*, 1993).

Yadav (2000) reported the similar results. Thakur and Singh (1996) conducted field experiments on a calcareous alluvial sandy loam soil (Calciorthent) to economise nitrogen in sugarcane with biofertilizers having *Azotobacter* and *Azospirillum* alone or with chemical fertilizers. It significantly increased sugarcane and sugar yields as compared to nitrogenous fertilizers. Cane juice quality was not significantly affected with biofertilizers.

Nasir Ahmed *et al.* (1997) studied the efficiency of phosphobacteria with single superphosphate (SSP) (or) masoorie rock phosphate (MRP) on cane yield and quality. They found that the cane and sugar productivity increased significantly with application of 50 per cent P as SSP (or) MRP in combination with phosphobacteria 10 kg ha⁻¹, as compared to 100 % P as SSP or MRP alone, cane juice quality did not alter significantly.

2.4 Integrated use of nutrients

Rajgopal and Idnani (1963) reported that addition of both ammonium sulphate and potassium nitrate increased the available phosphorus content in all the soils. In black clay loam soils and alluvial paddy soils, ammonium sulphate was more effective in

increasing available nitrogen content as compared with potassium nitrate.

Prabhakar *et al.* (1972) stated that the availability of phosphorus was further increased in all the soils due to the combined effect of organic manures and nitrogen salts. However, the difference was not much between ammonium sulphate and potassium nitrate on the availability of phosphorus when applied along with organic manures. He further reported that the ammonical nitrogen was more effective than nitrate nitrogen in increasing the phosphorus availability in soils. Daulat Ram *et al.* (1976) also reported that the increase of 4 per cent of total nitrogen could bring about an increase of 1013 ppm of total zinc. The correlation between organic carbon and available nitrogen also resulted in their significant and similar influence on available zinc status of the soils.

Olsen *et al.* (1977) studied phosphorus and its interaction with other nutrients in soils. They reported that solubility data of $\text{Zn}_3(\text{PO}_4)_4 \cdot 4\text{H}_2\text{O}$ indicated strong evidence that precipitation of this compound was not involved in P induced Zn deficiency in plants. Rate of P application had not been found to depress water soluble or extractable Zn in soils.

Schnng and Finck (1980) studied the different nitrogen sources on mobilization of micronutrients and concluded that fertilization with acid forming N sources was able to bridge

deficiencies of the micronutrients supply during early vegetative growth.

Jadhav *et al.* (1981) concluded that the application of organic matter increased the availability of zinc. However, availability of zinc was adversely affected due to higher levels of P. Thus, application of higher doses of phosphorus may intensify zinc deficiency. Orabi and Abuleenane (1980) conducted a pot experiment to study the zinc phosphorus relationship in rice nutrition and reported that the phosphorus application significantly increased the Zn content of the plants and interaction of super phosphate with ZnSO_4 and Zn-EDTA were highly significant. The P content of the plants was affected by Zn application.

Pal *et al.* (1980) reported that the application of 50 ppm phosphate caused an immediate increase in available Zn in both native and Zn treated soils but with 100 ppm phosphate and on prolonged incubation decreased the available Zn from native as well as Zn treated soil. Similarly, Prasad (1981) also reported that natural complexing agents such as organic matter was found to be important in increasing the availability of Zn and Fe even under moderate to accute deficiency conditions.

Sachdev and Deb (1981) conducted laboratory studies and reported that DTPA extractable native and applied Fe in three sodic soils was not influenced by Zn application but showed significant increase due to Fe and DTPA applications.

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Samui *et al.* (1981) studied the uptake of nutrients by mustard as influenced by zinc and iron application and revealed that P, Fe and Zn content of Indian mustard was not influenced by Zn and Fe application. Nitrogen content of seed however, increased due to Zn and Fe application. Total nitrogen, phosphorus and iron uptake were significantly increased due to Fe and Zn application. The application of 10 kg FeSO₄ was significantly increased Zn uptake over control. Contrary, Tandon (1982) concluded that the N uptake was increased by the lower dose of Fe whereas, the higher doses reduced it. The phosphorus uptake was influenced to lesser extent by the lower dose of Fe. The higher doses caused a reduction in uptake of phosphorus.

Chatterjee *et al.* (1983) studied the effects of phosphorus and zinc application on the extractable zinc, copper, iron, manganese and phosphorus and observed that the Zn application increased extractable Fe and Mn. The phosphorus application slightly increased the extractable Zn. Jha *et al.* (1984) reported that the total Fe in soil showed significant and positive relation with total Mn and P. The high degree of correlation between available Zn and Fe indicated their close association. Available Zn was positively correlated with available P. Nayyar and Singh (1984) studied response of sugarcane to zinc and iron sources and reported that application of ZnSO₄ before sugarcane planting in Zn deficient area was essential for obtaining higher yields.

Gupta *et al.* (1985) observed that phosphorus reduced zinc concentration but enhanced its uptake. There was no antagonism between Zn and P observed at $< 5 \text{ mg kg}^{-1} \text{ Zn}$.

Pawar *et al.* (1985) after conducting field experiment on a medium black calcareous soil concluded that grain yield and uptake of N, P, K and Zn by wheat (HD-2189) was increased with increase in Zn application. Application of complexed Zn (obtained by incubating a straw soil mixture with ZnSO_4 for about nine weeks) was more beneficial than fertilization with ZnSO_4 with respect to grain yield and nutrient uptake. Gupta *et al.* (1985) also reported that the P reduced the concentration of Zn but enhanced its uptake by pigeonpea (*Cajanus cajan*).

Dravid and Goswami (1986) conducted pot culture experiment to study the soil salinity, fertility, moisture interaction in relation to yield and nutrient uptake by wheat and maize. They observed that addition of Fe and Zn to NPK and increase in sub soil moisture level, yield and nutrient uptake.

Under saline conditions, addition of phosphorus minimized the reduction of Zn uptake in rice to the extent of 45, 40 and 29 per cent at 60, 90 and $120 \text{ kg P}_2\text{O}_5 \text{ ha}^{-1}$ as compared to 69 per cent in controls indicating that the application of higher doses of P in combination with Zn mitigated the effect to a large extent. The adverse effects of soil salinity/sodicity was observed in dry matter yield and uptake of P and Zn (Dravid and Goswami, 1986).

Ismail and Orbai (1986) studied the interactions of iron with phosphorus and zinc in nutrition of tomato seedlings grown in alluvial and calcareous soil. Dry matter yields and total Fe and Zn uptake increased with P application. However, Fe concentrations of plants increased only slightly while Zn concentration decreased when the same P treatments were applied.

Malcom *et al.* (1986) revealed that the interactions between phosphorus and iron in soils were not very simple. These reactions were complicated both by the level of acidity or alkalinity in the soil material and by the nature of the rhizosphere surrounding the roots of the particular crop. In general, iron deficiency or stress that may occur in a field crop is much more likely to result from elevated pH rather than from high phosphorus level.

Sakal *et al.* (1986) reported that the availability of iron was positively correlated with organic carbon, available phosphorus and potassium. Summer and Farina (1986) reported the increased growth required more of both N and P, the inference being that mutually synergistic effects resulted in growth stimulation and enhanced uptake of both elements. Additions of P to P-sufficient soil will not stimulate growth but may in fact significantly reduced yield as a result of an induced Zn deficiency. However, this phenomenon might not always be predictable from year to year. Acharya *et al.* (1988) reported that the application of FYM at 10-15 t ha⁻¹ along with the recommended dose of NPK were sustained the productivity.

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Swarup (1991) observed that zinc requirement of rice crop grown on sodic soils could be met through organic sources like green manure and FYM. The availability of Fe and Mn was also increased due to green manure and FYM. Bandopadhyay *et al.* (2000) reviewed the nutrient management in saline alkali soils and reported that the use of FYM, green manure, biofertilizers were resulted significant increases in yield and nutrient uptake by crops.

Bandopadhyay *et al.* (2000) reviewed nutrient management in saline alkali soils and they reported that loss of nitrogen from soil in gaseous form can checked by application of organic manure. They recommended the combined use of organic manure (FYM, green manure etc.) and fertilizers . The addition of NPK fertilizers along with FYM, green manure, biofertilizers resulted in significant increase in yield and nutrient uptake by crops. The regular application of organic matter to saline alkali soils was advocated for sustainable productivity and improvement of fertility and physico-chemical properties of soil.

Nayak and Gupta (2000) conducted pot culture experiment to study the influence of phosphorus, zinc and organic matter interaction on yield prediction in wheat. They observed that the application of organic matter in combinations with phosphorus and zinc increased the yield over its control. The addition of organic matter lessens the negative interaction effect of phosphorus and zinc.

Patel and Patel (2000) studied the dynamics of phosphorus and zinc in calcareous salt affected soils as influenced by natural drying, levels of phosphorus sources and FYM. They stated that the addition of FYM significantly increased the Zn content in presence of P over no FYM indicating its moderating effect against the antagonistic effect of P application. The phosphorus application through DAP in presence of FYM was noticed to be better in increasing the Zn availability in soil.

Swarup and Yaduvanshi (2000) studied the effects of integrated nutrient management on soil properties and yield of rice in alkali soils. They concluded that the soil organic carbon, available Zn and Mn in inorganic fertilizer treatments were significantly lower compared to the treatments involving fertilizer treatments with organic source. The soil pH was higher in inorganic fertilizer treated plots as compared to NPK + green manure and FYM treated plots. This might be attributed to release of sulphur from addition of green manure and FYM in soil.

2.5 Nutrient management in salt affected soils

The osmotic pressure of saline soil and poor physical conditions of highly dispersed sodic soils adversely affect the plant growth. The nutrient, through fertilizer in their optimum amount and ratio is essential for a satisfactory crop growth. The efficiency of fertilizers under saline sodic condition will largely depend upon.

- i. The activity of the ions in solution and exchangeable phase.
- ii. The rate of release of nutrients from the soil and fertilizer to the plant root.
- iii. Nutrient absorbing capacity of the root, and
- iv. Selective behaviour of the plant species with respect to each individual nutrient (Paliwal and Yadav, 1976).

The crop yields decreased with an increase in salinity but for a given salinity level there is an increase in the yield with increased fertilization (Lunin and Gallatin, 1965). Bains and Fireman (1968) are of view that the application of fertilizer does not reduce the adverse effects of salinity or alkalinity on plant growth but a partial response of fertilizer is seen because of the crop growth as affected by nutrient deficiencies than by salt or alkali.

Nutrient applied through fertilizers in the easily available form seems to stimulate the essential functions of the plant at moderate level of salinity and low sodicity. On highly sodic soils fertilizers appeared to increase the crop yield not only by increased available P of the nutrients in a form readily assimilable by plants but also indirectly by increasing the solubility of calcium, which is often deficient in sodic soils (Somani and Totawat, 1993).

2.5.1 Nitrogen

Singh *et al.* (1969) reported that on a moderately saline ($\text{ECe } 7.8 \text{ dSm}^{-1}$) soil the grain yield of barley improved by 64.6 and 51.0 per cent due to application of 80 and 40 kg N ha⁻¹, respectively.

Abrol (1974) reported that in alkali soils 15-20 per cent increase in the dose of nitrogen is essential during the initial year of reclamation for obtaining optimum yields.

The research findings of the Central Soil Salinity Research Institute, Karnal showed that the crops grown in sodic soils invariably responded to higher doses of N than those grown in non sodic soils (Dargan *et al.*, 1974). The results further recommended that the N dose to crops should be increased by 15-20 per cent over the dose recommended for crops under similar agro-climatic to non sodic soil.

The oil seed crops viz., mustard, linseed and safflower were also responded to nitrogen application (Panwar and Bhardwaj, 1975). Further the vegetables like cabbage and radish were also responded to 80 and 160 kg N ha⁻¹ under such conditions in moderately saline sodic soils. Spratt and Chowdhary (1978) reported that crop yield and fertilizer use efficiency was usually higher with split application than with a single application. Ahmed *et al.* (1980) observed that a good response of wheat crop in saline soils. Split application of nitrogen in saline soil was almost as effective as in normal and sodic soils. Biswas *et al.* (1985) observed that the crops grown on sodic soils required 15-20 per cent higher nitrogen application as compared to normal soil.

Since nitrogen is required for plant throughout the life and is also liable to be lost through leaching or volatilization/

denitrification, it should be applied in split doses (Williamson and Willey, 1964; Tandon, 1989). This will help in maintaining a regular supply of nitrogen and also reducing the losses of N through leaching and volatilization/denitrification.

Lal *et al.* (1993) reviewed the studies on fertilizer application on salt affected soils and reported that the beneficial effects of application of nitrogenous fertilizers on salt affected soils for the crops of cotton and maize. The increasing salinity and sodium concentration reduced the maize yield but the adverse effect of salinity was mitigated by increasing level of nitrogen application. They further reported that growth of rice plants increased with increasing the dose of nitrogen from 40 to 120 ppm.

2.5.2 Phosphorus

Nitant and Dargan (1974) reported that the fertilizers capable of supplying nutrient slowly to the plant would be most suitable and will still be better if they are associated with calcium. Calcium bearing fertilizers not only made available, the calcium ion to the plant which is deficient but also helps in replacing the excessive exchangeable sodium from the exchange complex of sodic soils. The sulphur bearing fertilizers are also considered superior specially in calcareous sodic soils.

Chhabra *et al.* (1980) conducted experiments on alkali soils and particularly reclaimed soils and reported that crops grown on alkali soils were not likely to respond to applied fertilizer P for the

initial three years. In spite of substantial P losses through leaching in long term field studies some workers have shown that because of high available P status of sodic soils, rice and wheat grown in rotation did not respond to applied P fertilizers (Dargan and Chiller, 1978).

The response of applied P fertilizers in saline soils even containing high amounts of available P was because of the fact that in saline soils the availability of P was more, which was a function of plant root length and area (which is restricted due to salinity) and the negative effect of excess chloride on P absorption by roots (Somani, 1980). The judicious use of P fertilizers in saline soils helps to improve crop yields (Abrol, 1990) by directly providing phosphorus and by decreasing the absorption of toxic element like chloride.

Application of phosphorus helps in increasing the yield of crops in saline soils by directly providing phosphorus or by decreasing the absorption of toxic elements like fluorine and chloride. The yields of wheat and mustard increased significantly with the application of phosphorus upto 13 kg P ha⁻¹ as compared to no application (Singh *et al.*, 1990).

Lal *et al.* (1993) reviewed response of phosphorus application on the yield of various crops and reported that the magnitude of phosphorus response by crop plants was observed similar to that of nitrogen in saline sodic soil for oat, barley, sugarbeat, wheat, beans, Lucern and maize. Lunin and Gallatin (1965)

observed that the yield of beans decreased with increasing salinity but it increased with increasing rates of phosphorus fertilization.

Somani and Totawat (1993) revealed that the superphosphate and ammonium phosphate are quite satisfactory and are better than meta and tricalcium phosphate. However, superphosphate particularly when applied as localized placement or line drilled would also prove better in sodic soil owing to its calcium and sulphur content.

2.5.3 Zinc

Abrol (1974) stated that amongst micronutrients the application of zinc resulted in higher crop yields, hence its application was recommended as a routine practice.

Shukla and Prasad (1974) studied ameliorative role of zinc on maize grown under alkali soil conditions and observed the beneficial effects on the germination and growth of plants.

Takkar and Singh (1978) conducted field trial to study the zinc nutrition of rice as influenced by rates of gypsum and Zn fertilization of alkali soils. They found that zinc application decreased the pH, but not so appreciably as did gypsum.

The application of gypsum, ZnSO_4 and fulvic acid significantly increased dry matter yield and uptake of Zn by rice crop in saline sodic soil (Chand Milap *et al.*, 1980). The similar results were reported by Takkar and Nayyar (1981) on rice crop grown on alkali soils.

Biswas *et al.* (1985) reported that the application of zinc sulphate @ 40 kg ha⁻¹ was effective to overcome zinc deficiency in sodic soils. Singh *et al.* (1991) also observed an increase in grain and straw yield of wheat by the application of ZnSO₄.7H₂O @ 40 kg ha⁻¹ under irrigation with sodic water.

2.5.4 Iron

The application of iron relatively in large quantities to iron deficient soils were required to alleviate Fe chlorosis and increased sorghum and bermudagrass yields in the green house (Ryan *et al.*, 1975; Ryan and Stroehlein, 1976). Banding 72 mg Fe kg⁻¹ as FeSO₄ increased sorghum yield on two calcareous soils in the greenhouse but was not effective as much as did Fe-EDDHA (Mortvedt, 1982). A broadcast application of 24 kg Fe ha⁻¹ as FeSO₄ increased alfa-alfa yields to the tune of 21 per cent on a calcareous soil (Rammah *et al.*, 1984). Rice yields were increased after correcting Fe chlorosis by banding 30 kg Fe ha⁻¹ as FeSO₄ (Snyder and Jones, 1988).

Soil application of inorganic Fe sources are ineffective for controlling Fe chlorosis except at very high rates. These sources are either too insoluble to be effective at low to moderate application rates and they became unavailable because of insoluble reaction products formed in soils (Mortvedt, 1991).

2.6 Integrated use of nutrients to sugarcane

Prasad *et al.* (1981) reported that there was significant increase in yield due to addition of 50 kg P_2O_5 ha⁻¹ in combination with nitrogenous fertilizers (170 kg N ha⁻¹) to sugarcane grown on salt affected soils of north Bihar.

Sen *et al.* (1984) revealed that the combinations of Zn, Mn and Fe (applied as sulphate 25 kg ha⁻¹) incorporated with FYM at eight times of their weights increased sugarcane yield significantly.

Kumaresan *et al.* (1985) reported that besides cane yield, the pol per cent was significantly increased with the application of 37.5 kg $ZnSO_4$ and 100 kg $FeSO_4$ ha⁻¹ alone over the NPK treated plot. The results also suggested that the application of pressmud 5 t ha⁻¹ with 37.5 kg $ZnSO_4$ and 100 kg $FeSO_4$ ha⁻¹ significantly increased the sugarcane yield over the NPK control.

In a long term experiment on sugarcane observed that continuous application of FYM together with NPK fertilizers improved CCS per cent in juice (Rabindra *et al.*, 1990). Shinde *et al.* (1990) reported that incorporation of cane trash increased nutrient uptake by sugarcane and improved soil fertility.

Bangar *et al.* (1991) reported that on a medium black soil increasing rates of application of $FeSO_4$ and $ZnSO_4$ each at 25, 50, 75 kg ha⁻¹ increased sugarcane growth, yield and quality parameters to a maximum at 75 kg ha⁻¹ $FeSO_4$ and 50 kg ha⁻¹ $ZnSO_4$ after which there was a fall in cane and sugar yield. Patel *et al.* (1991) studied impact of

various micronutrients and growth regulators on yield and quality of sugarcane. They concluded that supplement of Zn alone or mix micronutrients along with growth regulators applied into soil significantly increased the per cent commercial cane sugar.

Zende *et al.* (1991) reported that the application of inorganic fertilizers to sugarcane were more effective when used with organic manure. Dhillon *et al.* (1993) conducted field experiments on four different sites to examine the comparative effect of FYM, N, P and K application on productivity of sugarcane and sugar. FYM @ 20 t ha⁻¹, N @ 150 kg ha⁻¹ and P₂O₅ 60 kg ha⁻¹ significantly increased sugarcane yield over check. Dey *et al.* (1996) studied the integrated effect of organic and inorganic fertilizers for cane yield and sugar production in spring planted sugarcane. Maximum cane productivity was observed where, all the essential primary, secondary and trace elements in available and in an inorganic form were applied.

Thakur and Singh (1996) studied effect of biofertilizers on the nitrogen economy of sugarcane in calciorthent. They reported that nitrogen to sugarcane with biofertilizers viz., *Azotobacter* and *Azospirillum* alone or with chemical fertilizers significantly increased sugarcane and sugar yields as compared to nitrogenous fertilizers alone.

Yadav (2000) reported that a judicious and balanced application of nutrients through an integrated use of organic and inorganics (chemical fertilizers) has proved a potential tool for

sustaining the productivity of soils of crop in sugarcane based intensive cropping systems on a long term basis.

The forgoing review indicated that the integrated nutrient management for sugarcane production is a crucial factor in maintaining the soil sustainability. However, the studies undertaken to achieve this goal were scanty and in isolated manner and hence the project was formulated.

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MATERIAL AND METHODS

3. MATERIAL AND METHODS

In the present investigation, release pattern, interaction, use efficiency of applied inorganic fertilizers in conjunction with organics, their effects on growth and dry matter yield and nutrient uptake of sugarcane in respect of nitrogen, phosphorus, zinc and iron in saline sodic soil were studied under pot culture conditions during 2000-2001 at Department of Agricultural Chemistry and Soil Science, Post Graduate Institute, M.P.K.V., Rahuri. The separate laboratory incubation experiments were conducted to study the periodical release pattern and interactions of nitrogen, phosphorus, zinc and iron applied through combination of organic with inorganic fertilizers.

The details of the material used and methods adopted in present investigation are given in this chapter.

3.1 Material

3.1.1 Soil

The soil used for pot culture experiment and laboratory study was medium black calcareous in nature, belonging to Sawargaon series (*Vertic Ustropepts*) collected from post graduate instructional farm of the Mahatma Phule Krishi Vidyapeeth, Rahuri. It was dried under shade, powdered in wooden mortar and pestle and sieved through 2 mm sieve (nylon netted) and analysed for physical, chemical and biological properties (Table 1a).

Table 1a. The physical, chemical and biological properties of the soil

Sr. No.	Soil properties	Value
A.	Physical properties	
1.	Particle size distribution	
i.	Sand (%)	19.7
ii.	Silt (%)	24.4
iii.	Clay (%)	55.6
2.	Texture class	Clay
3.	Field capacity moisture (%)	42.26
4.	Bulk density (g cm^{-3})	1.30
B.	Chemical properties	
1.	Available nutrients (mg kg^{-1})	
i.	Nitrogen	57.14
ii.	Phosphorus (P)	6.46
iii.	Potassium (K)	147.69
8.	DTPA micronutrients (mg kg^{-1})	
i.	Iron	4.02
ii.	Zinc	0.40
iii.	Manganese	3.22
iv.	Copper	1.70
C.	Saturation paste extract analysis	
1.	pHe	8.30
2.	ECe (dSm^{-1})	4.70
3.	Cations (meq L^{-1})	
i.	Calcium	7.02
ii.	Magnesium	3.10
iii.	Sodium	32.15
iv.	Potassium	0.03
4.	Anions (meq L^{-1})	
i.	Carbonates	Traces
ii.	Bicarbonates	10.30
iii.	Chlorides	22.00
iv.	Sulphate	12.15
5.	SAR	14.29
6.	ESP	16.09
7.	RSC (meq L^{-1})	0.18
D.	Biological properties	
	Microbial count ($\times 10^5 \text{ g}^{-1} \text{ soil}$)	4×10^5

Table 1b. Chemical composition of manure (FYM) and fertilizers used in the experiments

Sr. No.	Ingredients	Manure/Fertilizers					
		FYM	Urea	Single super-phosphate	Muriate of potash	Ferrous sulphate	Zinc sulphate
1.	Moisture (%)	20.0	-	-	-	-	-
2.	Organic carbon (%)	11.5	-	-	-	-	-
3.	Total nitrogen (%)	0.50	46	-	-	-	-
4.	Total phosphorus (P) (%)	0.22	-	7.04	-	-	-
5.	Total potassium (K) (%)	0.50	-	-	49.8	-	-
6.	C/N ratio	23.0	-	-	-	-	-
7.	Iron $\mu\text{g g}^{-1}$	96.0	-	-	-	20.15	-
8.	Zinc $\mu\text{g g}^{-1}$	51.0	-	-	-	-	22.61

3.1.2 Pots

The sintex plastic pots of 34 x 34 x 47 cm size were used for growing the sugarcane seedlings. Each pot was filled with 40 kg air dried 2 mm sieved soil by maintaining the bulk density of 1.3 g cm^{-3} .

3.1.3 Seedlings

The tissue cultured seedlings of sugarcane (Co-86032, Nira) were procured from the Professor I/C Plant Tissue Culture Laboratory, Mahatma Phule Krishi Vidyapeeth, Rahuri.

3.1.4 Chemicals

The various chemicals used were procured from Qualigens, Sarabhai Chemical, BDH, and Sisco Research Laboratory, Mumbai.

3.1.5 Manure and fertilizers

The well decomposed FYM was obtained from the Senior Scientist, Cattle Project, Mahatma Phule Krishi Vidyapeeth, Rahuri. Similarly, the following commercial grade and laboratory grade fertilizers were used for experimentation.

Fertilizer	Chemical formula	Nutrient (%)
Urea	$\text{CO}(\text{NH}_2)_2$	N - 46
Single superphosphate	$\text{Ca}(\text{H}_2\text{PO}_4)_2$	P - 7.04
Muriate of potash	KCl	K - 49.8
Ferrous sulphate	$\text{FeSO}_4 \cdot 7\text{H}_2\text{O}$	Fe - 20.15
Zinc sulphate	$\text{ZnSO}_4 \cdot 7\text{H}_2\text{O}$	Zn - 22.61

3.1.6 Biofertilizers

The *Azotobacter*, phosphate solubilizing bacteria and *Thiobacillus ferrooxidans* were used as biofertilizers. These biofertilizers were obtained from the Bacteriologist, Biological Nitrogen Fixation Project, College of Agriculture Pune-5.

3.2 Experimental details

3.2.1 Incubation studies

The four separate sets of laboratory experiments were conducted to assess the periodical release pattern of nitrogen, phosphorus, zinc and iron from their respective sources incubated in saline sodic soil and also their interactions in this soil.

Plastic containers were filled with 200 g air dried 2 mm sieved soil and treated with treatments as detailed under set of experiment.

The required quantity of organic, inorganic and biofertilizers were applied are given as below.

Table 2. The quantity of organic, inorganic and biofertilizers added

Sr. No.	Fertilizer	Rate of application (mg kg ⁻¹)	Actual quantity added (mg)
1.	Urea	776	155.2
2.	Single super phosphate	949	189.8
3.	Ferrous sulphate	22.0	4.4
4.	Zinc sulphate	22.0	4.4
5.	<i>Azotobacter</i>	5.0	1.0
6.	P. solubilizers	5.0	1.0
7.	<i>Thiobacillus ferrooxidans</i>	5.0	1.0
8.	FYM	2200	440

The actual quantity of fertilizers applied for laboratory incubation and pot culture experiment was just double the recommended dose.

Expt. 1 : Periodical availability of nitrogen (Urea transformation)

Treatment	Treatment details
T ₁	Soil only
T ₂	Soil + FYM
T ₃	Soil + Urea
T ₄	Soil + Urea + FYM
T ₅	Soil + Urea + <i>Azotobacter</i>
T ₆	Soil + Urea + <i>Azotobacter</i> + FYM

Expt. 2 : Periodical availability of phosphorus (Phosphate transformation)

Treatment	Treatment details
T ₁	Soil only
T ₂	Soil + FYM
T ₃	Soil + SSP
T ₄	Soil + SSP + FYM
T ₅	Soil + SSP + PSB (P. solubilizers)
T ₆	Soil + SSP + PSB + FYM

Expt. 3 : Periodical availability of iron and zinc

(Ferrous sulphate and zinc sulphate transformation)

Treatment	Treatment details
T ₁	Soil only
T ₂	Soil + FYM
T ₃	Soil + FeSO ₄ + ZnSO ₄
T ₄	Soil + FeSO ₄ + ZnSO ₄ + FYM
T ₅	Soil + FeSO ₄ + ZnSO ₄ + TBF (<i>Thiobacillus ferrooxidans</i>)
T ₆	Soil + FeSO ₄ + ZnSO ₄ + FYM + TBF

Expt. 4 : Integrated nutrients transformation as influenced by different sources incubated in soil

Treatment	Treatment details
T ₁	Soil only
T ₂	Soil + FYM
T ₃	Soil + Urea + SSP
T ₄	Soil + Urea + SSP + FYM
T ₅	Soil + Urea + SSP + Biofertilizers (AZT, PSB, TBF)
T ₆	Soil + Urea + SSP + FYM + Biofertilizers
T ₇	Soil + Urea + FeSO ₄ + ZnSO ₄ + FYM
T ₈	Soil + Urea + FeSO ₄ + ZnSO ₄ + Biofertilizers
T ₉	Soil + Urea + SSP + FeSO ₄ + ZnSO ₄
T ₁₀	Soil + Urea + SSP + FeSO ₄ + ZnSO ₄ + FYM
T ₁₁	Soil + Urea + SSP + FeSO ₄ + ZnSO ₄ + Biofertilizers
T ₁₂	Soil + Urea + SSP + FeSO ₄ + ZnSO ₄ + FYM+ Biofertilizers

Soil moisture was maintained in plastic container at field capacity during incubation period gravimetrically. The treated soils samples were incubated to ambient conditions in the laboratory. The plastic containers were covered with lid to avoid the moisture loss. It was also aerated twice in a day by opening the lids throughout the incubation period. The separate sets of plastic containers were arranged for 0, 2, 4, 10, 20, 30, 45, 60, 90 and 120 days of incubation.

The soil samples were analysed for pH, EC, $\text{NH}_4^+\text{-N}$, $\text{NO}_3^-\text{-N}$, av. P and DTPA-Zn and Fe at above intervals.

3.2.2 Pot culture experiment

The pot culture experiment was conducted by using inorganic fertilizers in conjunction with organics and biofertilizers with a view to assess the use efficiency of added fertilizers in relation to growth, dry matter yield and nutrient uptake by sugarcane at 150 days of crop age grown in saline sodic soil.

The treatment details were as follows.

A. Main treatments

- i. Without FYM (Control)
- ii. With FYM (25 Mg ha⁻¹)

B. Sub treatments

- i. RDF (400:170:170 N:P₂O₅:K₂O kg ha⁻¹)
- ii. RDF + FeSO₄ (25 kg ha⁻¹)
- iii. RDF + ZnSO₄ (25 kg ha⁻¹)
- iv. RDF + FeSO₄ + ZnSO₄ (25 kg ha⁻¹ each)

- v. RDF + Biofertilizers (*Azotobacter* , P. solubilizers,
Thiobacillus ferrooxidans 5 kg ha⁻¹ each)
- vi. RDF + FeSO₄ + ZnSO₄ + Biofertilizers

Treatment combinations

- 1. RDF
- 2. RDF + FeSO₄
- 3. RDF + ZnSO₄
- 4. RDF + FeSO₄ + ZnSO₄
- 5. RDF + Biofertilizers
- 6. RDF + FeSO₄+ ZnSO₄ + Biofertilizers
- 7. RDF + FYM
- 8. RDF + FeSO₄ + FYM
- 9. RDF + ZnSO₄ + FYM
- 10. RDF + FeSO₄ + ZnSO₄ + FYM
- 11. RDF + FYM + Biofertilizers
- 12. RDF + FeSO₄ + ZnSO₄ + FYM + Biofertilizers

Replications : Three

Design : Factorial Completely Randomised Design (FCRD)

Table 3. Quantity of organic manure, inorganic fertilizers and biofertilizers added to pot culture experiment

Sr. No.	Manure/fertilizers/biofertilizers	Rate of application (mg kg ⁻¹)	Actual quantity added (g pot ⁻¹)
1.	Urea	776	31.04
2.	SSP	949	37.96
3.	MOP	253	10.12
4.	FeSO ₄	22.0	0.88
5.	ZnSO ₄	22.0	0.88
6.	<i>Azotobacter</i>	5.0	0.2
7.	P. solubilizers	5.0	0.2
8.	<i>Thiobacillus ferrooxidans</i>	5.0	0.2
9.	FYM	2200	880

3.2.2.1 Transplanting of sugarcane tissue culture seedlings

The tissue cultured sugarcane seedlings (Co-86032, Nira) were planted in the pots. The pots were irrigated with tap water.

3.2.2.2 Irrigation

The pots were irrigated by using following formulae.

i. $ET_o = K_{pan} \times E_{pan}$

ii. $ET_c = ET_o \times KC$

Where,

$$ET_o = \text{Reference crop evapotranspiration mm day}^{-1}$$

K_{pan} = Pan factor taken as 0.75

E_{pan} = Pan evaporation, mm day^{-1}

ET_c = Evapotranspiration, mm day^{-1}

K_C = Crop coefficient

K_C for sugarcane crop (FAO, 33)

<u>Days</u>	<u>K_C</u>
0-30	0.40 to 0.50
30-60	0.75 to 0.85
100-125	0.90 to 1.00
125-150	1.00 to 1.20

3.2.2.3 Harvesting of sugarcane

The sugarcane plants were removed from the pot along with root system carefully. The sugarcane plants were washed with deionized water and then with distilled water without loss of root or shoot biomass. The root and shoot part were separated carefully and dried in diffused sunlight in laboratory. Then it was dried in oven at 70°C temperature till constant weight obtained. The oven dried samples were ground to pass through 70 mesh sieve and then used for estimation of N, P, K, Fe and Zn content of sugarcane crop by following the standard methods.

The soils samples were collected after harvested of sugarcane crops and analysed for microbial population by adopting standard method.

Table 4. Method used for analysis

Sr. No.	Particulars	Method	Reference
A.	Saturation paste extract	Vacuum extraction	Richards (1968)
1.	pHe	Potentiometric	Richards (1968)
2.	ECe	Conductometric	Richards (1968)
3.	CO ₃ ²⁻ -HCO ₃ ⁻ and Cl ⁻	Volumetric	Richards (1968)
4.	SO ₄ ²⁻	Turbidimetric	Chopra and Kanwar (1980)
5.	Ca ⁺⁺ and Mg ⁺⁺	Versnate titration	Richards (1968)
6.	Na ⁺ and K ⁺	Flamephotometer	Richards (1968)
B.	Soil analysis		
1.	Mechanical analysis	Hydrometer	Bouyoucos (1962)
2.	pH (1 : 2.5)	Potentiometric	Jackson (1973)
3.	EC	Conductometric	Jackson (1973)
4.	Organic carbon	Walkley and Black wet oxidation	Nelson and Sommers, 1982
5.	CaCO ₃ equivalent	Rapid titration	Piper (1966)
6.	Available nitrogen	Alkaline permangnate	Subbiah and Asija, (1956)
7.	NH ₄ ⁺ -N	Steam distillation with MgO	Black (1965)
8.	NO ₃ ⁻ -N	Steam distilation with Devardas alloy + MgO	Black (1965)
9.	Available Phosphorus	NaHCO ₃ (0.5 M) pH 8.5 (Ascorbic acid)	Watanabe <i>et al.</i> (1965)
10.	Available Potassium	Neutral normal NH ₄ OAc extract pH 7.0	Knudsen <i>et al.</i> (1982)

Table 4 contd.....

Sr. No.	Particulars	Method	Reference
11.	Available zinc and iron	Atomic Absorption Spectrophotometric (Perkin Elmer 2380)	Lindsay and Norvell (1978)
12.	Microbial population	Serial dilution plate count	Pikovaskya (1948)
C.	Plant analysis		
1.	Nitrogen	Microkjeldahls	Jackson (1958)
2.	Phosphorus	Vandophospho molybdate yellow colour method in nitric acid system	Piper (1966)
3.	Potassium	Flamephotometer	Jackson (1973)
4.	Micronutrients (Zn and Fe)	Atomic absorption spectrophotometric (Perkin Elmer 2380)	Zoroski and Buran (1977)

3.3 Statistical analysis

The data obtained in respect of soil characteristics, growth observations, nutrient concentration and uptake by sugarcane crop were statistically processed as per the procedure given by Panse and Sukhatme (1967).

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RESULTS AND DISCUSSION

4. RESULTS AND DISCUSSION

The nutrient availability in saline sodic soil is major constraints in their productivity. The major cause of nutrient unavailability is the antagonistic effect of the nutrient element present in excessive amount as soluble or exchangeable ions or both. In view of this, present investigation was planned as “Integrated nutrient management in sugarcane grown on saline sodic soil”. The results obtained by conducting the nutrient release pattern from various sources in an incubation studies and pot culture experiment on saline sodic soil are presented and discussed in this chapter.

4.1 Urea application in saline sodic soil

The periodical changes in soil pH, EC, $\text{NH}_4\text{-N}$ and $\text{NO}_3\text{-N}$, available phosphorus, DTPA extractable micronutrients as influenced by application of urea, farmyard manure (FYM), *Azotobacter* and their conjoint use were studied under laboratory conditions. The results obtained in an incubation studies are discussed in foregoing pages.

4.1.1 Soil pH

The periodical changes in soil reaction (pH) of saline sodic soil as influenced by the urea, FYM, *Azotobacter*, their conjoint use and incubation time are reported in Table 5.

The addition of urea, FYM, *Azotobacter* alone and their conjoint use significantly influenced the soil pH of saline sodic soil.

Table 5. Periodical changes in the pH of saline sodic soil as influenced by different treatments and incubation period

Days of incubation	Treatments						
	T ₁	T ₂	T ₃	T ₄	T ₅	T ₆	Mean
0	8.40	8.37	8.50	8.52	8.51	8.54	8.47
2	8.41	8.39	8.52	8.56	8.51	8.59	8.50
4	8.41	8.37	8.56	8.56	8.56	8.56	8.50
10	8.41	8.35	8.51	8.46	8.52	8.42	8.44
20	8.42	8.35	8.53	8.35	8.42	8.32	8.40
30	8.41	8.32	8.40	8.25	8.40	8.23	8.33
45	8.42	8.30	8.35	8.18	8.35	8.18	8.30
60	8.44	8.30	8.28	8.17	8.29	8.17	8.28
90	8.43	8.30	8.26	8.12	8.26	8.15	8.25
120	8.42	8.25	8.25	8.09	8.24	8.06	8.22
Mean	8.42	8.33	8.41	8.33	8.41	8.32	-
		SE $\pm$		CD at 5 %			
Treatments		0.0029		0.0083			
Days of incubation		0.0037		0.011			
Treatments x Days of incubation		0.009		0.026			

The use of urea, FYM and their combined use with *Azotobacter* significantly decreased the soil pH with an increase in incubation period. The magnitude of decrease in soil pH of saline sodic soil over incubation period was more in conjoint use of urea, FYM and *Azotobacter* (8.54-8.06) followed by urea + FYM (8.52-8.09). The use of urea alone (8.50-8.25) and urea + *Azotobacter* (8.51-8.25) showed similar effects on soil pH over an incubation period. The maximum reduction in pH was observed in the treatments where FYM was added. The soil pH decreased from 8.40 (control) to 8.32 where urea was applied in combination with *Azotobacter* and FYM which was closely followed by soil + FYM and soil + urea + FYM (8.33). These treatments were significantly decreased soil pH over control.

There was significant decrease in soil pH with progress of incubation time. The maximum decrease from 8.47 to 8.22 was observed on 120th day of incubation. However, there was increase in soil pH during first 20 days of incubation in the treatment where urea was applied either alone or with FYM. The increase in soil pH may possibly be due to release of $\text{NH}_4^+\text{-N}$ during initial period. This generally happens in soil when enzymatic hydrolysis of urea due to soil urease convert urea to ammonium resulting in raising the soil pH.

At the end of incubation period there was reduction in soil pH. This may be because of reductions of ammonia due to volatilization and nitrification. Similar, observations have also been

reported by Baligar and Patil (1968) who observed reduction in the pH of sodic soil from 9.10 to 8.25 due to application of 500 ppm nitrogen through urea. Dinesh Kumar *et al.* (2000) reported similar results.

The decrease in soil pH due to addition of FYM might be due to improvement in soil physical conditions which reflected on increased microbial activity. Similarly on decomposition of added FYM by organisms the urea acted as energy source for microorganisms which might have released organic acids. These findings are in accordance with the observations noted by Swarup and Yaduvanshi (2000).

The interactions between urea, FYM, *Azotobacter* and their conjoint use were significant in influencing the soil pH. Thus, the conjoint use of urea, FYM and *Azotobacter* were effective in reducing the soil pH of saline sodic soil.

4.1.2 Electrical conductivity

The data on electrical conductivity of saline sodic soil as influenced by different treatments are presented in Table 6.

The data reveal that there was no significant effect of these treatments on electrical conductivity of soil. There was a linear increase in electrical conductivity due to FYM application either alone or with urea but the differences were non-significant. Incubation period had also no significant effect on electrical conductivity of the soil.

Table 6. Electrical conductivity (dSm^{-1}) of saline sodic soil as influenced by different treatments and incubation period

Days of incubation	Treatments						
	T ₁	T ₂	T ₃	T ₄	T ₅	T ₆	Mean
0	1.93	1.93	1.93	1.93	1.98	1.94	1.94
2	1.93	1.95	1.97	1.95	1.94	1.98	1.95
4	1.98	1.95	1.94	1.94	1.94	1.95	1.95
10	1.92	1.98	1.95	1.96	1.95	1.97	1.95
20	1.94	1.98	1.97	1.98	1.97	1.99	1.97
30	1.94	2.01	1.97	2.01	1.98	2.01	1.99
45	1.94	2.01	1.98	2.04	1.98	2.03	1.99
60	1.96	2.00	1.98	2.00	1.98	2.02	1.99
90	1.93	2.00	1.98	2.00	1.98	2.00	1.99
120	1.96	2.00	1.99	2.00	1.98	2.00	1.99
Mean	1.95	1.98	1.97	1.98	1.97	1.99	-
		SE $\pm$		CD at 5 %			
Treatments		0.015		NS			
Days of incubation		0.019		NS			
Treatments x Days of incubation		0.047		NS			

4.1.3 Ammonical nitrogen ($\text{NH}_4^+\text{-N}$)

The release of ammonical nitrogen in saline sodic soil due to the application of urea, FYM, *Azotobacter*, their combined use, incubation period and interaction between various sources of fertilizer and incubation time are presented in Table 7.

The application of urea, FYM, *Azotobacter* and their conjoint use was significant to release ammonical nitrogen in saline sodic soil. The release of ammonical nitrogen in saline sodic soil by urea + FYM (105.91 mg kg⁻¹ soil) and urea + FYM + *Azotobacter* (108.26 mg kg⁻¹ soil) were on par with each other and significantly superior over use of urea alone (96.48 mg kg⁻¹ soil) and urea + *Azotobacter* (97.38 mg kg⁻¹ soil). Whereas, the least amount of ammonical nitrogen was released due to addition of FYM alone (34.87 mg kg⁻¹ soil) and control (16.57 mg kg⁻¹ soil).

The increased ammonical nitrogen in saline sodic soil by the use of urea + FYM and urea + FYM + *Azotobacter* may be associated with slow rate of mineralization of nitrogen resulting into the accumulation of ammonical nitrogen.

The ammonical nitrogen content of saline sodic soil was significantly increased at 20 days of incubation (173.64 mg kg⁻¹ soil) which was on par with 10 days of incubation (168.90 mg kg⁻¹ soil). Thereafter, every succeeding incubation period it was decreased considerably. The decrease of ammonical nitrogen content at 60, 90

Table 7. Periodical release of $\text{NH}_4^+\text{-N}$ (mg kg^{-1}) in saline sodic soil as influenced by different treatments and incubation period

Days of incubation	Treatments						
	T ₁	T ₂	T ₃	T ₄	T ₅	T ₆	Mean
0	21.00	22.71	40.50	37.95	40.50	37.95	33.57
2	21.00	28.00	102.50	100.25	102.50	102.50	76.13
4	22.75	31.50	145.00	149.00	143.00	150.25	106.91
10	24.50	35.00	230.00	242.50	232.90	248.50	168.90
20	15.75	38.50	238.50	248.50	242.13	251.50	173.64
30	13.50	40.25	70.00	82.25	71.05	95.25	61.72
45	12.95	42.75	50.00	56.00	52.15	57.75	47.19
60	12.00	45.00	35.75	46.95	36.95	48.25	39.55
90	11.50	46.75	29.75	47.50	29.75	46.75	37.20
120	10.75	48.25	22.75	48.25	22.75	46.25	35.54
Mean	16.57	34.87	96.48	105.91	97.38	108.26	-
SE $\pm$ CD at 5 %							
Treatments			1.43	4.06			
Days of incubation			1.85	5.24			
Treatments x Days of incubation			4.54	12.83			

and 120 days of incubation was on par irrespective of the treatments (39.55, 37.20 and 35.54 mg kg⁻¹ soil respectively).

At later stage of an incubation *viz.*, 30 to 120 days the ammonical nitrogen might have subjected to oxidation converting it to nitrate nitrogen through nitrification. Similarly, due to high pH (>8.0) of the sodic soil a part of ammonical nitrogen might have lost through volatilization.

The interaction between use of urea, FYM, *Azotobacter*, their conjoint use with 10 and 20 days of incubation were at par with each other and significantly superior over rest of the interactions. The interactions between 30, 45, 60, 90 and 120 days of incubation period with all the treatments were on par for ammonical nitrogen content in saline sodic soil.

Thus, the conjoint use of urea, FYM and *Azotobacter* was very much beneficial for release of ammonical nitrogen in saline sodic soil upto 20 days after their application. These observations confirm the findings observed by Dinesh and Dubey (1999), Gupta *et al.* (1999) and Singh and Ram (2000).

4.1.4 Nitrate nitrogen (NO₃⁻-N)

The data on periodical release of nitrate nitrogen in saline sodic soil during an incubation period due to urea, FYM, *Azotobacter* and their combined use are reported in Table 8.

The conjoint use of urea, farmyard manure, *Azotobacter* and their single use were significantly superior in releasing the

Table 8. Periodical release of NO_3^- -N (mg kg^{-1}) in saline sodic soil as influenced by different treatments and incubation period

Days of incubation	Treatments						
	T ₁	T ₂	T ₃	T ₄	T ₅	T ₆	Mean
0	28.00	35.00	31.50	37.50	31.50	37.50	33.50
2	31.50	35.00	56.50	54.40	56.50	54.40	48.07
4	31.50	60.25	65.50	69.90	67.50	72.10	61.13
10	33.25	67.25	70.25	75.25	71.90	78.40	61.88
20	42.50	68.75	79.10	77.95	82.15	83.50	67.16
30	43.10	70.25	249.75	348.75	253.15	354.10	155.73
45	45.50	74.30	271.20	380.75	273.50	385.70	233.07
60	47.15	75.50	288.00	430.00	293.50	433.10	256.13
90	48.15	77.50	295.18	432.00	300.10	436.50	259.74
120	49.00	80.50	301.15	434.50	313.19	440.10	264.28
Mean	39.97	64.43	170.81	234.30	174.30	237.54	-
SE $\pm$ CD at 5 %							
Treatments	2.15			6.05			
Days of incubation	3.22			9.10			
Treatments x Days of incubation	7.89			22.29			

nitrate nitrogen in saline sodic soil. The highest nitrate nitrogen was released in urea + FYM + *Azotobacter* treatment (237.54 mg kg⁻¹ soil) which was at par with urea + FYM (234.10 mg kg⁻¹ soil) treatment and significantly superior over the remaining treatments. However, use of urea alone and urea + *Azotobacter* were at par with each other (170.81 and 174.30 mg kg⁻¹ soil) and significantly superior over control and FYM alone (39.97 and 64.43 mg kg⁻¹).

The increase in nitrate nitrogen in saline sodic soil by the urea + FYM and urea + FYM + *Azotobacter* might probably be due to increased microbial activity accelerating the process of nitrification.

The amount of nitrate nitrogen released irrespective of the treatments was significantly increased with the progress in incubation time. The highest nitrate nitrogen was recorded at 120th day of incubation (264.28 mg kg⁻¹ soil) which was on par with 90th day (259.74 mg kg⁻¹ soil) and 60th day (256.13 mg kg⁻¹ soil) of incubation period. The nitrate nitrogen content of saline sodic soil over a period of an incubation ranged from 33.50 to 264.28 mg kg⁻¹ soil irrespective of different treatments. Whereas, the average release of nitrate nitrogen due to different treatments ranged from 39.97 to 253.54 mg kg⁻¹ soil in saline sodic soil.

The interactions between various treatments and incubation periods were significant in releasing nitrate nitrogen in saline sodic soil. The interactions at treatment and incubation period at 60th day (288.0, 430.0, 293.5 and 433.10 mg kg⁻¹ soil), 90th day

(295.18, 432.00, 300.10, 436.50 mg kg⁻¹ soil) and 120th day (301.15, 434.50, 313.19 mg kg⁻¹ soil) with various treatments were on par with each other and significantly superior over the rest of the interactions. This indicated the positive effect of FYM addition alongwith urea over application of urea alone for longer period for release of nitrate nitrogen.

Thus, the ammonical and nitrate nitrogen content of saline sodic soil had negative relation with each other. There are fundamental constraints of fertilizer use in saline sodic soils because of the interactive effects of salts and exchangeable sodium with fertilizer nutrients. Generally, these problems are governed either by nature and degree of salinity and sodicity or chemical reactivity and solubility of added fertilizers on nutrient availability in soil. The integrated use of urea, FYM and *Azotobacter* were found to be beneficial for release of ammonical and nitrate nitrogen in saline sodic soil.

Similar findings were also reported by Fenn and Hossner (1985), Vinod Kumar (1988), Singh and Prasad (1992), Dinesh and Dubey (1999), Singh and Ram (2000), Bandopadhyay *et al.* 2000).

4.1.5 Available phosphorus

The availability of phosphorus in saline sodic soil due to the application of urea, FYM, their combined use and incubation period are presented in Table 9.

Table 9. Periodical release of phosphorus (mg kg⁻¹) in saline sodic soil as influenced by different treatments and incubation period

Days of incubation	Treatments						
	T ₁	T ₂	T ₃	T ₄	T ₅	T ₆	Mean
0	6.36	6.61	6.87	6.87	7.50	7.12	6.89
2	6.87	7.12	6.87	7.12	6.87	6.87	6.95
4	6.87	7.63	6.87	7.37	6.87	7.63	7.20
10	6.87	8.65	6.61	8.65	7.12	8.64	7.75
20	6.87	9.16	7.12	9.41	7.12	9.41	8.18
30	7.12	9.15	7.38	10.17	7.37	10.43	8.60
45	7.12	12.45	8.14	12.71	8.39	12.71	10.25
60	7.63	12.71	11.70	12.96	10.15	13.73	12.73
90	7.12	15.13	8.14	15.60	8.14	15.60	11.62
120	7.12	15.25	7.88	16.10	8.14	16.10	11.76
Mean	6.99	10.38	7.75	10.69	7.77	10.82	-
		SE ±		CD at 5 %			
Treatments		0.26		0.71			
Days of incubation		0.33		0.92			
Treatments x Days of incubation		0.80		2.25			

The data revealed that availability of phosphorus in saline sodic soil was ranged from 6.99 to 10.82 mg kg⁻¹ soil due to different treatments, whereas, the incubation period influenced the release of available phosphorus in the range of 6.89 to 12.73 mg kg⁻¹ soil. The release of phosphorus was significant in saline sodic soil due to various treatments, incubation period and interaction between treatments and incubation period. The use of farmyard manure alone, urea + FYM and urea + FYM + *Azotobacter* in saline sodic soil were found on par for release of available phosphorus (10.38, 10.69, 10.82 mg kg⁻¹ soil, respectively). The available phosphorus was significantly increased due to application of urea (7.75 mg kg⁻¹ soil) alone and urea + *Azotobacter* (7.77 mg kg⁻¹ soil) over control (6.99 mg kg⁻¹ soil). The release of phosphorus was significantly increased with an advancement in incubation period. It was maximum at 60th day of incubation (12.73 mg kg⁻¹ soil) and on par with 90th day (11.62 mg kg⁻¹ soil) and 120th day (11.76 mg kg⁻¹ soil) of incubation period.

The interactions of incubation period and treatments were significant in releasing the phosphorus in saline sodic soil. The magnitude of release of phosphorus was more due to interaction between the incubation period and urea alongwith FYM, incubation period and urea + FYM + *Azotobacter*. The availability of phosphorus under extremely saline sodic soils is much more complex. This complexity is generally associated with the nature and amount of

soluble salts, degree of sodium saturation and high pH in presence of calcium carbonate.

The increased availability of phosphorus due to addition of urea + FYM + *Azotobacter* in saline sodic soil might be because of combined effect of organic manures and nitrogen salts. The addition of organic manure (FYM) might have enhanced the activity of micro-organisms which ultimately would have solubilized the phosphorus in soil. The added FYM might have also liberated the organic acids on its decomposition in the soil probably helped in increasing the solubility of phosphorus. Prabhakar *et al.* (1972) reported that the ammonical nitrogen was more effective than nitrate nitrogen in increasing the phosphorus availability in soils. The application of FYM might have reduced phosphate fixation. The FYM addition reduced the pH of soil (Table 5) which might have helped in increasing P availability.

These observations are in close conformity with the findings reported of Dhargave *et al.* (1991), More (1999), Nayak and Gupta (2000).

4.1.6 DTPA zinc and iron

The DTPA zinc contents of the saline sodic soil as influenced by addition of urea, FYM, *Azotobacter* and their combined use with incubation time are presented in Table 10. The data indicated that the addition of urea, FYM and *Azotobacter* alone or as conjoint use increased the DTPA zinc over control. The increase in

Table 10. DTPA Zn (mg kg⁻¹) in saline sodic soil as influenced by different treatments and incubation period

Days of incubation	Treatments						
	T ₁	T ₂	T ₃	T ₄	T ₅	T ₆	Mean
0	0.38	0.38	0.38	0.40	0.38	0.40	0.39
2	0.38	0.40	0.40	0.40	0.40	0.40	0.40
4	0.40	0.40	0.40	0.40	0.40	0.42	0.40
10	0.40	0.40	0.42	0.44	0.44	0.43	0.42
20	0.40	0.44	0.42	0.44	0.44	0.48	0.44
30	0.42	0.48	0.42	0.48	0.44	0.54	0.46
45	0.40	0.48	0.44	0.50	0.44	0.56	0.47
60	0.42	0.50	0.44	0.54	0.46	0.46	0.47
90	0.40	0.50	0.46	0.56	0.48	0.60	0.50
120	0.44	0.50	0.46	0.60	0.46	0.62	0.51
Mean	0.40	0.45	0.42	0.48	0.43	0.49	-
		SE $\pm$		CD at 5 %			
Treatments		0.022		NS			
Days of incubation		0.028		0.079			
Treatments x Days of incubation		0.068		NS			

DTPA zinc was however, not significant. The increase in DTPA zinc due to incubation period was significant. The contents of zinc in saline sodic soil were on par at 20, 30, 45, 60, 90 and 120th day of incubation. (0.44, 0.46, 0.47, 0.47, 0.50 and 0.51 mg kg⁻¹ soil) respectively. However, the interactions were non-significant.

The data pertaining to DTPA iron of saline sodic soil due to addition of urea, FYM, *Azotobacter* and their combined use are reported in Table 11. The application of urea, FYM, *Azotobacter*, their conjoint use, incubation period and their interactions were found significant in respect of availability of iron in saline sodic soil.

The conjoint use of urea + FYM + *Azotobacter* recorded the highest level of available iron (4.60 mg kg⁻¹ soil) which was on par with use of FYM alone (4.45 mg kg⁻¹ soil) and urea + FYM (4.48 mg kg⁻¹ soil) whereas, urea alone and urea + *Azotobacter* did not vary the available iron contents of saline sodic soil. The increased DTPA iron in saline sodic soil by the use of FYM might be due to addition of iron through added quantity of FYM. Addition of FYM improved the physical properties of soil which ultimately helped to improve microbial activity for DTPA-iron in saline sodic soil.

The availability of iron in saline sodic soil was significantly increased with the progress in an incubation period. The highest DTPA iron (4.96 mg kg⁻¹ soil) was observed at 120th days of incubation period. The incubation period of 60th and 90th day (4.66 mg kg⁻¹ soil) recorded same DTPA iron content.

Table 11. DTPA-Fe (mg kg⁻¹) of soil as influenced by different treatments and incubation period

Days of incubation	Treatments						
	T ₁	T ₂	T ₃	T ₄	T ₅	T ₆	Mean
0	3.90	3.96	3.92	3.98	4.02	3.98	3.96
2	3.94	3.96	3.96	4.08	3.54	3.98	3.91
4	3.94	3.98	3.96	4.08	3.96	4.10	4.00
10	3.92	3.98	3.96	4.07	3.98	4.10	4.00
20	3.94	4.08	4.00	4.24	4.00	4.24	4.08
30	3.94	4.16	4.04	4.36	4.02	4.40	4.15
45	3.98	4.86	4.13	3.98	4.08	5.10	4.36
60	3.96	5.16	4.10	5.28	4.16	5.30	4.66
90	3.96	5.16	4.02	5.32	4.16	5.36	4.66
120	3.90	5.20	4.88	5.38	5.13	5.48	4.96
Mean	3.94	4.45	4.10	4.48	4.10	4.60	-
		SE ±		CD at 5 %			
Treatments		0.064		0.18			
Days of incubation		0.082		0.23			
Treatments x Days of incubation		0.20		0.57			

The interactions were significant for DTPA iron in saline sodic soil. The interaction between use of urea along with FYM + *Azotobacter* and incubation period recorded the higher values of DTPA iron which ranged from 3.98 to 5.48 mg kg⁻¹ soil followed by urea + FYM and incubation period (3.98 to 5.38 mg kg⁻¹ soil) and with FYM and incubation period (3.96 to 5.20 mg kg⁻¹ soil). The conjoint use of urea alongwith FYM and *Azotobacter* found to accelerate the release rate of DTPA iron under saline sodic soil.

4.2 Single superphosphate application in saline sodic soil

The availability of phosphorus in saline sodic soil is the main constraint because of its high clay content, excess calcium, calcium carbonates, interactions with other plant nutrients *viz.* zinc and iron. The efforts are made to overcome these constraints by adopting the conjoint use of single superphosphate, farmyard manure and P-solubilizers. The observations pertaining to soil properties and nutrient availability as influenced by single super phosphate application in saline sodic soil are discussed below.

4.2.1 Soil pH and electrical conductivity

The pH of saline sodic soil as affected by addition of single superphosphate, phosphate solubilizers, FYM, their combinations and incubation period are recorded in Table 12.

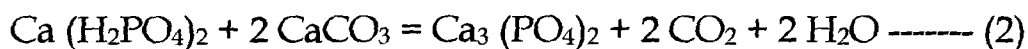
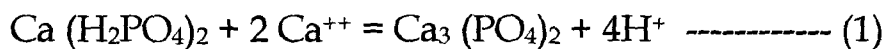
The data indicated that the soil pH was significantly changed due to the application of single superphosphate, phosphate solubilizers and farmyard manure alone or in combination. The

Table 12. Effect of single superphosphate on pH of saline sodic soil during incubation

Days of incubation	Treatments						
	T ₁	T ₂	T ₃	T ₄	T ₅	T ₆	Mean
0	8.40	8.39	8.41	8.36	8.38	8.36	8.38
2	8.40	8.39	8.37	8.34	8.37	8.33	8.37
4	8.41	8.37	8.35	8.31	8.34	8.31	8.35
10	8.41	8.35	8.33	8.30	8.31	8.30	8.33
20	8.42	8.35	8.33	8.31	8.30	8.31	8.34
30	8.41	8.32	8.34	8.28	8.30	8.27	8.32
45	8.42	8.30	8.34	8.26	8.30	8.26	8.31
60	8.43	8.30	8.33	8.26	8.31	8.24	8.31
90	8.43	8.30	8.32	8.24	8.31	8.22	8.30
120	8.42	8.25	8.32	8.24	8.30	8.22	8.30
Mean	8.41	8.33	8.34	8.29	8.32	8.29	-
SE $\pm$ CD at 5 %							
Treatments			0.014	0.039			
Days of incubation			0.018	0.051			
Treatments x Days of incubation			0.044	NS			

reduction in soil pH was much more pronounced due to addition of single superphosphate alongwith FYM (8.29) and single superphosphate with farmyard manure and phosphate solubilizers (8.29). Whereas, it was on par with single superphosphate alongwith phosphate solubilizers (8.32). The farmyard manure and single superphosphate were on par for change in soil pH when used individually.

The decrease in soil pH due to addition of single superphosphate was also reported by Basak (2000). The addition of single superphosphate to alkaline soil i.e. monocalcium phosphate is converted to tricalcium phosphate and ultimately to apatites with intermediate products such as dicalcium phosphate and octa-calcium phosphate. This reaction may be represented by following equations.



To cause the first reaction the exchangeable calcium is used up. Also, this reaction yields hydrogen ions. Thus, this reaction induces acidity (or decrease soil pH). In the second reaction the calcium carbonate in soil is used up. This reaction too induces acidity (or decrease soil pH). The change in soil pH might be due to the presence of phosphoric acid in single superphosphate. The FYM liberates different organic acids which also helps for reduction in soil pH.

The soil pH was significantly changed over an incubation period irrespective of the treatments. It was changed from 8.37 to 8.30. The change in soil pH during the incubation periods of 45th, 60th, 90th and 120th day was on par (8.31, 8.31, 8.30 and 8.30, respectively) with each other and significantly superior over 0, 2, 4, 10, 20 and 30 days (8.37, 8.35, 8.33, 8.34 and 8.32, respectively) of an incubation period. The interaction effects of different treatments and incubation period were non-significant.

The data pertaining to effects of single superphosphate on soil electrical conductivity (Table 13) showed that when single superphosphate applied alone and in conjunction with FYM and phosphate solubilizers increased electrical conductivity. When single superphosphate was used in conjunction with FYM recorded 2.15 dSm⁻¹ and with phosphate solubilizers 2.16 dSm⁻¹ electrical conductivity. However, it was significantly higher over control (1.94 dSm⁻¹) and FYM alone (1.98 dSm⁻¹). Application of FYM alone significantly increased the electrical conductivity of soil over control.

The change in soil EC was associated with the composition of single superphosphate. The single superphosphate contained about 50 % sparingly soluble calcium sulphate which was slowly dissolved in soil to Ca²⁺ and SO₄²⁻. The SO₄²⁻ ions may increase the electrical conductivity of soil. Apart from that the added quantity of farmyard manure might have accelerated the dissolution of

Table 13. Effect of single superphosphate on electrical conductivity (dSm^{-1}) of saline sodic soil during incubation

Days of incubation	Treatments						
	T ₁	T ₂	T ₃	T ₄	T ₅	T ₆	Mean
0	1.93	1.93	2.00	2.00	2.00	2.01	1.98
2	1.92	1.95	2.04	2.06	2.04	2.05	2.01
4	1.98	1.95	2.08	2.10	2.08	2.12	2.05
10	1.92	1.98	2.11	2.13	2.15	2.17	2.08
20	1.94	1.98	2.14	2.18	2.16	2.19	2.10
30	1.94	2.01	2.14	2.19	2.18	2.19	2.11
45	1.94	2.01	2.12	2.21	2.19	2.21	2.11
60	1.96	2.00	2.15	2.21	2.19	2.21	2.12
90	1.93	2.00	2.16	2.22	2.17	2.22	2.12
120	1.96	2.00	2.16	2.24	2.18	2.21	2.13
Mean	1.94	1.98	2.11	2.15	2.13	2.16	-
		SE $\pm$		CD at 5 %			
Treatments		0.011		0.03			
Days of incubation		0.014		0.039			
Treatments x Days of incubation		0.034		NS			

sparingly soluble salts thereby increasing the electrical conductivity of the soil. Similar findings were also reported by Basak (2000).

The incubation period had significant effect on electrical conductivity of the soil. The EC was increased significantly over 0 days (1.98 dSm^{-1}) upto 120 days (2.13 dSm^{-1}). The interactions of single superphosphate, FYM, phosphate solubilizers, their conjoint use with the incubation periods were non-significant. This might be due to very slow release of SO_4^{2-} ions from calcium sulphate in soil.

4.2.2 Ammonical nitrogen ($\text{NH}_4^+\text{-N}$)

The data on periodical release of ammonical nitrogen of saline sodic soil as influenced by the use of single superphosphate, FYM, phosphate solubilizers, their combined use and incubation period are presented in Table 14.

The conjoint use of single superphosphate, FYM and phosphate solubilizers recorded significantly higher amount of ammonical nitrogen ($41.38 \text{ mg kg}^{-1} \text{ soil}$) which was on par with single superphosphate and FYM ($40.35 \text{ mg kg}^{-1} \text{ soil}$) application. The use of FYM alone recorded $34.87 \text{ mg kg}^{-1} \text{ soil}$ of ammonical nitrogen. Whereas, there was no significant difference in control ($16.57 \text{ mg kg}^{-1} \text{ soil}$) and single superphosphate ($18.36 \text{ mg kg}^{-1} \text{ soil}$) application for ammonical nitrogen content of saline sodic soil. The numerical increase in ammonical nitrogen due to application of single superphosphate might be due to Ca from CaSO_4 in single superphosphate could decrease the pH effectively by precipitating

Table 14. Effect of single superphosphate on periodical release of $\text{NH}_4^+\text{-N}$ (mg kg^{-1}) in saline sodic soil

Days of incubation	Treatments						
	T ₁	T ₂	T ₃	T ₄	T ₅	T ₆	Mean
0	21.00	22.71	24.50	21.00	24.50	21.00	22.46
2	21.00	28.00	25.75	35.00	25.75	35.00	28.41
4	22.75	31.50	26.50	38.50	26.50	40.25	31.00
10	24.50	35.00	25.50	38.50	26.50	40.25	31.71
20	15.75	38.50	17.10	43.75	17.50	45.75	29.72
30	13.50	40.25	15.25	43.45	17.25	46.00	29.33
45	12.95	42.75	14.95	44.00	14.95	46.00	29.27
60	12.00	45.00	12.95	45.00	12.95	46.00	28.98
90	11.50	46.00	11.10	47.00	10.50	46.50	28.94
120	10.75	48.25	10.00	47.00	10.50	47.00	28.91
Mean	16.57	34.87	18.36	40.35	18.61	41.38	-
		SE $\pm$		CD at 5 %			
Treatments		0.81		2.30			
Days of incubation		1.05		2.96			
Treatments x Days of incubation		2.57		7.26			

carbonates and also forming a complex calcium salt with ammonium hydroxide which might have prevented ammonia loss from soil (Kundu *et al.*, 2000). The increase in $\text{NH}_4^+\text{-N}$ content in saline sodic soil by the application of FYM might be due to mineralization of nitrogen and lowering the pH which reduced volatilization loss of ammonia (NH_3).

The ammonical nitrogen of saline sodic soil ranged from 22.46 to 31.71 mg kg^{-1} soil due to incubation period. The incubation period from 10th to 120th days were on par showing decreasing trend. These results indicated that there was no pronounced effect of an incubation period on release of ammonical nitrogen of saline sodic soil.

The interactions between various treatments and incubation period were statistically significant. The release of ammonical nitrogen due to interaction between single superphosphate + FYM with incubation period was higher followed by single superphosphate + FYM with incubation period and FYM and incubation period. The significance of interaction of ammonical nitrogen in saline sodic soil was mostly because of conjunctive use of single superphosphate, farmyard manure and phosphate solubilizer rather than the incubation period.

4.2.3 Nitrate nitrogen ($\text{NO}_3\text{-N}$)

The data pertaining to release of nitrate nitrogen as affected by the application of single superphosphate, FYM,

phosphate solubilizers, their combined use and incubation period are reported in Table 15. A close look to the data revealed that nitrate nitrogen in saline sodic soil significantly influenced by the use of single superphosphate, FYM and phosphate solubilizers. The highest nitrate nitrogen recorded by the conjunctive use of single superphosphate, FYM and phosphate solubilizers ($66.50 \text{ mg kg}^{-1} \text{ soil}$). However, other treatments *viz.*, control, single superphosphate alone and single superphosphate + phosphate solubilizers were on par (39.97 , 40.95 and $41.15 \text{ mg kg}^{-1} \text{ soil}$ respectively) for their nitrate nitrogen release in saline sodic soil.

The increased release of nitrate nitrogen was observed with progress of time during incubation period. The magnitude of nitrate nitrogen release was the highest at 120th days ($60.46 \text{ mg kg}^{-1} \text{ soil}$), which was closely followed by 90th days (60.06 mg kg^{-1}) of incubation.

The interaction between various treatments and incubation period were significant. The release of nitrate nitrogen by the interaction between single superphosphate + FYM with incubation period was higher followed by single superphosphate + FYM with incubation period and FYM and incubation period. The conjoint use of phosphatic fertilizers i.e. single superphosphate and phosphate solubilizers with FYM can therefore be beneficial proposition to enhance the nitrate nitrogen in saline sodic soil upto 120 days. Similar findings are reported by Prabhakar *et al.* (1972).

Table 15. Effect of single superphosphate on periodical release of NO₃⁻-N (mg kg⁻¹) in saline sodic soil

Days of incubation	Treatments						
	T ₁	T ₂	T ₃	T ₄	T ₅	T ₆	Mean
0	28.00	35.00	34.50	53.50	34.50	56.00	44.75
2	31.50	35.00	36.25	57.00	36.25	56.00	46.50
4	31.50	60.25	36.25	57.00	38.00	59.50	48.25
10	33.25	67.25	38.00	57.00	38.00	59.50	48.83
20	42.50	68.75	41.50	60.50	38.50	59.50	50.88
30	43.10	70.25	41.50	71.00	43.25	70.00	56.42
45	45.50	74.30	43.25	74.75	43.25	73.50	57.00
60	47.15	75.50	43.25	72.50	45.00	73.50	58.17
90	48.45	77.50	44.75	73.50	47.60	77.00	60.06
120	49.00	80.50	46.75	74.00	50.25	78.75	60.46
Mean	39.97	64.43	40.95	65.48	41.15	66.50	-
			SE ±		CD at 5 %		
Treatments			0.98		2.77		
Days of incubation			1.27		3.58		
Treatments x Days of incubation			3.10		8.77		

4.2.4 Available phosphorus

The available phosphorus contents of saline sodic soil as effected by use of single superphosphate, farmyard manure, phosphate solubilizers, their conjoint use and incubation periods are presented in Table 16.

The available phosphorus content in soil significantly influenced by the various treatments which ranged from 6.99 mg kg⁻¹ to 35.51 mg kg⁻¹ soil. The highest phosphorus was observed with the conjoint use of single superphosphate, FYM and phosphate solubilizers (35.81 mg kg⁻¹ soil) which was on par with single superphosphate and FYM (34.84 mg kg⁻¹ soil). The use of single superphosphate alone (27.21 mg kg⁻¹ soil) and along with phosphate solubilizers (27.61 mg kg⁻¹ soil) were found on par with each other. These results revealed that there was no much beneficial effect of phosphate solubilizers as far as availability of phosphorus is concerned. The conjoint use of single superphosphate alongwith FYM accelerated the availability of phosphorus in saline sodic soil.

The increase in availability of soil phosphorus might be due to application of single superphosphate either alone or in conjugated use of single superphosphate with FYM. The release of strong acids by single superphosphate in soil might have help in increasing phosphorus availability. The rate of increase of available phosphorus was primarily influenced by the presence of CaCO₃ and

Table 16. Effect of single superphosphate on periodical release of phosphorus (mg kg⁻¹) in saline sodic soil

Days of incubation	Treatments						
	T ₁	T ₂	T ₃	T ₄	T ₅	T ₆	Mean
0	6.36	6.61	24.92	26.95	24.91	26.94	19.45
2	6.87	7.12	25.42	28.98	25.93	29.23	20.59
4	6.87	7.63	25.42	32.29	26.18	33.30	21.95
10	6.87	8.65	27.20	33.04	25.93	35.08	22.79
20	6.87	9.16	27.60	35.46	27.95	35.08	23.68
30	7.12	9.15	27.71	34.59	28.04	35.38	23.67
45	7.12	12.45	27.71	38.89	28.08	39.91	25.69
60	7.63	12.71	28.22	38.89	29.23	40.16	26.14
90	7.12	15.13	28.98	39.15	29.77	41.12	26.88
120	7.12	15.25	28.98	40.17	30.12	41.94	27.26
Mean	6.99	10.38	27.21	34.84	27.61	35.81	-
		SE ±		CD at 5 %			
Treatments		0.30		0.84			
Days of incubation		0.38		1.08			
Treatments x Days of incubation		0.94		2.66			

its close correlation with the pH. The rate of increase of available phosphorus after phosphorus fertilization was also observed by Fulkey (1978). He further, reported that 60-70 % of added phosphorus in calcareous soil can be extracted. In alkaline soil because of the higher activities of calcium compounds the per cent recovery of added phosphorus as Ca-P might be higher.

The addition of FYM had also pronounced effect on increasing phosphorus content in soil. Phosphorus contained in FYM liberated with progress of decomposition which in turn might be increased the available phosphorus content in soil.

The organic anions and hydroxyacids such as tartaric, citric, malonic and malic acid liberated during the decomposition of organic manure may complex or chelate iron, aluminium, magnesium and calcium and prevent them from reacting with phosphate ions to form insoluble phosphorus. The calcareous soils amended with green manure increases labile phosphorus thus, enhancing the availability of phosphorus in soils.

The increased availability of phosphorus was observed with an increase in incubation period. The highest available phosphorus 27.26 mg kg⁻¹ soil recorded at 120th days of incubation period which was on par with 90th days (26.88 mg kg⁻¹ soil). The increase in available phosphorus ranged from 19.45 to 27.26 mg kg⁻¹ soil.

The interaction effects were significant for available phosphorus in saline sodic soil. The magnitude of release of available phosphorus due to interaction between treatments and incubation period in terms of range values was in the order of single superphosphate + FYM + phosphate solubilizers (26.94 to 41.94 mg kg⁻¹ soil) > single superphosphate + FYM (26.95 to 40.17 mg kg⁻¹ soil) > single superphosphate + phosphate solubilizers (24.91 to 30.12 mg kg⁻¹ soil) > single superphosphate (24.92 to 28.98 mg kg⁻¹ soil) > FYM (6.61 to 15.25 mg kg⁻¹ soil) > content (6.36 to 7.12 mg kg⁻¹ soil) respectively.

The increase in available phosphorus due to addition of single superphosphate, FYM or their combination was also recorded by Prabhakar *et al.* (1972), Singhania *et al.* (1973), Fulkey (1978), Swarup (1986), Dhillon and Dev (1986), Singh and Sarkar (1986), Dhargave *et al.* (1991), Tek Chand and Tomar (1993), Yashpal *et al.* (1999), Patel and Patel (2000).

4.2.5 DTPA Zinc

The data in relation to DTPA-Zn content of saline sodic soil as influenced by the use of single superphosphate, FYM, phosphorus solubilizers and incubation period are presented in Table 17.

The DTPA zinc content of saline sodic soil was significantly influenced by the various treatments. The conjunctive use of single superphosphate and FYM and single superphosphate +

Table 17. Effect of single superphosphate on periodical release of DTPA-Zn (mg kg⁻¹ soil) in saline sodic soil

Days of incubation	Treatments						
	T ₁	T ₂	T ₃	T ₄	T ₅	T ₆	Mean
0	0.38	0.38	0.38	0.40	0.38	0.40	0.39
2	0.38	0.40	0.40	0.44	0.40	0.44	0.41
4	0.40	0.40	0.40	0.48	0.40	0.48	0.43
10	0.40	0.40	0.40	0.47	0.40	0.48	0.43
20	0.40	0.44	0.46	0.52	0.44	0.52	0.46
30	0.42	0.48	0.46	0.54	0.46	0.52	0.48
45	0.40	0.48	0.46	0.54	0.48	0.52	0.48
60	0.42	0.50	0.48	0.56	0.48	0.56	0.50
90	0.40	0.50	0.50	0.58	0.50	0.58	0.51
120	0.44	0.50	0.50	0.58	0.50	0.58	0.52
Mean	0.40	0.45	0.44	0.51	0.44	0.51	-
SE $\pm$ CD at 5 %							
Treatments			0.013	0.037			
Days of incubation			0.016	0.047			
Treatments x Days of incubation			0.040	0.12			

FYM + phosphate solubilizers recorded the highest amount of DTPA Zn ($0.51 \text{ mg kg}^{-1} \text{ soil}$). The application FYM had significant effect ($0.45 \text{ mg kg}^{-1} \text{ soil}$) over control. The application of single superphosphate either alone or with P-solubilizers ($0.44 \text{ mg kg}^{-1} \text{ soil}$) increased DTPA Zn significantly over control. The incubation period had significant effect of DTPA Zn. The significant increase was observed from 20 days ($0.46 \text{ mg kg}^{-1} \text{ soil}$) and on par upto 120 days.

Patel and Patel (2000) reported that addition of FYM significantly increased the Zn content in presence of phosphorus over no FYM indicating its moderating effect against the antagonistic effect of phosphorus application. Dev and Shukla (1981) reported that use of single superphosphate for Zn deficient soils may be preferred because of its impurities, especially its Zn content.

Daulat Ram *et al.* (1976) reviewed the chelating properties of soil organic matter and observed that it was more important in influencing and promoting the availability of ions like Zn. Sharma and Deb (1988) reported that organic manures decreased the capacity factor of zinc significantly over no manure. The capacity factor decreased with the increase in the level of application of organic manures. The decrease in capacity factor indicated more of zinc from soil phase has come to the solution phase by forming stable complexes with organic matter. The manures enhances the diffusion rate of zinc in all the soils. These findings are in close conformity

with those reported Pal *et al.* (1980), Srivastava and Sethi (1981), Swarup (1982) and Prasad *et al.* (1990).

4.2.6 DTPA iron

The data regarding DTPA Fe as affected by single superphosphate and FYM application are presented in Table 18. It could be seen from the data, that the DTPA Fe was significantly influenced by application of either single superphosphate, FYM or both single superphosphate + FYM.

The DTPA Fe was significantly increased due to application of single superphosphate alone or single superphosphate + PSB. The DTPA Fe was increased significantly from 3.94 mg kg⁻¹ (control) to 4.50 mg kg⁻¹ (single superphosphate + FYM + phosphate solubilizers). Application of single superphosphate in conjunction with FYM had positive effect on DTPA Fe. The DTPA Fe had significantly increased due to single superphosphate applied with FYM. The application of FYM only (4.45 mg Fe kg⁻¹) increased DTPA Fe significantly over control (3.94 mg kg⁻¹). However, application of FYM + single superphosphate (4.47 mg kg⁻¹ soil) was increased DTPA Fe significantly over control.

It indicated that there was beneficial role of single superphosphate in increasing DTPA Fe in these treatments. The significant increase in DTPA Fe due to application of single superphosphate clearly indicated that there was synergistic effect of applied phosphorus on availability of Fe. The depressing effect of

Table 18. Effect of single super phosphate on periodical release of DTPA Fe (mg kg⁻¹) in saline sodic soil

Days of incubation	Treatments						
	T ₁	T ₂	T ₃	T ₄	T ₅	T ₆	Mean
0	3.90	3.96	3.90	3.92	3.92	3.92	3.92
2	3.94	3.96	3.95	3.92	3.98	3.92	3.98
4	3.94	3.98	3.96	3.98	3.99	4.00	3.98
10	3.92	3.98	3.96	4.00	4.01	4.10	4.00
20	3.94	4.08	4.00	4.10	4.05	4.12	4.05
30	3.94	4.16	4.10	4.18	4.13	4.20	4.12
45	3.98	4.86	4.18	4.88	4.22	4.91	4.51
60	3.96	5.16	4.22	5.20	4.25	5.23	4.67
90	3.96	5.16	4.28	5.26	4.32	5.29	4.71
120	3.90	5.20	4.80	5.28	4.85	5.30	4.89
Mean	3.94	4.45	4.14	4.47	4.17	4.50	-
		SE $\pm$		CD at 5 %			
Treatments		0.040		0.11			
Days of incubation		0.050		0.14			
Treatments x Days of incubation		0.13		0.36			

phosphorus on availability of DTPA Fe had mitigated by FYM. The increase in DTPA Fe might be due to reduction in soil pH due to single superphosphate application.

Influence of organic matter on the availability of iron is probably owing to its higher state of reduction developed in presence of decomposing organic matter which subsequently reduced the Fe^{3+} to Fe^{2+} form. High values of DTPA Fe in soils incubated with organic manures was due to enhanced reduction of the soil. The similar findings were reported by Babaria and Patel (1980), Malcom *et al.* (1986), Sakal *et al.* (1986), Lindsay (1991) and Singh *et al.* (1992).

4.3 Ferrous sulphate and zinc sulphate application in saline sodic soil

The availability of micronutrients in saline sodic soil is the limiting factor depending on the chemical nature and pH of saline sodic soil as well as its calcium content. The efforts are made for the management of micronutrients through FeSO_4 , ZnSO_4 , FYM, *Thiobacillus ferrooxidans* and their conjoint use in saline sodic soil under laboratory conditions. The results obtained during course of investigation are summerised below.

4.3.1 Soil pH

The data in respect of soil pH as influenced by FeSO_4 , ZnSO_4 , FYM, *Thiobacillus ferrooxidans*, their combined use and interaction are presented in Table 19.

Table 19. Effect of FeSO_4 + ZnSO_4 on pH of saline sodic soil during incubation

Days of incubation	Treatments						
	T ₁	T ₂	T ₃	T ₄	T ₅	T ₆	Mean
0	8.40	8.39	8.40	8.36	8.39	8.35	8.38
2	8.40	8.39	8.35	8.33	8.35	8.30	8.35
4	8.41	8.37	8.34	8.31	8.33	8.28	8.34
10	8.41	8.35	8.32	8.29	8.33	8.25	8.32
20	8.42	8.35	8.30	8.25	8.33	8.24	8.31
30	8.41	8.32	8.30	8.23	8.30	8.22	8.30
45	8.42	8.30	8.28	8.21	8.28	8.19	8.28
60	8.43	8.30	8.27	8.19	8.24	8.18	8.27
90	8.43	8.30	8.25	8.17	8.23	8.15	8.26
120	8.42	8.25	8.20	8.17	8.19	8.14	8.23
Mean	8.41	8.33	8.30	8.25	8.30	8.23	-
		SE $\pm$		CD at 5 %			
Treatments		0.014		0.039			
Days of incubation		0.018		0.050			
Treatments x Days of incubation		0.044		NS			

The soil reaction (pH) of saline sodic soil due to the use of FeSO_4 , ZnSO_4 , FYM, *Thiobacillus ferrooxidans* and their conjoint use in saline sodic soil was significantly reduced. It was reduced from 8.41 to 8.23. The conjunctive use of FeSO_4 , ZnSO_4 and FYM and *Thiobacillus ferrooxidans* significantly reduced soil pH (8.23) which was on par with the use of FeSO_4 , ZnSO_4 and FYM (8.25). The use of FYM alone and $\text{FeSO}_4 + \text{ZnSO}_4$ was on par for their pH value.

The reduction in soil pH might be due to the amending effect of FeSO_4 . It is an acid former amendment. When FeSO_4 is applied to calcareous alkali soils following reactions take place.

- i. $\text{FeSO}_4 + \text{H}_2\text{O} \leftrightarrow \text{H}_2\text{SO}_4 + \text{FeO}$
- ii. $\text{H}_2\text{SO}_4 + \text{CaCO}_3 \leftrightarrow \text{CaSO}_4 + \text{CO}_2 + \text{H}_2\text{O}$
- iii. $2 \text{NaX} + \text{CaSO}_4 \leftrightarrow \text{Ca X}_2 + \text{Na}_2\text{SO}_4 \downarrow$

(Richards 1954)

The H_2SO_4 so produced might be responsible for reduction in soil pH. Further $\text{CO}_2 + \text{H}_2\text{O}$ may produce H_2CO_3 which would be again helpful in reducing soil pH. The addition of FYM improved the physical and biological properties of soil, forming of organic acids may helps to reduce the soil pH. The use of *Thiobacillus ferrooxidans* might have oxidized different forms of sulphur and released the elemental sulphur, further elemental sulphur may form sulphurous acid leading to reduce soil pH.

The change in pH of saline sodic soil was observed significantly as a function of incubation period. The decrease in pH

over a period of incubation was from 8.38 to 8.23. The significant reduction in pH was observed from an incubation period of 45th days to 120th days.

4.3.2 Electrical conductivity

The data in respect of electrical conductivity of saline sodic soil as affected by the application FeSO₄, ZnSO₄, FYM, *Thiobacillus ferrooxidans* and their conjunctive use are presented in Table 20.

The electrical conductivity of saline sodic soil was significantly increased by the conjoint use of FeSO₄, ZnSO₄, FYM and *Thiobacillus ferrooxidans* (2.22 dSm⁻¹) which was on par with the use of FeSO₄, ZnSO₄ and FYM (2.19 dSm⁻¹). Whereas, combined use of FeSO₄ and ZnSO₄ (2.15 dSm⁻¹) and FeSO₄ + ZnSO₄ + *Thiobacillus ferrooxidans* (2.14 dsm⁻¹) was on par for their electrical conductivity.

The increase in electrical conductivity with increase in incubation period was observed from 1.95 to 2.23 dSm⁻¹. The incubation period of 45, 60, 90 and 120 days were found on par for increased electrical conductivity (2.17, 2.20, 2.22 and 2.23 dSm⁻¹ respectively).

The interactions between the incubation period and conjoint use of FeSO₄, ZnSO₄, FYM and *Thiobacillus ferrooxidans* were significant to change the electrical conductivity of soil. The rate of increase in electrical conductivity was maximum in interaction of an incubation period and use of FeSO₄ + ZnSO₄ + FYM (1.96 to 2.37

Table 20. Effect of FeSO_4 + ZnSO_4 on electrical conductivity (dSm^{-1}) of saline sodic soil during incubation

Days of incubation	Treatments						
	T ₁	T ₂	T ₃	T ₄	T ₅	T ₆	Mean
0	1.93	1.93	1.96	1.96	1.96	1.97	1.95
2	1.93	1.95	1.99	1.99	1.98	2.01	1.98
4	1.98	1.95	2.02	2.00	1.99	2.03	1.99
10	1.92	1.98	2.10	2.14	2.10	2.16	2.07
20	1.94	1.98	2.12	2.18	2.13	2.19	2.09
30	1.94	2.01	2.15	2.25	2.16	2.29	2.13
45	1.94	2.01	2.24	2.29	2.19	2.34	2.17
60	1.96	2.00	2.28	2.35	2.25	2.38	2.20
90	1.93	2.00	2.32	2.37	2.33	2.39	2.22
120	1.96	2.00	2.32	2.37	2.33	2.39	2.23
Mean	1.94	1.98	2.15	2.19	2.14	2.22	-
		SE $\pm$		CD at 5 %			
Treatments		0.017		0.048			
Days of incubation		0.022		0.061			
Treatments x Days of incubation		0.053		0.15			

dSm⁻¹ and FeSO₄ + ZnSO₄ + FYM + *Thiobacillus ferrooxidans* (1.97 to 2.39 dSm⁻¹).

The interaction effects on electrical conductivity of saline sodic soil were on par at 45, 60, 90 and 120 days of incubation with various treatments. The increase in electrical conductivity of saline sodic soil might be attributed to decrease in soil pH enhancing the solubility of salts. The SO₄²⁻ content of soil increased with the addition of ZnSO₄ and FeSO₄ forms salts with Na, Ca and Mg. These salts might have influenced an increase electrical conductivity. Thus, conjunctive use of FeSO₄, ZnSO₄, FYM and *Thiobacillus ferrooxidans* were conducive in increasing the electrical conductivity of saline sodic soil.

4.3.3 Ammonical nitrogen (NH₄⁺-N)

The data on ammonical nitrogen content of saline sodic soil by the use of FeSO₄, ZnSO₄, FYM, *Thiobacillus ferrooxidans*, their conjoint use and incubation period are reported in Table 21.

The conjunctive use of FeSO₄ + ZnSO₄ + FYM alongwith the *Thiobacillus ferrooxidans* significantly increased the amount of ammonical nitrogen (38.15 and 38.55 mg kg⁻¹ soil) in saline sodic soil followed by FYM alone (34.87 mg kg⁻¹ soil). The combined use of FeSO₄ and ZnSO₄ (17.67 mg kg⁻¹ soil) and FeSO₄ + ZnSO₄ + *Thiobacillus ferrooxidans* (17.88 mg kg⁻¹ soil) were numerically increased ammonical nitrogen over control (16.57 mg kg⁻¹ soil).

Table 21. Effect of FeSO₄ + ZnSO₄ on periodical release of NH₄⁺-N (mg kg⁻¹) in saline sodic soil

Days of incubation	Treatments						
	T ₁	T ₂	T ₃	T ₄	T ₅	T ₆	Mean
0	21.00	22.71	21.00	22.71	21.00	22.71	21.86
2	21.00	28.00	21.00	28.98	21.00	28.98	24.83
4	22.75	31.50	24.85	37.23	24.11	37.44	29.65
10	24.50	35.00	35.60	40.48	25.86	40.07	31.92
20	15.75	38.50	17.95	40.00	18.21	41.44	28.80
30	13.50	40.25	15.70	41.62	16.96	42.19	28.37
45	12.95	42.75	14.05	41.69	14.77	42.69	28.15
60	12.00	42.00	13.10	42.00	14.31	42.94	28.24
90	11.50	46.75	12.60	42.50	11.58	43.29	28.04
120	10.75	48.25	10.75	43.29	11.00	43.75	27.97
Mean	16.57	34.87	17.67	37.15	17.88	38.55	-
SE ±							
CD at 5 %							
Treatments	1.15			3.25			
Days of incubation	1.49			4.20			
Treatments x Days of incubation	3.64			10.29			

The ammonical nitrogen content of soil was increased irrespective of the treatment effect upto 20 days of incubation. Thereafter, it was gradually decreased upto 120 days of an incubation. Further, incubation periods were found significant in influencing the ammonical nitrogen content in saline sodic soil.

The interaction effects of the various treatments and incubation period were significant for ammonical nitrogen content of saline sodic soil. The magnitude of release of ammonical nitrogen as result of interaction effect was more in conjoint use of $\text{FeSO}_4 + \text{ZnSO}_4 + \text{FYM} + \text{Thiobacillus ferrooxidans}$.

The change in ammonical nitrogen content in saline sodic soil was probably associated with the use of organic manure. The transformation and mineralization of nitrogen from soil organic matter was rather slow in saline sodic soils because of its high pH and salt concentration. These observations are in accordance with those reported earlier by Vinod Kumar^{et.al.} (1988).

4.3.4 Nitrate nitrogen ($\text{NO}_3\text{-N}$)

The use of FeSO_4 , ZnSO_4 , FYM, *Thiobacillus ferrooxidans*, their combined use and incubation period in saline sodic soil influenced the nitrate nitrogen content. The data in this respect are reported in Table 22.

The nitrate nitrogen content was significantly influenced by the use of FeSO_4 , ZnSO_4 , FYM, *Thiobacillus ferrooxidans* and their conjunctive use in saline sodic soil. The application of $\text{FeSO}_4 + \text{ZnSO}_4$

Table 22. Effect of FeSO_4 + ZnSO_4 on periodical release of $\text{NO}_3\text{-N}$ (mg kg^{-1}) in saline sodic soil

Days of incubation	Treatments						
	T ₁	T ₂	T ₃	T ₄	T ₅	T ₆	Mean
0	28.00	35.00	33.25	36.75	33.25	54.42	36.78
2	31.50	35.00	33.25	38.75	33.25	54.42	37.70
4	31.50	60.25	35.00	64.15	35.00	57.92	47.30
10	33.25	67.25	36.75	65.90	38.50	63.17	50.80
20	42.50	68.75	42.00	71.15	38.50	66.67	54.93
30	43.10	70.75	43.75	71.15	42.00	67.67	56.40
45	45.50	73.75	43.75	72.90	45.50	68.42	58.30
60	47.15	75.50	45.50	74.65	45.50	71.42	59.95
90	48.15	77.50	45.50	75.65	49.00	73.22	61.50
120	49.00	80.50	49.00	77.15	52.50	73.67	63.64
Mean	39.97	64.63	40.78	64.75	41.30	65.10	-
		SE $\pm$		CD at 5 %			
Treatments		1.13		3.19			
Days of incubation		1.46		4.12			
Treatments x Days of incubation		3.66		10.08			

and $\text{FeSO}_4 + \text{ZnSO}_4 + \text{Thiobacillus ferrooxidans}$ had no significant effect on nitrate nitrogen content of soil. However, the conjoint use of $\text{FeSO}_4 + \text{ZnSO}_4 + \text{FYM}$ ($64.75 \text{ mg kg}^{-1} \text{ soil}$) and $\text{FeSO}_4 + \text{ZnSO}_4 + \text{Thiobacillus ferrooxidans} + \text{FYM}$ (65.10 mg kg^{-1}) and FYM alone ($64.45 \text{ mg kg}^{-1} \text{ soil}$) in saline sodic soil were significant for nitrate nitrogen over other treatments and on par with each other.

This might be because of additive effects of FYM with $\text{FeSO}_4 + \text{ZnSO}_4$ for higher mineralization of nitrogen. This was attributed to lowering of soil pH due to $\text{FeSO}_4 + \text{ZnSO}_4$ either alone or with FYM and might have reduced loss of nitrogen through volatilization and caused higher nitrification. The organic matter stimulates the *Nitrosomonas* activities which are responsible for conversion of $\text{NH}_4^+\text{-N}$ to $\text{NO}_2^-\text{-N}$. There might be less accumulation of $\text{NO}_2^-\text{-N}$.

The similar finding were observed by Martin *et al.* 1942, Chapman and Leibig, (1952), Williamson and Willey, (1964), Fenn and Kissel, (1973), Sahrawat, (1979), Vinod Kumar^{et.al.} (1988), Sharma *et al.* (1992), Singh and Prasad (1992), Dinesh and Dubey, (1999), Yaduvanshi, (2001).

The incubation period had significant effect on nitrate nitrogen content of saline sodic soil. The nitrate nitrogen was increased with an advanced incubation period. The increase of nitrogen as a function of incubation period was 36.78 to $63.64 \text{ mg kg}^{-1} \text{ soil}$. The highest nitrate nitrogen was registered at 120th days of an

incubation (63.64 mg kg⁻¹ soil) followed by 90th days (61.50 mg kg⁻¹ soil) of incubation period.

The interaction effects of the various treatments for nitrate nitrogen were significant and followed similar trend as was observed in the release of ammonical nitrogen.

4.3.5 Available phosphorus

The available phosphorus of saline sodic soil as influenced by the use of FeSO₄, ZnSO₄, FYM, *Thiobacillus ferrooxidans* and their combined use and incubation period are presented in Table 23.

The data reveal that the available phosphorus contents of saline sodic soil were significantly changed due to various treatments. It was ranged between 6.99-11.18 mg kg⁻¹ soil. The use of FeSO₄ + ZnSO₄ + *Thiobacillus ferrooxidans* in conjunction with FYM recorded the highest amount of available phosphorus (11.18 mg kg⁻¹ soil) followed by and on par with FeSO₄ + ZnSO₄ + FYM (11.07 mg kg⁻¹ soil). The use of FYM alone (10.38 mg kg⁻¹ soil) recorded significantly higher amount of available phosphorus over FeSO₄ + ZnSO₄ + *Thiobacillus ferrooxidans* (7.99 mg kg⁻¹ soil). However, use of FeSO₄ + ZnSO₄ and FeSO₄ + ZnSO₄ + *Thiobacillus ferrooxidans* significantly increased available phosphorus over control.

The increase in available phosphorus due to FeSO₄, ZnSO₄, *Thiobacillus ferrooxidans* application might be because of production of H₂SO₄ which reduced the soil pH and increased the

Table 23. Effect of FeSO₄ + ZnSO₄ on periodical release of phosphorus (mg kg⁻¹) in saline sodic soil

Days of incubation	Treatments						
	T ₁	T ₂	T ₃	T ₄	T ₅	T ₆	Mean
0	6.36	6.61	6.36	6.61	6.36	6.61	6.48
2	6.87	7.12	6.87	8.89	6.89	8.90	7.59
4	6.87	7.63	6.89	9.37	6.95	9.47	7.86
10	7.87	8.65	7.97	9.39	8.00	9.49	8.40
20	6.86	9.16	8.06	9.45	8.10	9.84	8.58
30	7.12	9.16	8.35	9.54	8.37	9.64	8.70
45	7.12	12.45	8.40	12.65	8.73	12.75	10.35
60	7.63	12.71	8.50	12.91	8.67	13.00	10.57
90	7.12	15.13	8.56	15.89	8.87	15.95	11.92
120	7.12	15.25	8.66	16.00	8.96	16.10	12.02
Mean	6.99	10.38	7.87	11.07	7.99	11.18	-
SE ±							
CD at 5 %							
Treatments	0.22			0.62			
Days of incubation	0.28			0.80			
Treatments x Days of incubation	0.69			1.96			

available phosphorus. The conjoint use of FeSO_4 , ZnSO_4 , *Thiobacillus ferrooxidans* with FYM might have helped to increase the available phosphorus significantly which was attributed to production of organic acids like H_2SO_4 , H_2SO_3 , H_2CO_3 responsible for lowering the soil pH and enhanced the availability of phosphorus. Similarly the $\text{SO}_4^{=}$ ions might have reduced the concentration of calcium by forming the salt of CaSO_4 leading to increased availability of phosphorus. Prabhakar *et al.* (1972) reported that certain acids and carbon dioxide formed during decomposition of organic matter had solubilizing effects on iron, aluminium, magnesium and calcium phosphate. The phosphorus contained in organic matter is liberated as the decomposition proceeds which in turn increases the available phosphorus content in soil. The organic anions and hydroxy acids such as tartaric, citric, malonic and malic acid liberated during the decomposition of organic manure may complex or chelate iron, aluminum, magnesium and calcium and prevent them from reacting with phosphate to form insoluble phosphates.

The significant increase in available phosphorus was observed with an increase in incubation period. The increase in available phosphorus ranged ^{FYM} from 6.48 mg kg⁻¹ to 12.02 mg kg⁻¹ soil. The incubation period of 90th and 120th days were on par for available phosphorus content of soil (11.92 and 12.02 mg kg⁻¹ soil, respectively).

The interaction effects were significant for the available phosphorus content of saline sodic soil. The magnitude of release of available phosphorus as a result of interaction effect was more in conjoint use of $\text{FeSO}_4 + \text{ZnSO}_4 + \text{FYM} + \text{Thiobacillus ferrooxidans}$ (6.61 to 16.10 mg kg^{-1} soil) followed by $\text{FeSO}_4 + \text{ZnSO}_4 + \text{FYM}$ (6.61 to 16.00 mg kg^{-1} soil) and FYM alone (6.61 to 15.25 mg kg^{-1} soil).

Thus, the conjunctive use of $\text{FeSO}_4 + \text{ZnSO}_4 + \text{FYM}$ alongwith *Thiobacillus ferrooxidans* found beneficial to enhance the availability of phosphorus in saline sodic soil.

4.3.6 DTPA Zinc

The DTPA zinc content of saline sodic soil as influenced by the application of FeSO_4 , ZnSO_4 , FYM, *Thiobacillus ferrooxidans*, their conjoint use and incubation period are reported in Table 24.

The conjoint use of FeSO_4 , ZnSO_4 , FYM and *Thiobacillus ferrooxidans* significantly increased the zinc content (2.73 mg kg^{-1} soil) of saline sodic soil which was closely followed by $\text{FeSO}_4 + \text{ZnSO}_4 + \text{FYM}$ (2.70 mg kg^{-1} soil). The use of $\text{FeSO}_4 + \text{ZnSO}_4 + \text{Thiobacillus ferrooxidans}$ recorded 2.46 mg kg^{-1} soil zinc and $\text{FeSO}_4 + \text{ZnSO}_4$ recorded 2.43 mg kg^{-1} of zinc in saline sodic soil.

The availability of zinc in saline sodic soil increased with an increase in incubation period. The increase of zinc was from 1.56 to 2.17 mg kg^{-1} soil. The available zinc at 30, 45, 60, 90 and 120 days of incubation were on par (1.93, 1.99, 2.06, 2.10 and 2.17 mg kg^{-1} soil, respectively).

**Table 24. Effect of FeSO_4 + ZnSO_4 on periodical release of DTPA
Zn (mg kg^{-1} soil) in saline sodic soil**

Days of incubation	Treatments						
	T ₁	T ₂	T ₃	T ₄	T ₅	T ₆	Mean
0	0.38	0.38	2.16	2.16	2.14	2.16	1.56
2	0.38	0.40	2.18	2.26	2.14	2.16	1.59
4	0.40	0.40	2.20	2.22	2.18	2.20	1.60
10	0.40	0.40	2.40	2.48	2.40	2.56	1.77
20	0.40	0.44	2.48	2.60	2.46	2.70	1.85
30	0.42	0.48	2.48	2.80	2.54	2.84	1.93
45	0.40	0.48	2.54	2.94	2.60	2.96	1.99
60	0.42	0.50	2.56	3.06	2.70	3.10	2.06
90	0.40	0.50	2.64	3.16	2.72	3.20	2.10
120	0.44	0.50	2.64	3.36	2.70	3.40	2.17
Mean	0.40	0.45	2.43	2.70	2.46	2.73	-
SE $\pm$ CD at 5 %							
Treatments			0.055		0.16		
Days of incubation			0.071		0.20		
Treatments x Days of incubation			0.18		0.49		

The interaction was significant for availability of zinc in saline sodic soil. The conjoint use of $\text{FeSO}_4 + \text{ZnSO}_4 + \text{FYM} + \text{Thiobacillus ferrooxidans}$ with incubation period was superior over all other treatments.

The increase in Zn availability in ZnSO_4 treated soil might be due to addition Zn through ZnSO_4 . Zinc availability is enhanced with increasing levels of Zn by its application. Rahmatullah (1984) reported that more than 70 % of Zn could not be extracted by 0.005 N DTPA in loamy clay soils after 4 weeks.

The enhanced effects of $\text{ZnSO}_4 + \text{FeSO}_4$ along with FYM in releasing DTPA-Zn might be due to its chelating action. The increased biological activities might have hastened the decomposition of organic matter present in soil. During the decomposition of organic matter, root exudation and microbial synthesis by *rhizosphere*, organic acids, amino acids and phenolic compounds might have formed in soils. Thus, the capacity factor might have decreased due to addition of organic manure (FYM). The decrease in capacity factor with application of manure indicated that more of zinc from the soil phase has entered to the solution phase by forming stable complexes with the organic manure. The organic manure enhanced the diffusion rate of zinc in all the soils.

Chand Milap *et al.* (1980) reported that the application of fulvic acid to a saline sodic soil augmented the solubility of Zn by more than 1000 folds. Chand Millap *et al.* (1981) also reported that zinc chelates were more effective than zinc sulphate.

Thus, the results indicated that the availability of zinc in saline sodic soil only can be managed by conjoint use of $\text{FeSO}_4 + \text{ZnSO}_4 + \text{Thiobacillus ferrooxidans}$ and FYM. Similarly, it is interesting to note that the availability of zinc was persisted for period from 30th to 120th days of incubation.

Similar findings were reported by Daulat Ram *et al.* (1976), Takkar and Singh (1978), Jadhav *et al.* (1981), Sachdev and Deb (1981), Singh *et al.* (1982), Chatterjee *et al.* (1983), Rahmatullah (1984), Singh and Abrol (1986), Sharma and Deb (1988).

4.3.7 DTPA iron

The data regarding the effects of conjunctive use of FeSO_4 , ZnSO_4 , *Thiobacillus ferrooxidans*, FYM alone, interactions of treatments and incubation period are reported in Table 25.

The DTPA iron content significantly influenced by the use of different treatments in saline sodic soil. It was ranged from 3.94 to 6.25 mg kg⁻¹ soil. The use of $\text{FeSO}_4 + \text{ZnSO}_4$ alone and in conjunction with *Thiobacillus ferrooxidans* were found on par with each other for DTPA Fe of saline sodic soil (2.43 and 2.46 mg kg⁻¹ soil). The highest DTPA iron (6.25 mg kg⁻¹ soil) was recorded in $\text{FeSO}_4 + \text{ZnSO}_4 + \text{FYM} + \text{Thiobacillus ferrooxidans}$, which was closely followed by $\text{FeSO}_4 + \text{ZnSO}_4 + \text{FYM}$ (6.24 mg kg⁻¹ soil). These treatments were significantly superior over rest of the treatments.

The DTPA Fe was found on par with 30, 45, 60, 90 and 120 days of an incubation period. These observations were indicated

Table 25. Effect of $\text{FeSO}_4 + \text{ZnSO}_4$ on periodical release of DTPA-Fe (mg kg^{-1}) in saline sodic soil

Days of incubation	Treatments						
	T ₁	T ₂	T ₃	T ₄	T ₅	T ₆	Mean
0	3.90	3.96	5.20	5.28	5.28	5.28	4.82
2	3.94	3.96	5.26	5.32	5.30	5.36	4.86
4	3.94	3.98	5.28	5.36	5.28	5.38	4.87
10	3.92	3.98	5.36	5.58	5.30	5.66	4.98
20	3.94	4.08	5.48	6.12	5.26	6.26	5.23
30	3.94	4.16	6.00	6.92	5.38	7.02	5.68
45	3.98	4.86	6.06	6.87	5.52	6.46	5.71
60	3.96	5.16	6.06	6.96	6.32	7.02	5.91
90	3.96	5.16	6.06	6.98	6.67	7.00	5.97
120	3.90	5.20	6.10	7.04	6.73	7.04	6.00
Mean	3.94	4.45	5.69	6.24	5.69	6.25	-
		SE $\pm$		CD at 5 %			
Treatments		0.054		0.16			
Days of incubation		0.071		0.20			
Treatments x Days of incubation		0.17		0.49			

that the DTPA Fe sustained for a period of 30 days of incubation to 120 days of an incubation period in saline sodic soil.

The interaction of treatments and incubation periods were significant for DTPA Fe content in saline sodic soil. It was ranged from 3.90 mg kg⁻¹ soil to 7.04 mg kg⁻¹ soil. The DTPA Fe increased in all the treatments with advanced days of incubation. The order of increase in DTPA Fe was in an interaction between FeSO₄ + ZnSO₄ + FYM + *Thiobacillus ferrooxidans* > FeSO₄ + ZnSO₄ + FYM > FeSO₄ + ZnSO₄ + *Thiobacillus ferrooxidans* > FeSO₄ + ZnSO₄ > FYM > Control. The increase in Fe availability due to addition of FeSO₄ + ZnSO₄ is ultimately due to addition of Fe from FeSO₄. Sachdev and Deb (1981) reported the similar findings.

The increase in available Fe due to application of FYM alongwith FeSO₄ + ZnSO₄ was might be due to iron released during microbiological breakdown of organic residues contributed directly in supplying available Fe. Organic matter added to soils deficient in available Fe often corrects the deficiency. Organic matter can be subjected to partial decomposition and give rise to organic acids and breakdown products which combine to form soluble Fe-organic complexes. Influence of organic matter on the availability of iron is probably owing to its higher state of reduction developed in presence of decomposing organic matter which subsequently reduced the Fe³⁺ to Fe²⁺ form.

Elgala and Amberger (1982) reported that an increase in extractable Fe from FeSO₄ treatment of alkaline soil was evident only when the soil was enriched with organic matter and incubated for three months. Addition of iron salts to correct the deficiency was not useful unless it was accompanied by changes in the oxidation status of the soil brought about by addition of organic matter. These findings are in accordance with the result observed by many workers Katyal and Sharma (1980), Swarup (1980), Jha *et al.* (1984), Pendias and Pendias (1984), Sakal *et al.* (1986), Rajkumar^{*et al.*} (1990), Lindsay (1991).

Babaria and Patel (1980) observed progressive increase in incubation period increased the available iron. Jha *et al.* (1984) reported the high degree of correlation between available Zn and Fe indicating their close association.

4.4 Integrated nutrient application in saline sodic soil

Saline sodic soils are either deficient in their nutrient status or inhibited nutrient availability by the antagonistic effects of nutrient elements present in excessive amount as soluble or exchangeable ions or both. To mitigate the adverse effect of excessive salts or exchangeable sodium, it is necessary to increase the fertility status of such salt affected soils through judicious use of fertilizers. In this context it is therefore of prime importance to have integrated system of nutrient supply.

The observations recorded and results obtained in the studies on effect of conjoint use of inorganic, organic and biofertilizers in saline sodic soil pertaining to soil properties and nutrient availability are presented and discussed in the following subheads.

4.4.1 Soil pH

The periodical changes in pH of saline sodic soil as influenced by integrated nutrient application and incubation period are reported in Table 26. The addition of an integrated nutrients to saline sodic soil was found significant to change the soil pH. The pH of the saline sodic soil was observed to be reduced from 8.42 to 8.23. The use of FYM as one of the components of integrated nutrient application in T₄ (8.29), T₆ (8.29), T₇ (8.25), T₁₀ (8.25) and T₁₂ (8.23) reduced soil pH significantly over rest of the treatments. Similarly, the use of urea, single superphosphate, FeSO₄, ZnSO₄ and biofertilizers in combination with each other reduced soil pH significantly over control.

The reduction in soil pH due to application of FYM alongwith different sources of nutrients may be attributed to formation of acids by the reaction between inorganic fertilizers, release of organic acids on decomposition of added FYM and conversion of nutrient elements in the available forms due to the activity of micro-organisms supplied through various biofertilizers.

Table 26. Effect of integrated nutrient management on pH of saline sodic soil during incubation

Treatments	Days of incubation										
	0	2	4	10	20	30	45	60	90	120	Mean
T ₁	8.40	8.40	8.41	8.41	8.42	8.41	8.42	8.43	8.43	8.42	8.41
T ₂	8.39	8.39	8.37	8.35	8.35	8.32	8.30	8.30	8.30	8.25	8.33
T ₃	8.39	8.38	8.40	8.33	8.33	8.31	8.31	8.28	8.28	8.26	8.33
T ₄	8.36	8.34	8.34	8.30	8.30	8.28	8.28	8.25	8.23	8.22	8.29
T ₅	8.40	8.40	8.37	8.32	8.33	8.31	8.31	8.31	8.29	8.26	8.33
T ₆	8.38	8.38	8.33	8.30	8.30	8.27	8.27	8.25	8.22	8.22	8.29
T ₇	8.35	8.34	8.32	8.27	8.23	8.22	8.19	8.17	8.17	8.20	8.25
T ₈	8.40	8.40	8.38	8.32	8.29	8.29	8.23	8.23	8.21	8.21	8.30
T ₉	8.39	8.38	8.36	8.30	8.28	8.27	8.26	8.21	8.21	8.21	8.29
T ₁₀	8.38	8.38	8.36	8.27	8.24	8.22	8.17	8.16	8.16	8.16	8.25
T ₁₁	8.35	8.35	8.33	8.29	8.20	8.19	8.18	8.17	8.17	8.14	8.31
T ₁₂	8.34	8.35	8.33	8.27	8.21	8.19	8.19	8.17	8.14	8.10	8.23
Mean	8.41	8.37	8.35	8.30	8.28	8.27	8.25	8.24	8.23	8.21	
S.E. $\pm$ CD at 5 %											
Treatments	0.011					0.030					
Days of incubation	0.0099					0.028					
Treatments $\times$ Days of incubation	0.034					NS					

The soil pH was decreased significantly with an increase of an incubation period irrespective of the treatments. The reduction in pH of saline sodic soil was ranged form 8.41 to 8.21. The interactions between integrated nutrient treatment and incubation period were non-significant for influencing the pH of saline sodic soil. From these results it could be seen that the reduction in soil pH was more in integrated nutrient application as compared with application of single nutrient through its respective source.

4.4.2 Electrical conductivity

The data regarding electrical conductivity of saline sodic soil as influenced by the treatments of integration, incubation period and their interactions are reported in Table 27.

The application of integrated nutrients significantly increased electrical conductivity of saline sodic soil. The highest electrical conductivity of saline sodic soil was registered in an integration of urea + single superphosphate + FeSO_4 + ZnSO_4 + biofertilizers + FYM (2.33 dSm^{-1}) which was closely followed and on par with urea + single superphosphate + FeSO_4 + ZnSO_4 + biofertilizers (2.31 dSm^{-1}). Similar trend was observed in treatment T_4 (2.18 dsm^{-1}) and T_5 (2.19 dSm^{-1}).

The increase in electrical conductivity of saline sodic soil due to the integrated nutrient supply approach was associated with the dissolution of salts by the acids formed in an integration of nutrients and SO_4^{2-} ions released from FeSO_4 , ZnSO_4 and single

Table 27. Effect of integrated nutrient management on electrical conductivity (dSm^{-1}) of saline sodic soil during incubation

Treatments	Days of incubation										
	0	2	4	10	20	30	45	60	90	120	Mean
T ₁	1.93	1.93	1.98	1.92	1.94	1.94	1.94	1.95	1.93	1.96	1.94
T ₂	1.93	1.95	1.95	1.98	1.98	2.01	2.01	2.00	2.00	2.00	1.98
T ₃	2.02	2.05	2.10	2.13	2.15	2.16	2.18	2.19	2.22	2.25	2.15
T ₄	2.02	2.07	2.11	2.15	2.20	2.21	2.23	2.25	2.28	2.29	2.18
T ₅	2.02	2.07	2.13	2.16	2.22	2.23	2.25	2.27	2.28	2.30	2.19
T ₆	2.03	2.07	2.15	2.17	2.25	2.27	2.14	2.30	2.32	2.32	2.20
T ₇	2.01	2.03	2.05	2.07	2.10	2.10	2.14	2.19	2.39	2.39	2.15
T ₈	2.03	2.06	2.07	2.08	2.11	2.11	2.13	2.17	2.41	2.41	2.16
T ₉	2.05	2.08	2.09	2.11	2.13	2.13	2.17	2.19	2.43	2.43	2.17
T ₁₀	2.05	2.07	2.10	2.26	2.30	2.36	2.40	2.46	2.46	2.48	2.29
T ₁₁	2.05	2.09	2.11	2.28	2.31	2.37	2.42	2.48	2.48	2.50	2.31
T ₁₂	2.05	2.10	2.12	2.29	2.33	2.39	2.46	2.50	2.52	2.53	2.33
Mean	2.02	2.05	2.08	2.13	2.17	2.19	2.21	2.24	2.31	2.32	
S.E. $\pm$ CD at 5 %											
Treatments	0.011					0.030					
Days of incubation	0.0097					0.027					
Treatments $\times$ Days of incubation	0.034					0.094					

superphosphate formed salts like Na_2SO_4 , MgSO_4 and CaSO_4 which has increased the electrical conductivity of soil.

The incubation periods were also significant in influencing the electrical conductivity of the soil. There was an increasing trend in electrical conductivity with an increase of incubation period. The incubation period of 20, 30, 45, 60, 90 and 120 days showed linear increase in electrical conductivity of saline sodic soil. However, it was on par with each other.

The interaction between treatments and incubation period significantly increased the electrical conductivity of saline sodic soil. The interactions of 0, 2 and 4 days with T_3 to T_{12} treatments were on par for their electrical conductivity. Whereas, interactions between T_{10} , T_{11} and T_{12} with 10, 20, 30, 45, 60, 90 and 120 days of incubation were on par for the electrical conductivity of saline sodic soil. These observations are in accordance with those of reported by Richards (1954) and Basak (2000).

The results revealed that the electrical conductivity of saline sodic soil was increased by the conjoint use of urea, single superphosphate, ferrous sulphate, zinc sulphate, farmyard manure and biofertilizers. The conjoint use of organic, inorganic and biofertilizers was beneficial for alteration of pH of saline sodic soil and its electrical conductivity.

4.4.3 Ammonical nitrogen ($\text{NH}_4^+\text{-N}$)

The data pertaining to ammonical nitrogen as influenced by integrated use of inorganic, organic, biofertilizers, incubation periods and their interactions are reported in Table 28 and graphically depicted in Fig. 1.

It could be observed from the data that the ammonical nitrogen content of saline sodic soil was higher wherein nutrients were applied with FYM. The higher magnitude of ammonical nitrogen was observed in T_{12} (114.85 mg kg^{-1} soil), followed by T_{10} (113.47 mg kg^{-1} soil), T_7 (109.54 mg kg^{-1} soil), T_6 (111.88 mg kg^{-1} soil) and T_4 (110.63 mg kg^{-1} soil). These treatments were at par with each other. The application of inorganic fertilizers *viz.*, urea, single superphosphate, FeSO_4 and ZnSO_4 significantly increased the ammonical nitrogen over control. The release of ammonical nitrogen was higher with integration of more than one nutrient indicating beneficial role of different nutrient sources for ammonification.

The ammonical nitrogen content was increased significantly with an increase in an incubation period of 20 days. Thereafter, it was drastically reduced from 212.27 mg kg^{-1} soil to 76.84 mg kg^{-1} soil at 20 days and 30 days of incubation. The drastic reductions might be associated with transformation of ammonical nitrogen to nitrate nitrogen.

The interactions between treatments and incubation periods for ammonical nitrogen of saline sodic soil were significant.

Table 28. Effect of integrated nutrient management on periodical release of $\text{NH}_4^+\text{-N}$ (mg kg^{-1}) in saline sodic soil

Treatments	Days of incubation										Mean
	0	2	4	10	20	30	45	60	90	120	
T ₁	21.00	21.00	22.75	24.50	15.75	13.50	12.95	12.00	11.50	10.75	16.57
T ₂	22.71	28.00	31.50	35.00	38.50	40.25	42.75	45.00	46.75	48.25	34.87
T ₃	40.50	104.25	147.00	231.00	241.00	72.75	52.00	38.50	30.00	23.75	98.08
T ₄	37.50	102.50	158.00	251.00	253.50	95.27	59.90	51.95	48.50	47.75	110.63
T ₅	40.50	104.25	150.00	233.00	242.00	73.75	54.00	39.50	32.00	25.50	99.45
T ₆	37.95	102.50	160.00	253.00	254.50	97.27	61.50	54.00	49.50	48.50	111.88
T ₇	37.95	102.50	154.00	250.00	252.50	94.27	58.90	50.95	47.50	46.75	109.54
T ₈	40.50	103.50	146.00	231.00	239.00	71.75	52.00	37.50	30.00	23.75	97.50
T ₉	40.50	104.25	152.00	235.00	243.00	75.75	55.00	40.50	33.00	25.50	100.45
T ₁₀	37.95	102.50	162.00	255.00	256.50	99.27	63.50	56.00	51.50	50.50	113.47
T ₁₁	40.50	104.25	154.00	239.00	245.00	76.75	58.00	41.50	33.00	25.50	101.75
T ₁₂	37.95	102.50	165.00	257.00	259.00	100.50	64.50	58.00	53.50	50.50	114.85
Mean	36.29	90.17	133.52	207.88	212.27	76.84	53.87	44.83	39.83	36.35	-
S.E. $\pm$ CD at 5 %											
Treatments					2.28		6.37				
Days of incubation					2.08		5.82				
Treatments x Days of incubation					7.20		20.15				

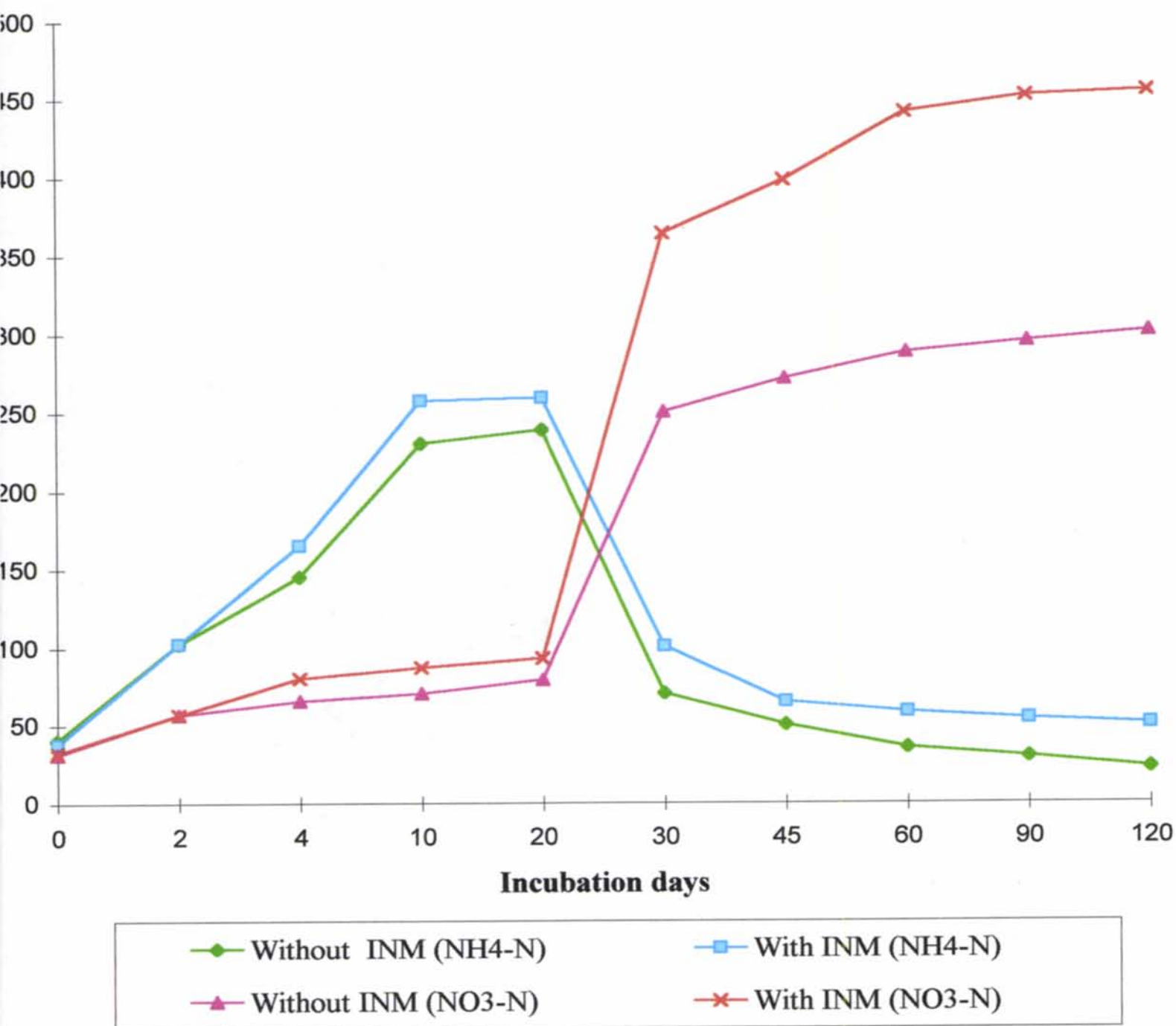


Fig. 1. Periodical release of ammonical and nitrate nitrogen as influenced by integrated nutrient management

The interactions between treatments with 4, 10 and 20 days of an incubation periods were significantly superior over rest of the interactions. Which was on par with each other. The ammonical nitrogen increased in all the interactions upto 20 days and 30 days of incubation and thereafter, the drastic reduction was observed. This might be attributed to completion of ammonification process in soil by organisms and the least availability of substrate for ammonification. Similarly, the enzymatic oxidation of ammonia to nitrates was started by the organisms in the soil. Further, the decrease in soil pH might have helped to reduce the loss of ammonia through volatilization and completed the hydrolysis of urea.

These observations are in conformity with the findings of Nitant (1974), Nitant and Bhumbla (1974), Sahrwat (1979), Bandopadhyay and Bandopadhyay (1983) and Sharma and Chauhan (1994).

Thus, the conjoint application of urea, single superphosphate, ferrous sulphate, zinc sulphate and biofertilizers were found beneficial for the release of ammonical nitrogen in saline sodic soil.

4.4.4 Nitrate nitrogen ($\text{NO}_3\text{-N}$)

The data pertaining to the effects of integrated nutrient application incubation period and their interactions on the release of nitrate nitrogen in saline sodic soil are presented in Table 29 and graphically presented in Fig. 1.

Treatments	Days of incubation										Mean
	0	2	4	10	20	30	45	60	90	120	
T ₁	28.00	31.50	31.50	33.25	42.50	43.10	45.50	47.15	48.15	49.00	39.97
T ₂	35.00	35.00	60.25	67.25	68.75	70.75	73.75	75.50	77.50	80.50	64.43
T ₃	32.50	58.50	70.00	73.90	85.00	255.00	276.00	297.00	302.10	317.25	176.73
T ₄	32.50	54.40	76.50	82.50	87.50	359.00	390.00	436.00	442.00	445.00	240.54
T ₅	32.50	59.00	71.50	74.50	87.00	257.00	279.00	299.00	304.00	319.00	178.25
T ₆	32.50	56.40	78.50	83.00	89.90	361.00	393.00	439.00	445.00	447.00	242.53
T ₇	32.50	54.40	74.50	80.50	85.50	356.00	387.00	435.00	438.50	443.20	238.71
T ₈	35.50	56.50	68.50	72.95	83.15	254.00	275.00	295.00	301.10	315.19	175.19
T ₉	32.50	60.25	73.50	76.50	89.00	259.00	281.25	301.50	305.00	320.50	180.00
T ₁₀	32.50	56.40	79.75	85.00	91.00	362.00	396.00	440.00	448.00	450.00	244.07
T ₁₁	32.50	60.25	76.50	78.50	91.25	261.15	282.25	302.50	306.00	322.50	181.34
T ₁₂	32.50	56.40	80.25	87.00	93.00	364.00	398.00	441.00	451.00	454.00	245.72
Mean	32.58	53.25	68.44	72.49	80.21	264.24	287.06	314.90	319.79	327.53	
S.E. $\pm$ CD at 5 %											
Treatments					3.69		10.34				
Days of incubation					3.34		9.35				
Treatments x Days of incubation					11.08		31.03				

The nitrate nitrogen contents were significantly influenced by different treatments over control. The highest nitrate nitrogen content was observed under T₁₂ (245.72 mg kg⁻¹ soil) followed by T₁₀ (244.07 mg kg⁻¹ soil), T₆ (242.53 mg kg⁻¹ soil), T₇ (238.71 mg kg⁻¹ soil) and T₄ (240.07 mg kg⁻¹ soil). These treatments were on par with each other and significantly superior over the rest of treatments. This might be due to interaction of nutrients with FYM rendered beneficial effects in the release of nitrate nitrogen.

Vinod Kumar^{et al.} (1988) reported significant effects of FYM on nitrate concentration over control indicating that the process of nitrification was accelerated by FYM. Vinod Kumar and Wagenet (1984) reported that decomposed organic matter increased soil urease activity which is responsible for urea hydrolysis. FYM also reduced ammonia volatilization thereby increasing nitrogen content of soil. Singh and Prasad (1992) and Dinesh and Dubey (1999) found that net N mineralization was significantly higher in soils amended with organic manures.

Singh and Ram (2000) concluded that the addition of urea alongwith organic manures was always advantageous as compared to addition of urea alone. This addition will be helpful for improving physico-chemical properties of soil with positive effects on microbial population and their activities. Baligar and Patil (1968) reported that more mineral nitrogen (NH₄⁺-N and NO₃⁻-N) recovered in Karl

(sodic) soil when urea was applied as nitrogen source and mixed with soil.

4.4.5 Available phosphorus

The data in respect of available phosphorus of saline sodic soil as influenced by the treatments of integration, incubation period and their interactions are reported in Table 30 and graphically shown in Fig. 2.

The integration of different sources of nutrients showed significant variation in available phosphorus content of saline sodic soil. The integration of urea + single superphosphate + FeSO_4 + ZnSO_4 + biofertilizers + FYM recorded the highest available phosphorus T_{12} (36.84 mg kg^{-1} soil) followed by T_{10} (36.28 mg kg^{-1} soil), T_6 (35.59 mg kg^{-1} soil), T_4 (35.35 mg kg^{-1} soil) which were significantly superior over rest of treatment combinations. The integration with FYM showed significant effect. The use of urea + FeSO_4 + ZnSO_4 + biofertilizers (T_8) recorded the least available phosphorus (9.20 mg kg^{-1} soil) but was significantly higher than control. The application of urea + FeSO_4 + ZnSO_4 with FYM (T_9) recorded significantly higher available phosphorus (12.13 mg kg^{-1} soil) over T_8 indicating promising role of FYM in increasing phosphorus availability.

The availability of phosphorus irrespective of integrated nutrient management was maximum and on par at 120 days (33.80 mg kg^{-1} soil) and 90 days (32.46 mg kg^{-1} soil) of incubation. The

Table 30. Effect of integrated nutrient management on periodical release of phosphorus (mg kg⁻¹) in saline sodic soil

Treatments	Days of incubation										Mean
	0	2	4	10	20	30	45	60	90	120	
T ₁	6.36	6.87	6.87	6.87	6.87	7.12	7.12	7.63	7.12	7.12	6.99
T ₂	6.61	7.12	7.63	8.65	9.16	9.16	12.45	12.71	15.13	15.25	10.38
T ₃	25.17	25.93	26.18	27.96	27.96	28.10	28.22	28.98	29.33	29.94	27.79
T ₄	26.59	29.49	21.54	33.81	35.33	35.59	39.40	39.91	40.67	41.18	35.35
T ₅	25.42	26.18	26.69	28.72	28.98	28.98	29.49	39.49	29.49	29.49	28.29
T ₆	27.45	29.74	32.54	34.32	36.10	36.35	29.40	39.66	39.91	40.42	35.59
T ₇	7.61	10.12	10.38	11.38	11.63	12.92	13.15	13.50	14.04	16.47	12.13
T ₈	6.87	7.12	7.88	7.88	7.88	9.15	9.15	9.92	11.95	14.40	9.20
T ₉	25.16	25.93	25.68	27.96	27.96	28.47	28.21	28.47	28.73	28.73	27.53
T ₁₀	31.48	31.90	34.93	35.31	35.74	37.58	37.89	38.15	38.90	41.40	36.28
T ₁₁	27.20	29.23	27.87	23.81	26.84	25.33	26.63	28.13	28.64	29.40	27.31
T ₁₂	30.48	31.49	34.03	35.31	36.42	37.58	38.89	39.13	40.64	44.40	36.84
Mean	20.53	26.11	26.23	28.20	29.19	29.63	31.00	31.57	32.46	33.80	-
S.E. $\pm$ CD at 5 %											
Treatments	0.43					1.21					
Days of incubation	0.39					1.10					
Treatments x Days of incubation	1.36					3.81					

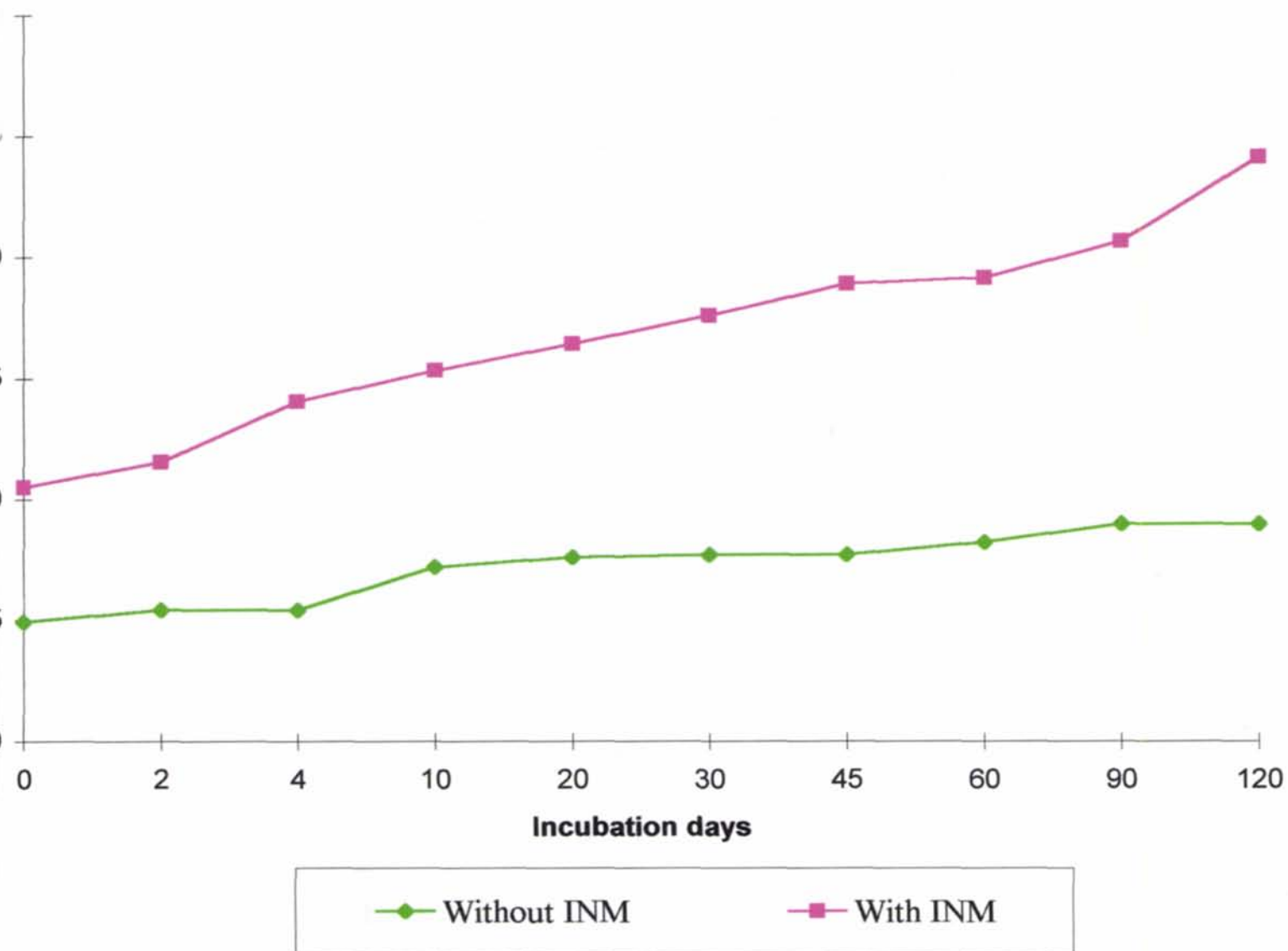


Fig. 2. Periodical release of available phosphorus as influenced by integrated nutrient management

availability of phosphorus was increased with an advancement of incubation period.

The interactions of nutrient integration and incubation time were found significant in increasing the phosphorus availability in saline sodic soil. Patel and Patel (2000) found that the application of FYM significantly increased (more than double) the Olsens P in the soil. Prabhakar *et al.* (1972) also observed beneficial effects of FYM in increasing available phosphorus in soil.

Nayak and Gupta (2000) applied organic matter in the form of FYM and reported that the addition of organic matter reduce the negative effects of P x Zn interaction. The organic anions and hydroxy acids such as tartaric, citric, malonic and malic acid liberated during the decomposition of organic matter may complex or chelates iron, aluminium, magnesium and calcium and prevent them from reacting with phosphate.

Tomar (2000) reviewed that the addition of single superphosphate with FYM largely influenced the form of Ca-P. Both phosphorus and FYM treatments increased the available phosphorus considerably. The organic matter increases the availability of phosphorus by chelating the phosphate fixing cations (Al^{3+} , Fe^{3+} , Ca^{2+}), exchange of adsorbed PO_4^{3-} by organic anions by protective action and decreased the pH of the soils. The addition of different phosphorus fertilizers of varying solubilities alongwith organic manure in soil retained higher amounts of saloid phosphorus and

available for longer period due to their reduced fixation as calcium phosphate. Thus, phosphorus fixation was reduced due to addition of organic manure with phosphorus. Due to application of FYM, decrease in pH, increase of CO₂ partial pressure and increased solubility of fixed phosphorus may have increased the available phosphorus (Gaffar *et al.*, 1992). The incubation period showed significant increase in available phosphorus in soil irrespective of the treatments. This might be due to mineralization of humified FYM which is a slow and steady process and acts as a slow release fertilizer.

In general, the integrated application of nutrients showed higher values of available phosphorus as compared to application of single superphosphate alone or with FYM. This has clearly indicated that the synergetic effect of all the components of nutrient integration in positive manner.

4.4.6 DTPA zinc

The data regarding periodical release of DTPA zinc in saline sodic soil as influenced by the integrated nutrient supply treatments, incubation period and their interactions are presented in Table 31 and graphically depicted in Fig. 3.

The release of DTPA zinc was significantly increased due to application of ZnSO₄ in saline sodic soil. The highest DTPA zinc was observed in T₁₂, (4.41 mg kg⁻¹ soil) followed by T₁₀ (4.39 mg kg⁻¹ soil), T₇ (4.00 mg kg⁻¹ soil) and T₁₁ (3.94 mg kg⁻¹ soil). It was also

Table 31. Effect of integrated nutrient management on periodical release of DTPA-Zn (mg kg^{-1}) in saline-sodic soil

Treatments	Days of incubation										Mean
	0	2	4	10	20	30	45	60	90	120	
T ₁	0.38	0.38	0.40	0.40	0.40	0.42	0.40	0.42	0.40	0.44	0.40
T ₂	0.38	0.40	0.40	0.40	0.44	0.48	0.48	0.50	0.50	0.50	0.45
T ₃	0.34	0.46	0.48	0.48	0.52	0.54	0.56	0.56	0.58	0.68	0.53
T ₄	0.53	0.53	0.53	0.55	0.59	0.59	0.61	0.61	0.65	0.67	0.59
T ₅	0.41	0.51	0.51	0.53	0.53	0.55	0.57	0.59	0.60	0.70	0.56
T ₆	0.51	0.51	0.55	0.59	0.63	0.65	0.65	0.69	0.69	0.69	0.62
T ₇	3.40	3.42	3.46	3.74	3.86	4.04	4.28	4.50	4.56	4.70	4.00
T ₈	3.20	3.22	3.28	3.52	3.62	3.86	3.88	3.99	4.46	4.64	3.69
T ₉	3.12	3.13	3.15	3.17	3.19	3.22	3.25	3.26	3.30	3.32	3.21
T ₁₀	4.04	4.04	4.06	4.06	4.56	4.60	4.60	4.64	4.66	4.68	4.39
T ₁₁	3.79	3.81	3.85	3.91	3.93	3.95	3.96	4.01	4.10	4.24	3.94
T ₁₂	4.00	4.02	4.06	4.14	4.16	4.52	4.72	4.76	4.82	4.88	4.41
Mean	2.01	2.02	2.05	2.11	2.19	2.26	2.26	2.32	2.43	2.48	-
S.E. $\pm$ CD at 5 %											
Treatments	0.043					0.12					
Days of incubation	0.039					0.11					
Treatments $\times$ Days of incubation	0.14					0.38					

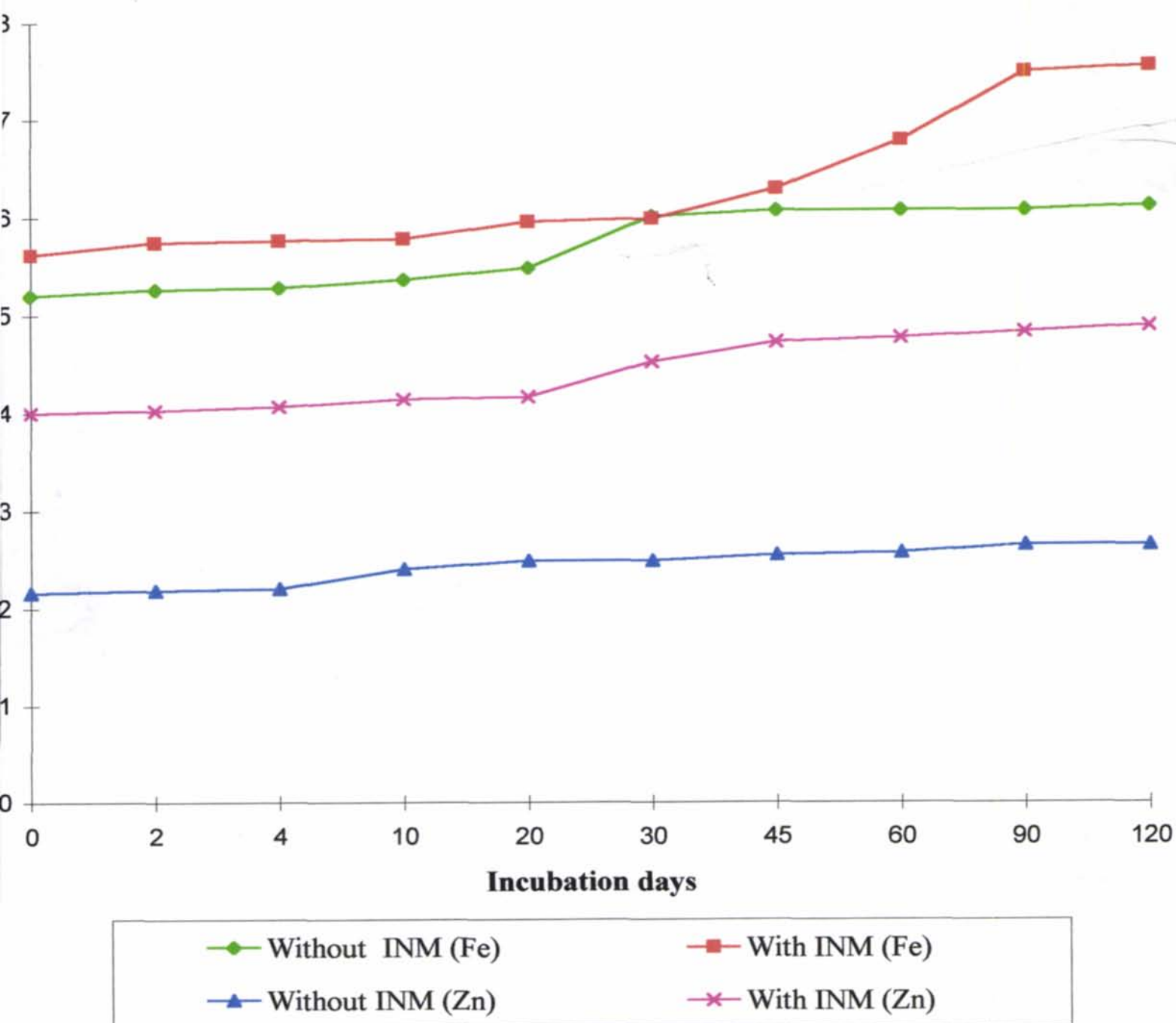


Fig. 3. Periodical release of DTPA Fe and Zn as influenced by integrated nutrient management

observed that the addition of single superphosphate with FYM + FeSO_4 + ZnSO_4 + biofertilizers, T_{12} (4.41 mg kg^{-1} soil) was significant in increasing the release of DTPA Zn over T_7 (4.00 mg kg^{-1} soil) and T_8 (3.69 mg kg^{-1} soil). The application of FYM alongwith nutrients had an additive effect on increasing DTPA zinc. The application of urea as one of the components had also promising role in increasing release of DTPA zinc. Dev and Shukla (1981) reported the use of single superphosphate for Zn deficient soils may be preferred because of its impurities especially its Zn content. Similarly, Daulat Ram *et al.* (1976) reported an increase of 4 % total nitrogen could bring about an increase of 1013 ppm of total zinc in black soils. Rahmatullah (1984) also reported that premixing of ZnSO_4 with FYM in alkaline soil increased Zn availability in comparison with ZnSO_4 added alone. The available Zn status (DTPA extractable) of the soil was raised in ZnSO_4 + FYM treated plots (Swarup, 1982).

The increase in DTPA Zn due to FYM might be due to supplying micronutrients in readily available forms to plant and also react with native reserves of micronutrient elements rendering them available. Zinc is known to form relatively stable chelates with organic ligands which decrease their susceptibility to adsorption, fixation and/or precipitation. The incorporation of manures might have resulted in the formation of such organic chelates of higher stability. It may be mentioned that the organic manures (FYM, GM) contribute about 20 ppm Zn which enhanced the availability. These

results are in close conformity with results obtained by Daulat Ram *et al.* (1976), Jadhav *et al.* (1981), Chand Milap *et al.* (1981) and Prasad *et al.* (1990).

Singh *et al.* (1983) reported that the solubility of Zn was highly dependent on pH and that a 100 fold decrease in solubility occurred with each unit increase in pH.

The urea + FYM had an additive effect. This might be due to increase in total N content due to addition of FYM.

The increased availability of zinc was observed with an increase in an incubation period. It was significantly higher at 120 days of incubation (2.48 mg kg⁻¹ soil) followed by 90 days (2.43 mg kg⁻¹ soil). The interactions between integrated nutrient supply treatments and incubation periods showed similar trends as that of integrated nutrient supply treatments alone.

4.4.7 DTPA iron

The data in respect of effect of integrated nutrient supply treatments incubation period and their interaction in saline sodic soil on periodical release of DTPA Fe are presented in Table 32 and graphically shown in Fig. 3.

The data reveal that integrations of nutrient supply through different sources were significant in influencing the periodical release of DTPA Fe of saline sodic soil. The integration treatments recorded significantly higher amount of DTPA Fe in T₁₂ (6.29 mg kg⁻¹ soil) and T₁₀ (6.27 mg kg⁻¹ soil). However, it was on par

Table 32. Effect of integrated nutrient management on periodical release of DTPA Fe (mg kg^{-1}) in saline sodic soil

Treatments	Days of incubation										Mean
	D ₁	D ₂	D ₃	D ₄	D ₅	D ₆	D ₇	D ₈	D ₉	D ₁₀	
T ₁	3.90	3.94	3.94	3.97	3.94	3.94	3.98	3.96	3.96	3.90	3.94
T ₂	3.96	3.96	3.98	3.98	4.04	4.16	4.86	5.16	5.16	5.20	4.46
T ₃	4.00	4.00	4.06	4.12	4.12	4.16	4.17	4.20	4.28	4.30	4.14
T ₄	4.38	4.42	4.47	4.54	4.54	4.58	4.60	4.68	4.68	4.74	4.56
T ₅	3.40	3.40	4.47	4.50	4.64	4.69	4.72	4.78	4.83	4.84	4.43
T ₆	4.48	4.54	4.54	4.70	4.78	4.80	4.80	4.82	4.82	4.86	4.72
T ₇	5.58	5.70	5.72	5.74	5.91	5.94	6.24	6.74	7.44	7.50	6.25
T ₈	4.98	4.90	5.04	5.16	5.18	6.02	6.17	6.27	6.32	6.42	5.79
T ₉	5.08	5.14	5.14	5.28	5.40	5.42	5.44	5.48	5.83	5.86	5.40
T ₁₀	5.60	5.72	5.74	5.76	5.93	5.96	6.26	6.76	7.46	7.52	6.27
T ₁₁	5.42	5.42	5.46	5.48	5.58	5.72	5.78	5.88	5.91	6.30	5.70
T ₁₂	5.62	5.74	5.76	5.78	5.95	5.98	6.28	6.78	7.48	7.54	6.29
Mean	4.69	4.73	4.86	5.04	5.05	5.12	5.28	5.45	5.68	5.75	-
S.E. $\pm$ CD at 5 %											
Treatments					0.052		0.15				
Days of incubation					0.048		0.13				
Treatments x Days of incubation					0.16		0.46				

with each other and significantly superior over the other treatments. This might be due to the chelating effect of FYM for added iron through ferrous sulphate.

The increase of DTPA Fe by the application of $\text{FeSO}_4 + \text{ZnSO}_4$ might be due to direct addition of Fe from FeSO_4 . The H_2SO_4 produced after addition of FeSO_4 had indirect effect on availability of Fe. The water soluble iron was increased significantly by the increased formation of acid (Babaria and Patel, 1980).

Influence of organic matter added in the form of FYM on the availability of iron is probably owing to higher state of reduction developed in presence of decomposing organic matter which subsequently reduced Fe^{3+} to Fe^{2+} form (Babaria and Patel, 1980). Elgala and Amberger (1982) reported that an increase in extractable Fe from FeSO_4 treatment of alkaline soil was evident only when the soil was enriched with organic matter and incubated for three months.

An increase in the availability of Fe upon addition of organic matter like FYM and green manuring may be due to intensified microbial and chemical reduction and decrease in pH of sodic soils. The beneficial effects of application of FeSO_4 with FYM were also reported by many earlier researchers. (Pendias and Pendias 1984, Sakal *et al.*, 1986, Rajkumar *et al.*, 1990, Swarup, 1991, Lindsay 1991, Singh *et al.*, 1992).

The incubation period were significantly increased the DTPA- Fe with an increase in incubation period. The magnitude of increase in DTPA Fe was in the following descending order viz., 120 days (5.75 mg kg⁻¹ soil) > 90 days (5.68 mg kg⁻¹ soil) > 60 days (5.45 mg kg⁻¹ soil) > 45 days (5.28 mg kg⁻¹ soil) > 30 days (5.12 mg kg⁻¹ soil), respectively.

The interaction for the release of DTPA Fe due to integration treatments and incubation period was significant in saline sodic soil. The interaction with an incubation of ferrous sulphate as source of iron in an integration treatment alongwith FYM recorded the higher values of DTPA Fe.

4.5 Pot culture studies

The pot culture experiment was conducted by using, inorganic fertilizers with organic and biofertilizers with a view to assess the use efficiency of added fertilizers in relation to growth, biomass and nutrient uptake by sugarcane at earthing up in saline sodic soil. The research results generated during incubation studies under laboratory conditions were used as the basis for finalization of the treatments in pot culture experiment for integrated nutrient management of sugarcane grown in saline sodic soil.

The results obtained during the course of experimentation under pot culture conditions are presented and discussed below under appropriate headings.

4.5.1 Biomass production of sugarcane

The data in respect of effect of recommended dose of NPK alone and along with FeSO_4 , ZnSO_4 , biofertilizers and their interactions with and without FYM on biomass production of sugarcane are presented in Table 33.

A close look to the data revealed that the application of FYM recorded significantly more fresh shoot weight ($444.80 \text{ g pot}^{-1}$) over no FYM application ($321.04 \text{ g pot}^{-1}$). Similarly the use of inorganic fertilizers alone and inconjunction with biofertilizers were found significant to produce the fresh shoot weight of sugarcane at earthing up. The conjoint application of recommended dose of NPK, FeSO_4 , ZnSO_4 and biofertilizers registered the highest fresh shoot weight ($430.40 \text{ g pot}^{-1}$). Which was significantly superior over rest of the treatments. This treatment was closely followed by application of $\text{FeSO}_4 + \text{ZnSO}_4$ alongwith recommended dose of fertilizers. Further, it is interesting to note that use of ZnSO_4 either alone ($326.47 \text{ g pot}^{-1}$) or with FYM ($454.40 \text{ g pot}^{-1}$) recorded significantly higher yield over FeSO_4 alone ($307.20 \text{ g pot}^{-1}$) or FeSO_4 with FYM ($435.20 \text{ g pot}^{-1}$), respectively. Similarly, the application of biofertilizers along with recommended dose of fertilizers recorded significantly higher fresh shoot weight ($366.40 \text{ g pot}^{-1}$) over recommended dose only ($324.70 \text{ g pot}^{-1}$). The conjoint use of recommended dose of fertilizers alongwith ZnSO_4 , FeSO_4 , and biofertilizers significantly increased the fresh shoot weight of sugarcane.

Table 33. Effect of integrated nutrient management on total biomass (g pot⁻¹) of sugarcane

Treat- ments	Fresh shoot			Fresh root			Total biomass		
	With- out FYM	With FYM	Mean	With- out FYM	With FYM	Mean	With- out FYM	With FYM	Mean
T ₁	271.80	377.60	324.70	91.27	135.12	113.20	363.07	512.72	437.90
T ₂	307.20	435.20	371.20	118.95	139.98	129.46	426.15	575.17	500.66
T ₃	326.47	454.40	390.43	123.12	145.47	134.30	449.59	599.87	524.73
T ₄	355.20	473.59	414.40	129.89	151.14	140.52	485.09	624.73	554.91
T ₅	304.00	428.80	366.40	95.15	135.14	115.15	399.15	563.91	481.53
T ₆	361.60	499.20	430.40	130.12	161.15	145.64	491.72	660.35	576.04
Mean	321.04	444.80	-	114.75	144.67	-	435.79	589.46	-
	S.E. $\pm$		CD at 5 %	S.E. $\pm$		CD at 5 %	S.E. $\pm$		CD at 5 %
Main treatment	0.61		1.77	0.63		1.84	0.82		2.39
Sub. treatment	1.05		3.07	1.10		3.19	1.41		4.10
Interaction	1.49		4.35	1.55		4.51	1.99		5.82

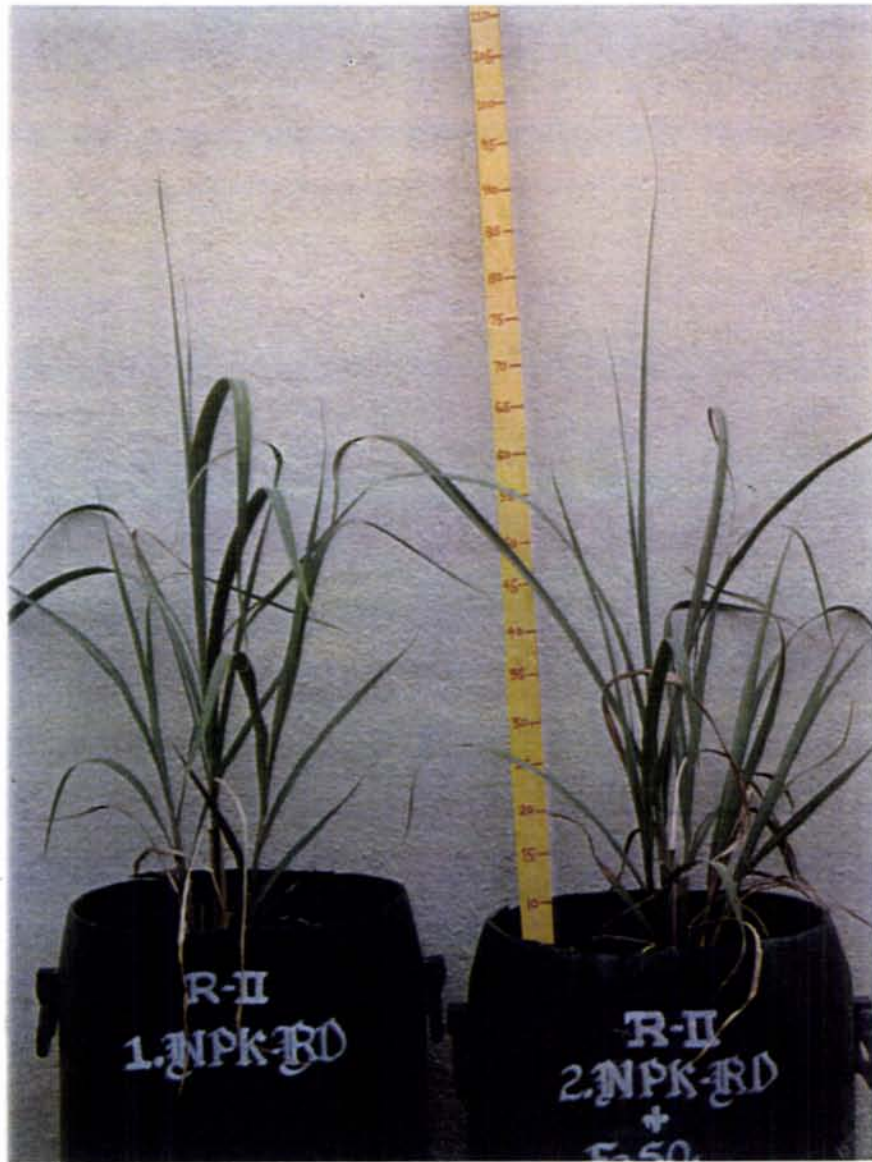


Plate 1 : Effect of FeSO_4 on growth of sugarcane

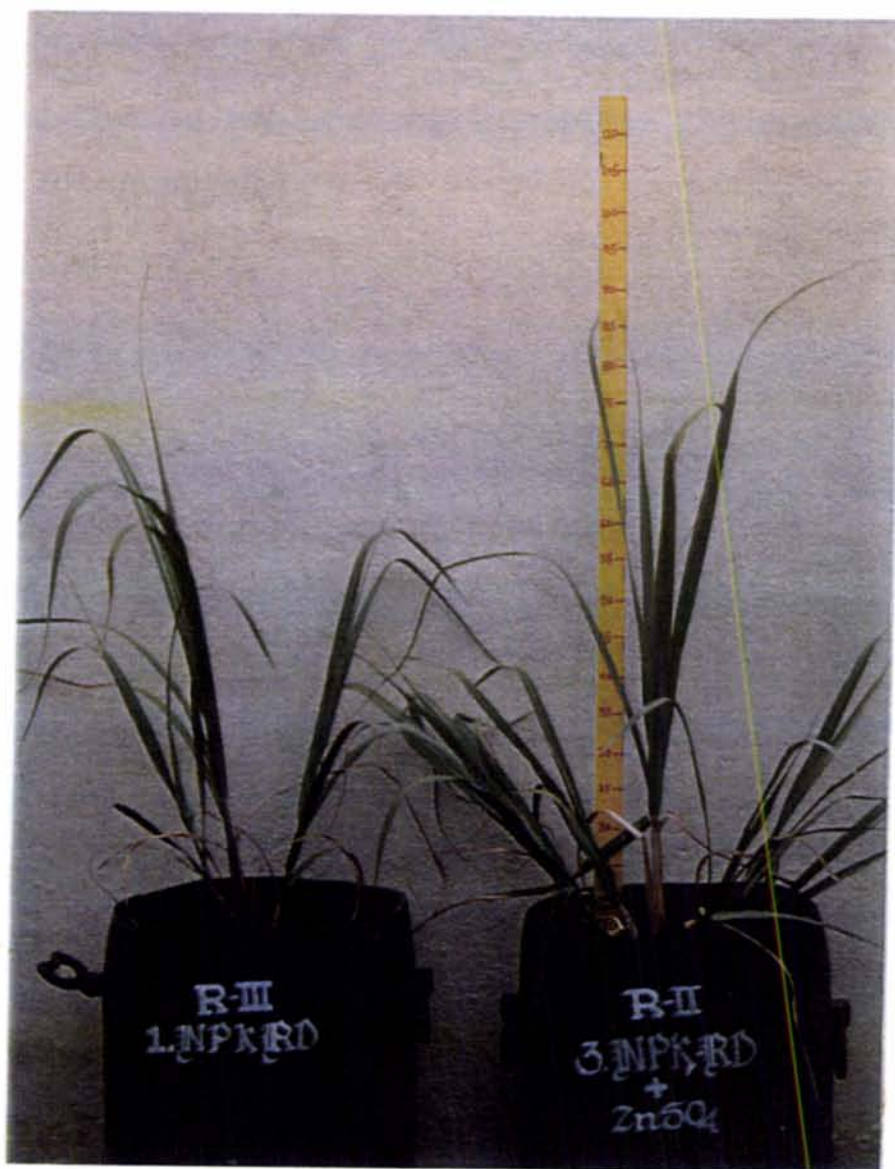


Plate 2 : Effect of ZnSO_4 on growth of sugarcane

The increase in fresh shoot weight of sugarcane due to application of FYM may be attributed to the improvement in physical and biological properties of soil. This might have helped to increase the nutrient availability to sugarcane crop, thereby increasing nutrient uptake. Yadav (2000) reported that the organic manures play a direct role by supplying macro and micronutrients and indirect role by improving the physico-chemical and biological environment of the soils. The decline in sugarcane yield can be arrested to some extent by the application of FYM/compost and more so by an integrated application of mineral fertilizers with organic manures.

These findings confirm the results reported by Shinde *et al.*, (1990), Rabindra *et al.* (1990), Zende *et al.* (1991), More (1994) and Nema *et al.* (1995).

The increase in weight of fresh shoot due to ZnSO_4 than FeSO_4 might be because of higher requirement of sugarcane for zinc during early stage and relatively higher requirement for iron at later stage. Yadav and Yaduvanshi (1989) reported the similar findings. The ameliorative role of Zn is attributed to alleviation of Zn deficiency and the changes in chemical composition of the plants including the widening of Ca/Na and K/Na ratios as also enhanced absorption of Ca, K and Zn (Shukla and Prasad, 1974, Shukla and Mukhi, 1980).

The increase in fresh weight of sugarcane due to application of ZnSO_4 may be attributed to supply of zinc to sugarcane crop. Zinc plays an important role in plant nutrition. It is a constituent of carbonic anhydrase and it is also essential for production of auxins. It is also required for synthesis of tryptophan which in turn is a precursor of IAA. Besides, it is also a constituent of respiratory enzymes, associated with chlorophyll formation and plays important role in protein metabolism (Zende, 1999).

The increase in weight of fresh shoot of sugarcane due to FeSO_4 over NPK only, might be attributed to the supply of Fe which increased the chlorophyll content of sugarcane plant in turn assimilated more photosynthates required for growth and development of plants.

The interactions due to integration of treatments with or without FYM were found significant for fresh weight of sugarcane. This was obvious because of combined effect of organic, inorganic and biofertilizers on bio-physicochemical changes in soil and metabolic activities of plant reflected in an increase in fresh weight of sugarcane at earthing up.

The use of FYM recorded significantly higher fresh roots ($144.67 \text{ g pot}^{-1}$) over no FYM application ($114.75 \text{ g pot}^{-1}$). The conjunctive use of recommended dose of FeSO_4 , ZnSO_4 and biofertilizers significantly produced more root weight. The application of $\text{FeSO}_4 + \text{ZnSO}_4 + \text{biofertilizers}$ along with



Plate 3 : Effect of ZnSO_4 with FYM on growth of sugarcane



Plate 4 : Effect of $\text{FeSO}_4 + \text{ZnSO}_4$ with FYM on growth of sugarcane



Plate 5 : Effect of INM on growth of sugarcane

recommended dose of fertilizers recorded significantly higher fresh root weight (145.64 g pot⁻¹). The application of zinc sulphate significantly increased the fresh root weight (134.30 g pot⁻¹) over FeSO₄ application alone (129.46 g pot⁻¹).

The increase in root weights due to ZnSO₄ may be attributed to increase in indol acetic acid (IAA) as Zn is necessary for tryptophan production which is a precursor of IAA.

The interactions of integration with FYM additions was significantly superior in production of fresh weight of sugarcane over no FYM addition to sugarcane.

These results are in close agreement with those reported by Verma *et al.* (1992), More (1994), Nayak and Gupta (2000) and Bandopadhyay *et al.* (2000).

The total biomass production (Table 33) was significantly influenced due to FYM application (589.46 g pot⁻¹) over no FYM application (435.79 g pot⁻¹). The conjunctive use of recommended dose FeSO₄, ZnSO₄ and biofertilizers significantly produced more biomass (576.04 g pot⁻¹) followed by application of recommended dose FeSO₄ + ZnSO₄ (554.91 g pot⁻¹). The application of ZnSO₄ produced significantly higher total biomass (524.73 g pot⁻¹) over FeSO₄ application (500.66 g pot⁻¹). Thus, the addition of FYM with an integration of recommended dose of fertilizers, FeSO₄, ZnSO₄ and biofertilizers was found beneficial for better development of

sugarcane as evidenced by higher biomass production in saline sodic soil.

4.5.2 Dry matter production of sugarcane

The data in respect of the weight of dry shoots and dry root of sugarcane at earthing up as influenced by integrated use of recommended fertilizers, FeSO_4 , ZnSO_4 , biofertilizers, FYM and interaction between integration of nutrients with and without FYM are reported in Table 34 and Fig. 4.

The use of FYM recorded significantly higher dry shoots ($249.79 \text{ g pot}^{-1}$) over no FYM application ($186.54 \text{ g pot}^{-1}$). The conjunctive use of recommended dose of FeSO_4 , ZnSO_4 and biofertilizers significantly produced more dry shoot weight ($248.78 \text{ g pot}^{-1}$) followed by recommended dose with $\text{FeSO}_4 + \text{ZnSO}_4$ ($239.34 \text{ g pot}^{-1}$). The application of ZnSO_4 produced significantly higher shoot yield ($216.81 \text{ g pot}^{-1}$) over FeSO_4 application ($204.59 \text{ g pot}^{-1}$).

The use of FYM recorded significantly higher dry roots (85.37 g pot^{-1}) over no FYM application (63.33 g pot^{-1}) (Table 34).

The conjunctive use of recommended dose FeSO_4 , ZnSO_4 and biofertilizers significantly produced more dry root weight. The application of $\text{FeSO}_4 + \text{ZnSO}_4 + \text{biofertilizers}$ with recommended dose of fertilizers recorded significantly higher dry root weight (81.88 g pot^{-1}). The application of zinc sulphate had significantly superior dry root yield (77.77 g pot^{-1}) over FeSO_4 application (73.95 g pot^{-1}).

Table 34. Effect of integrated nutrient management on total dry matter (g pot⁻¹) of sugarcane

Treat- ments	Dry shoot			Dry root			Total dry matter		
	With- out FYM	With FYM	Mean	With- out FYM	With FYM	Mean	With- out FYM	With FYM	Mean
T ₁	168.92	226.76	197.84	50.56	78.18	64.37	219.48	304.94	262.21
T ₂	175.52	233.66	204.59	65.45	82.44	73.95	240.98	316.10	278.54
T ₃	181.16	252.46	216.81	67.65	87.89	77.77	248.80	340.35	294.58
T ₄	204.21	274.46	239.34	71.54	88.18	79.86	275.75	362.64	319.20
T ₅	170.67	232.65	201.66	52.69	79.87	66.28	223.36	312.52	267.74
T ₆	218.80	278.76	248.78	72.10	91.65	81.88	290.90	370.41	330.66
Mean	186.54	249.79	-	63.33	85.37	-	249.88	334.49	-
	S.E. $\pm$		CD at 5 %	S.E. $\pm$		CD at 5 %	S.E. $\pm$		CD at 5 %
Main treatment	0.74		2.15	0.45		1.30	0.91		2.66
Sub. treatment	1.28		3.73	0.77		2.25	1.57		4.58
Interaction	1.81		5.27	1.09		3.19	2.23		6.48

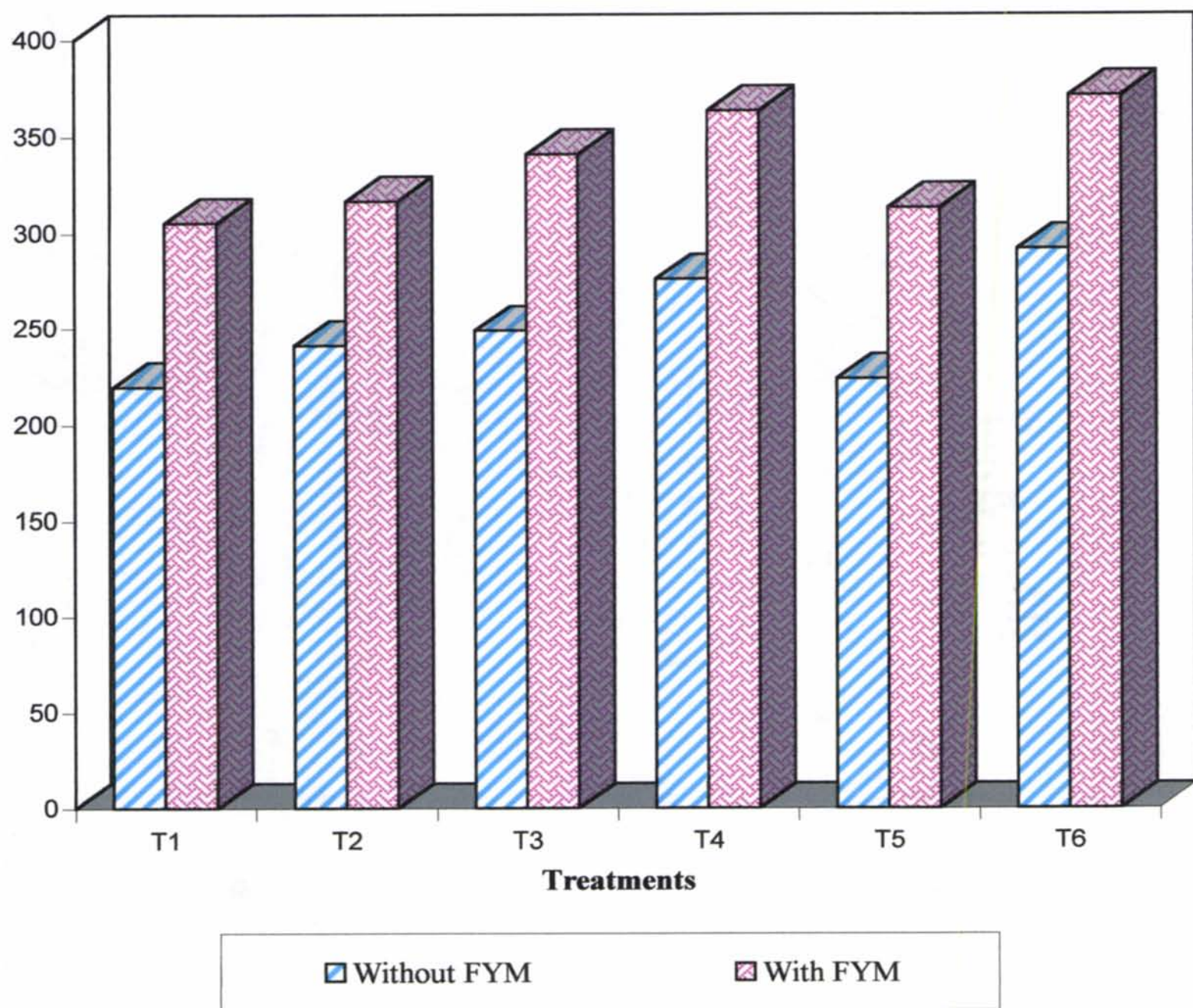


Fig.4. Effect of integrated nutrient management on total dry matter of sugarcane

The interactions due to integration with FYM was significantly superior in the production of dry root weight of sugarcane over no FYM application to sugarcane.

Thus, the addition of FYM with an integration of recommended dose of fertilizers, FeSO_4 , ZnSO_4 and biofertilizers were found beneficial for better development of sugarcane roots in saline sodic soil.

The total dry matter production (Table 34 and Fig. 4) significantly influenced due to integrated nutrient management.

The FYM application produced significantly higher dry matter ($334.49 \text{ g pot}^{-1}$) over no FYM addition to sugarcane ($249.88 \text{ g pot}^{-1}$).

The conjunctive use of recommended dose FeSO_4 , ZnSO_4 , biofertilizers produced significantly higher dry matter ($330.66 \text{ g pot}^{-1}$) over rest of the treatments. The application of ZnSO_4 ($294.58 \text{ g pot}^{-1}$) significantly increased the dry matter than application of FeSO_4 ($278.54 \text{ g pot}^{-1}$).

The interaction of integration of treatments with or without FYM were found significant in influencing the dry matter production of sugarcane.

4.6 Nutrient uptake

The data regarding nutrient uptake (NPK) by sugarcane grown on saline sodic soil as influenced by the integrated nutrient management are presented in Table 35 and Fig. 5, 6, 7.

Table 35. Effect of integrated nutrient management in nutrient uptake (g pot⁻¹) by sugarcane

Treat- ments	Nitrogen			Phosphorus			Potassium		
	With- out FYM	With FYM	Mean	With- out FYM	With FYM	Mean	With- out FYM	With FYM	Mean
T ₁	1.21	2.38	1.80	0.34	0.67	0.51	1.16	2.23	1.61
T ₂	1.60	2.51	2.05	0.41	0.78	0.60	1.46	2.30	1.88
T ₃	1.71	2.95	2.33	0.48	1.00	0.74	1.57	2.65	2.11
T ₄	2.00	3.29	2.65	0.55	1.03	0.79	1.84	2.75	2.29
T ₅	1.35	2.44	1.90	0.36	0.75	0.55	1.25	2.24	1.74
T ₆	2.13	3.45	2.79	0.55	1.04	0.80	2.02	2.78	2.40
Mean	1.67	2.84	-	0.45	0.95	-	1.55	2.49	-
	S.E. $\pm$		CD at 5 %	S.E. $\pm$		CD at 5 %	S.E. $\pm$		CD at 5 %
Main treatment	0.047		0.14	0.0092		0.0027	0.099		0.0287
Sub. treatment	0.081		0.23	0.016		0.046	0.017		0.050
Interaction	0.11		0.34	0.023		0.065	0.024		0.070

4.6.1 Nitrogen

The integration of recommended dose, FeSO_4 , ZnSO_4 and biofertilizers registered significantly the highest nitrogen uptake (2.79 g pot^{-1}) followed by no inclusion of biofertilizers (2.65 g pot^{-1}) (Table 35 and Fig. 5). The application of recommended dose and alongwith biofertilizers registered 1.80 and 1.90 g pot^{-1} nitrogen uptake which was on par to each other and significantly lower than the other treatments of integration.

The increase in uptake of nitrogen due to FeSO_4 , ZnSO_4 and biofertilizer was might be due to synergistic effects. Yadav (2000) reported that balanced application of nutrients considerably increased the yield of sugarcane. The FeSO_4 , ZnSO_4 might have reduced soil pH. The reduction in soil pH decreased the volatilization losses of nitrogen and thereby enhanced the nitrification. The released nitrate nitrogen might have certainly used by sugarcane plants as evidenced by increase in nitrogen uptake.

The nitrogen uptake by sugarcane due to the use of FYM was significantly higher (2.84 g pot^{-1}) over no FYM (1.67 g pot^{-1}). The interactions also significantly influenced the nitrogen uptake by the sugarcane crop. However, the interactions between treatments of integration with use of FYM were significantly superior than no FYM application. The values of nitrogen uptake with FYM treatment ranged from 2.38 to 3.45 g pot^{-1} and 1.21 to 2.13 g pot^{-1} with no FYM (Table 35).

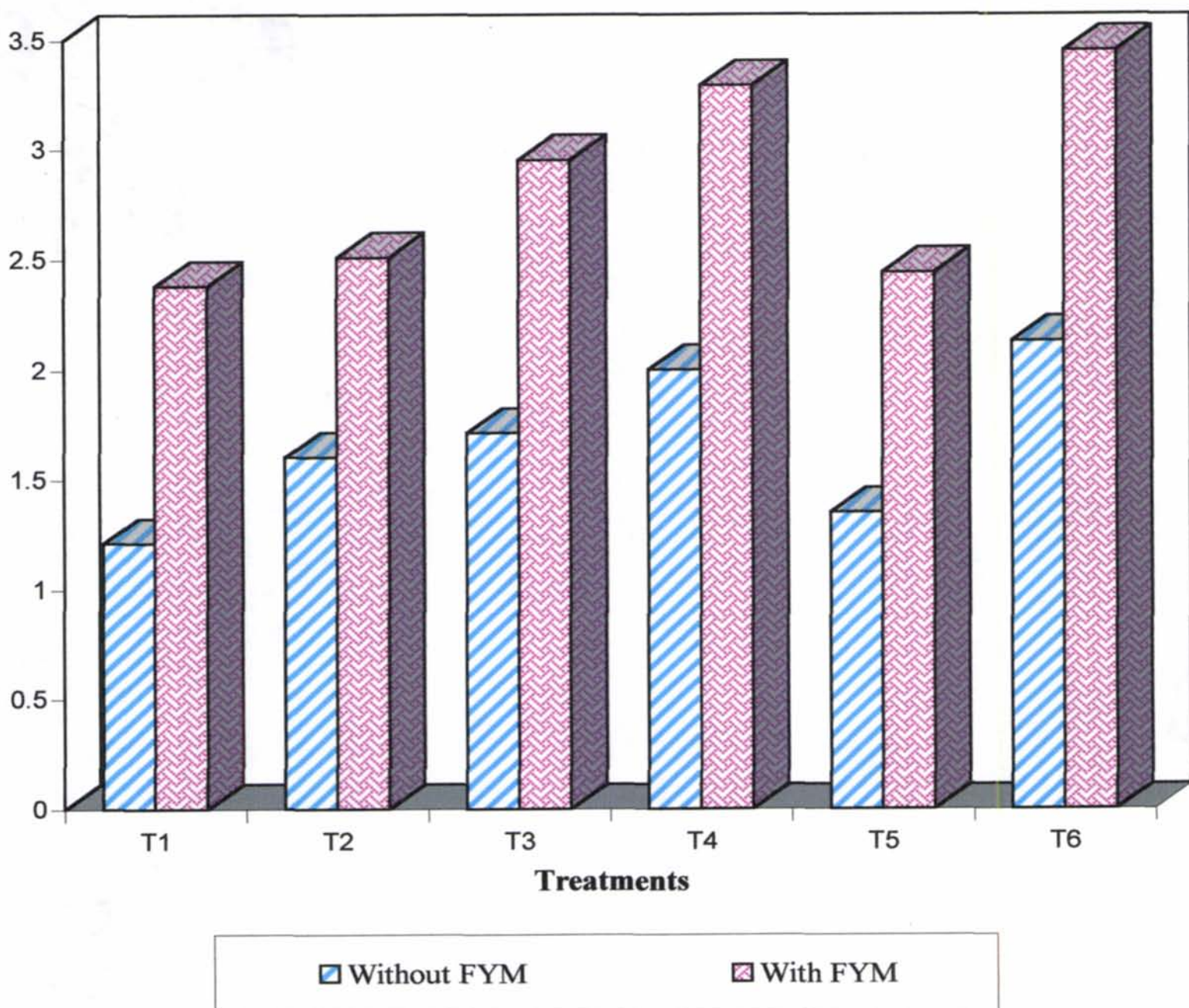


Fig.5. Effect of integrated nutrient management on nitrogen uptake by sugarcane

The increase in uptake of nitrogen due to addition of FYM might be because of increase in urease activity responsible for urea hydrolysis, increasing the activities of *Nitrosomonas* required for conversion of $\text{NH}_4^+\text{-N}$ to $\text{NO}_2^-\text{-N}$ which ultimately converted to $\text{NO}_3^-\text{-N}$ and helped to increase the nitrogen uptake. These findings are in accordance with Vinod Kumar et al. (1988), Sharma et al. (1992), Yaduvanshi (2001).

Thus, the integration of nutrients in nutrient management for sugarcane in saline sodic soil with FYM is beneficial for the nitrogen uptake by sugarcane. This might be due to improvement in the soil physicochemical and biological properties as a function of nutrient availability to sugarcane.

4.6.2 Phosphorus

The data regarding phosphorus uptake by sugarcane grown in saline sodic soil as influenced by the integration of recommended dose, ferrous sulphate, zinc sulphate, biofertilizers in presence and absence of FYM are presented in Table 35 and Fig. 6.

The integrations of different organic and inorganic fertilizers were found significant over each other for the phosphorus uptake by sugarcane grown in saline sodic soil. The highest uptake of phosphorus (0.80 g pot^{-1}) was observed in integration of recommended dose of fertilizers, with $\text{FeSO}_4 + \text{ZnSO}_4 + \text{biofertilizers}$ followed by application of $\text{FeSO}_4 + \text{ZnSO}_4$ (0.79 g pot^{-1}) but the effect was non-significant. The application of ZnSO_4 had significant effect

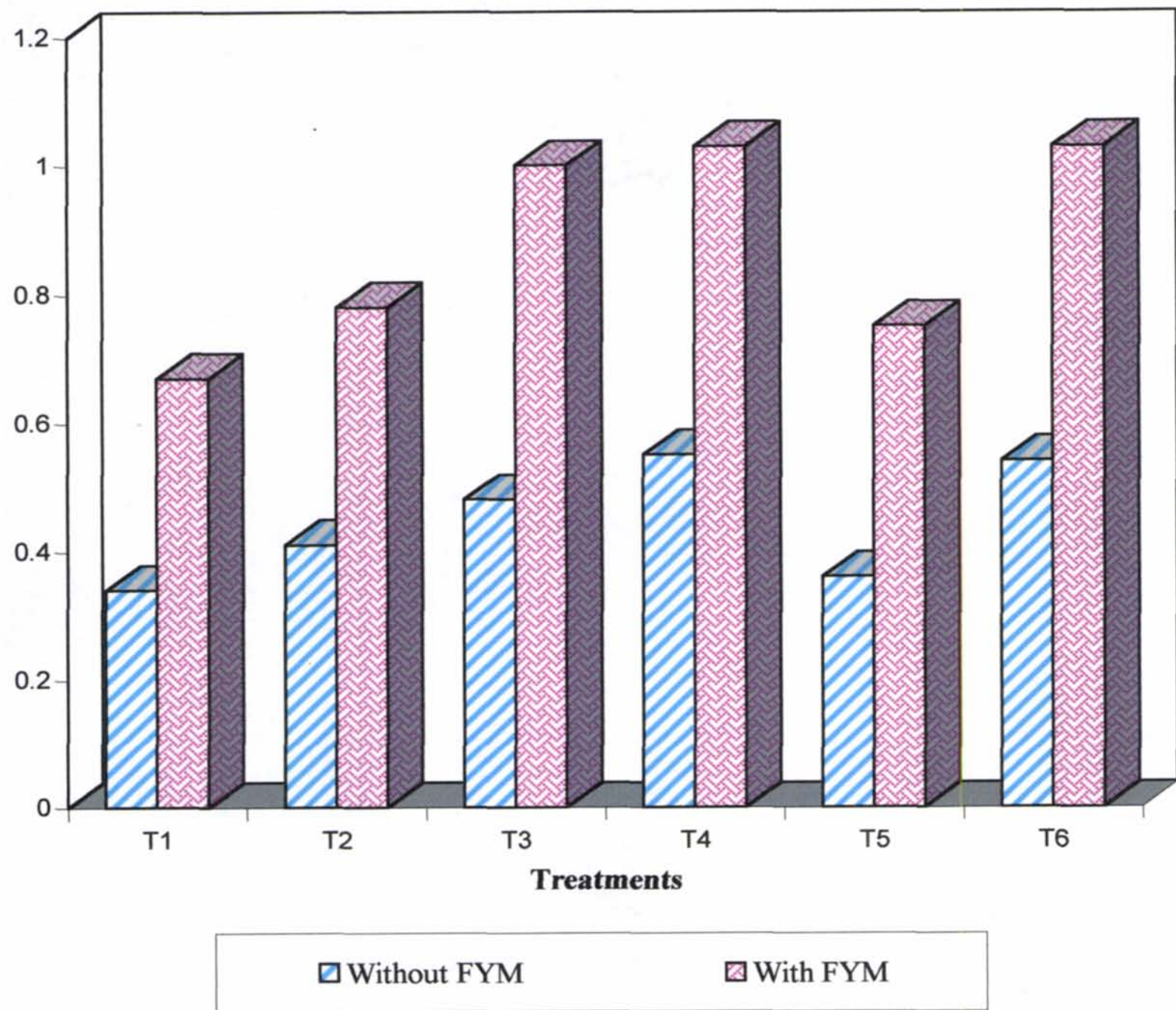


Fig. 6. Effect of integrated nutrient management on phosphorus uptake by sugarcane

(0.74 g pot⁻¹) on phosphorus uptake over FeSO₄ (0.60 g pot⁻¹). Gupta *et al.* (1985) reported no antagonism between Zn and P at < 5 ppm zinc.

The use of FYM irrespective of the integration of treatments was found to increase the phosphorus uptake by sugarcane (0.94 mg pot⁻¹). The increased uptake might be due to production of organic acids during decomposition of organic matter prevented the phosphorus from precipitation and rendering it available to the plant. The microbial activities were greatly increased due to FYM causing increased availability of phosphorus. These observations are collaborated with those reported by Prabhakar *et al.* (1972).

4.6.3 Potassium

The data regarding effect of nutrient integration, use of farmyard manure and their interactions on potassium uptake by sugarcane are reported in Table 35 and Fig. 7.

The data indicated that integration of farmyard manure, FeSO₄, ZnSO₄ and biofertilizers were significantly increased the potassium uptake (2.40 g pot⁻¹) by sugarcane. Which was followed by recommended dose + FeSO₄ + ZnSO₄ (2.29 g pot⁻¹). The recommended dose of fertilizers along with ZnSO₄ was significantly superior for potassium uptake (2.11 g pot⁻¹) over FeSO₄ application (1.88 g pot⁻¹). Tandon (1982) also reported that the uptake of K was enhanced by Zn. The application of FYM to sugarcane significantly

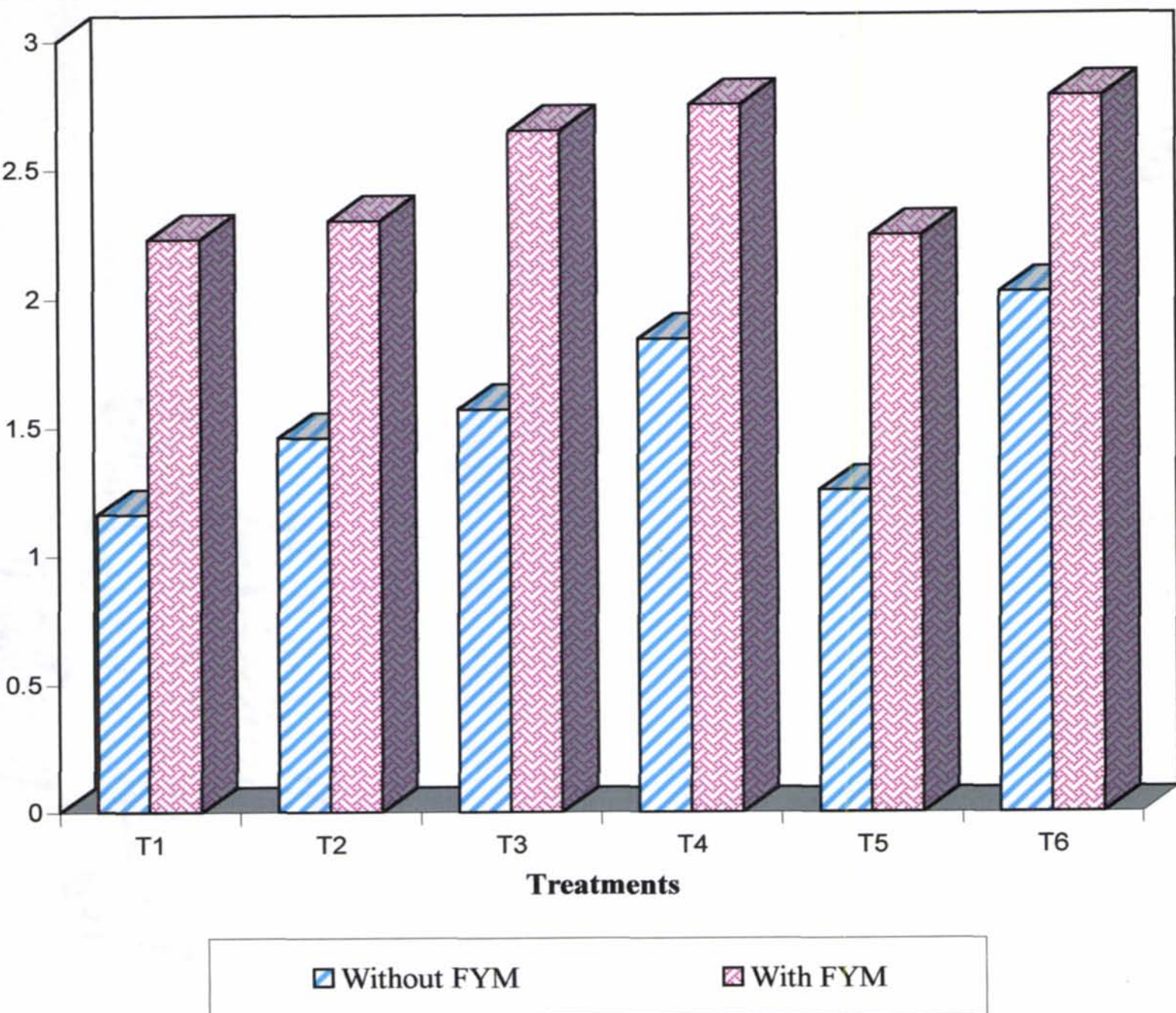


Fig. 7. Effect of integrated nutrient management on potassium uptake by sugarcane

increased the potassium uptake (2.49 g pot^{-1}) than no FYM (1.55 g pot^{-1}).

The interaction effects of integration treatment with FYM were significantly higher for the potassium uptake by sugarcane. It ranged from 2.23 to 2.78 g pot^{-1} and the highest uptake was noted in conjoint use of recommended dose + FeSO_4 + ZnSO_4 + biofertilizers with FYM. Whereas, it was ranged between 1.16 - 2.02 g pot^{-1} in no FYM interactions.

4.6.4 Micronutrient

The data in respect of uptake micronutrients (Zn and Fe) as influenced by effect of recommended dose, FeSO_4 , ZnSO_4 , biofertilizers, FYM and their interactions by sugarcane in saline sodic soil are reported in Table 36 and Fig. 8, 9.

4.6.4.1 Zinc

The uptake of zinc by sugarcane in saline sodic soil (Table 36 and Fig. 8) was significantly influenced by various treatments. The highest uptake of zinc was observed in the treatment of recommended dose + FeSO_4 + ZnSO_4 + Biofertilizers ($11.05 \text{ mg pot}^{-1}$) followed by recommended dose + FeSO_4 + ZnSO_4 ($10.49 \text{ mg pot}^{-1}$). The application of FYM significantly influenced the zinc uptake ($12.33 \text{ mg pot}^{-1}$) over no FYM (4.91 mg pot^{-1}).

The interaction effects due to integration of treatments with farmyard manure were significantly higher for the potassium uptake by sugarcane. It was ranged from 10.20 to $15.59 \text{ mg pot}^{-1}$ with

Table 36. Effect of integrated nutrient management on micronutrient uptake (mg pot⁻¹) by sugarcane

Treatments	Iron			Zinc		
	Without FYM	With FYM	Mean	Without FYM	With FYM	Mean
T ₁	5.18	10.26	7.72	3.93	10.20	6.82
T ₂	7.32	15.16	11.24	3.51	10.51	7.01
T ₃	5.43	12.91	9.17	5.43	13.05	9.24
T ₄	7.49	16.46	11.98	6.81	14.18	10.49
T ₅	5.63	10.56	6.10	3.75	10.47	7.11
T ₆	7.95	17.65	12.81	6.50	15.59	11.05
Mean	6.50	13.84	-	4.91	12.23	-
	S.E. $\pm$	CD at 5 %		S.E. $\pm$	CD at 5 %	
Main treatments	0.17	0.48		0.086	0.25	
Sub. treatments	0.21	0.84		0.15	0.44	
Interaction	0.41	1.20		0.21	0.62	

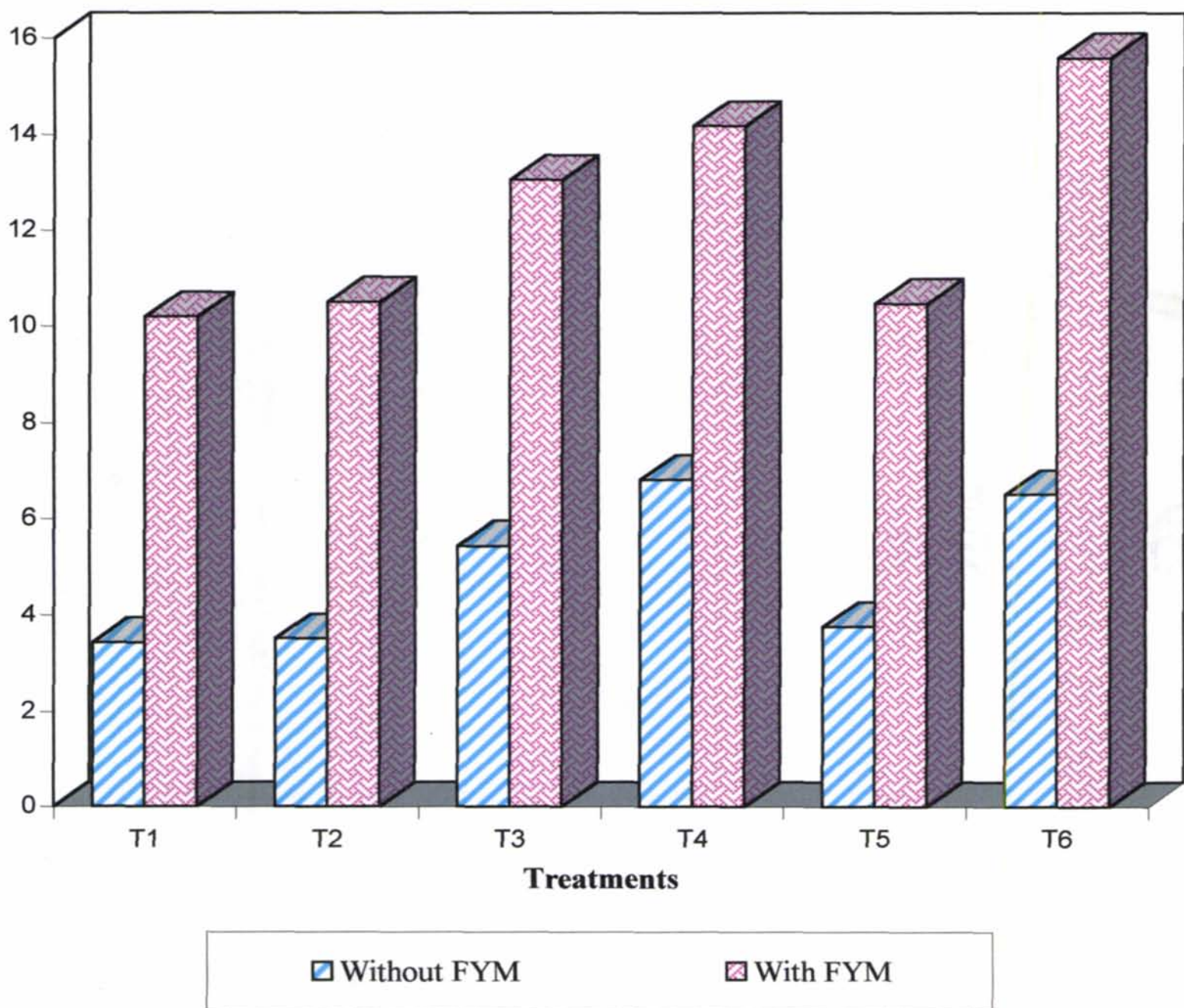


Fig.8. Effect of integrated nutrient management on zinc uptake by sugarcane

FYM and 3.43 to 6.50 mg pot⁻¹ with no FYM. The FYM decreases the capacity factor indicating more of zinc from soil phase has come to the solution phase by forming stable complexes with organic manures. Schnng and Finck (1980) reported that acid forming nitrogen fertilization presents an alternative or supplementary treatments for yield limiting Zn deficiency. These findings are supported by Daulat Ram *et al.* (1976) and Chand Milap *et al.* (1980).

4.6.4.2 Iron

A close look to the data presented in Table 36 and Fig. 9 revealed that the conjunctive use of recommended dose of NPK, FeSO₄, ZnSO₄ and biofertilizers recorded significantly higher iron uptake (12.81 mg pot⁻¹) followed by recommended dose, FeSO₄ + ZnSO₄ (11.98 mg pot⁻¹). The addition of farmyard manure to sugarcane in saline sodic soil significantly enhanced the iron uptake (13.84 mg pot⁻¹) over no FYM (6.50 mg pot⁻¹).

The interaction effects were significant for iron uptake by sugarcane. The uptake of iron by sugarcane was significantly higher when FYM was used in integration. The range was from 10.26 to 17.65 mg pot⁻¹ over no FYM 5.18 to 7.95 mg pot⁻¹.

Yerriswamy *et al.* (1994) reported that due to application of FeSO₄ with FYM increased concentration of iron by nine times as a result of organometal complexation in soil and thereby its higher utilization by plants. An increase in the availability of Fe upon addition of organic matter may be attributed to conversion of higher

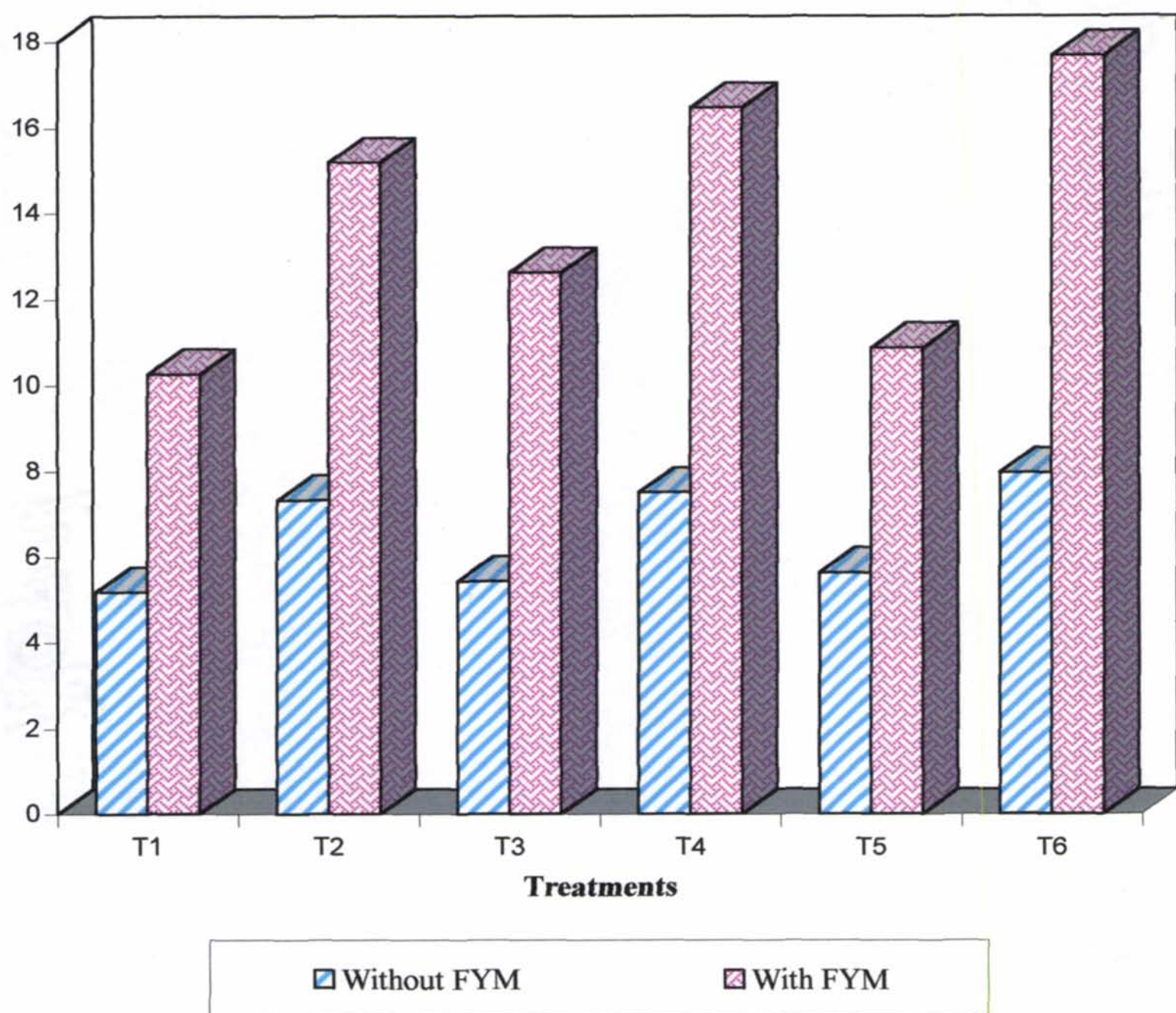


Fig. 9. Effect of integrated nutrient management on iron uptake by sugarcane

oxides of ferric to ferrous as a result of intensified microbial and chemical reduction and decrease in pH and ESP.

4.7 Correlation studies

Correlation coefficient values between nitrogen, phosphorus, iron and zinc under integrated nutrient management of sugarcane were worked out and the data are presented in Table 37.

The coefficients of correlation values reveal that the availability of phosphorus and iron in saline sodic soil go hand in hand with the nitrogen. The values for coefficient of correlation between nitrogen with phosphorus and nitrogen with iron were +0.602* and +0.614*. The positive significant correlations showed the synergistic effect of nitrogen, phosphorus and iron. There was positive correlation between nitrogen and zinc (+0.407). The phosphorus, zinc and iron showed positive correlation. The correlation between zinc and iron was found highly positive and significant (+0.860**) in saline sodic soil for their synergistic effect.

4.8 Microbial population

The data on microbial population of saline sodic soil as influenced by the integration of nutrients with an application of recommended dose of NPK, ferrous sulphate, zinc sulphate, biofertilizers with and without FYM to sugarcane are presented in Table 38.

The data indicated that there was decrease in microbial count than initial microbial count ($4 \times 10^5 \text{ g}^{-1} \text{ soil}$) in all the treatments

Table 37. The coefficient of correlation between nitrogen, phosphorus, iron and zinc under integrated nutrient management (n = 12)

	N	P	Fe	Zn
N	-	+0.602*	+0.614*	+0.407
P	+0.602*	-	+0.293	+0.135
Fe	+0.614*	+0.293	-	+0.860**
Zn	+0.407	+0.135	+0.860**	-

Significant at 5 % level : 0.576

Significant at 1 % level : 0.708

Table 38. Effect of integrated nutrient management on micorbial count ($\times 10^5 \text{ g}^{-1} \text{ soil}$)

Sr. No.	Treatments	Microbial count		
		No FYM	FYM	Mean
1.	NPK	2.60	4.27	3.44
2.	NPK + FeSO_4	2.97	4.53	3.75
3.	NPK + ZnSO_4	2.90	4.60	3.75
4.	NPK + FeSO_4 + ZnSO_4	3.27	5.03	4.15
5.	NPK + BF	2.77	4.57	3.67
6.	NPK + FeSO_4 + ZnSO_4 + BF	3.33	5.50	4.42
	Mean	2.97	4.75	
		S.E. $\pm$	CD at 5 %	
Main treatment		0.041	0.12	
Sub treatment		0.071	0.21	
Interaction		0.10	0.29	

where inorganic fertilizers without FYM was added. This might be due to higher concentration of salts and chemical reactions of different fertilizers. It was ranged from 2.60×10^5 to $3.33 \times 10^5 \text{ g}^{-1}$ soil in the treatments wherein FYM was not used.

The FYM application had positive effect on microbial count. There was increase in microbial population from 4.27×10^5 to $5.50 \times 10^5 \text{ g}^{-1}$ soil. This was might be because of the FYM which acted as food and energy source for micro-organisms helped to increase the microbial population.

Among the chemical fertilizers the combination of FeSO_4 + ZnSO_4 + biofertilizers had significantly higher count ($4.42 \times 10^4 \text{ g}^{-1}$ soil) over rest of the treatments. This ~~was~~ might be attributed to lowering of pH of soil which helped to increase microflora.

Gaur and Kumar (1993) observed that plant growth may be affected positively or negatively by soil microflora. Salinity is adversely affecting many microorganisms as it is doing with plant growth. There can be indirect relationship if not direct between plant growth and soil microflora. It was evident that soils do not become productive immediately after reclamation but gradually when the favourable micro-organisms start multiplying.

4.9 Fertilizer use efficiency

Fertilizer use efficiency as influenced by integrated nutrient management of sugarcane in saline sodic soil was worked

out by taking dry matter production and nutrient uptake as the markers. This is well depicted through Fig. 10.

4.9.1 Dry matter production

The information depicted through Fig. 10 indicated that there was 68.77 per cent increase in dry matter production of sugarcane due to application of recommended dose of NPK + FeSO_4 + ZnSO_4 + biofertilizers along with FYM. There was 55.07 per cent increase in dry matter production due to addition of NPK + ZnSO_4 along with FYM over recommended dose without FYM. There was 65.22 per cent increase in dry matter weight when recommended dose of NPK + FeSO_4 + ZnSO_4 were applied with FYM.

4.9.2 Nitrogen uptake

It could be seen from the Fig. 10 that there was 185.12 per cent increase in nitrogen uptake by sugarcane when recommended dose of NPK + FeSO_4 + ZnSO_4 + biofertilizers were applied with FYM. The recommended dose + ZnSO_4 with FYM had 143.80 per cent more nitrogen uptake over recommended dose only.

4.9.3 Phosphorus uptake

It was indicated from Fig. 10 that there was 205.88 per cent increase in phosphorus uptake in T_6 where integration of fertilizers were with FYM whereas, it was 202.94 per cent when recommended dose of NPK + FeSO_4 + ZnSO_4 was applied along with FYM. Application of ZnSO_4 with FYM had 194.12 per cent phosphorus uptake.

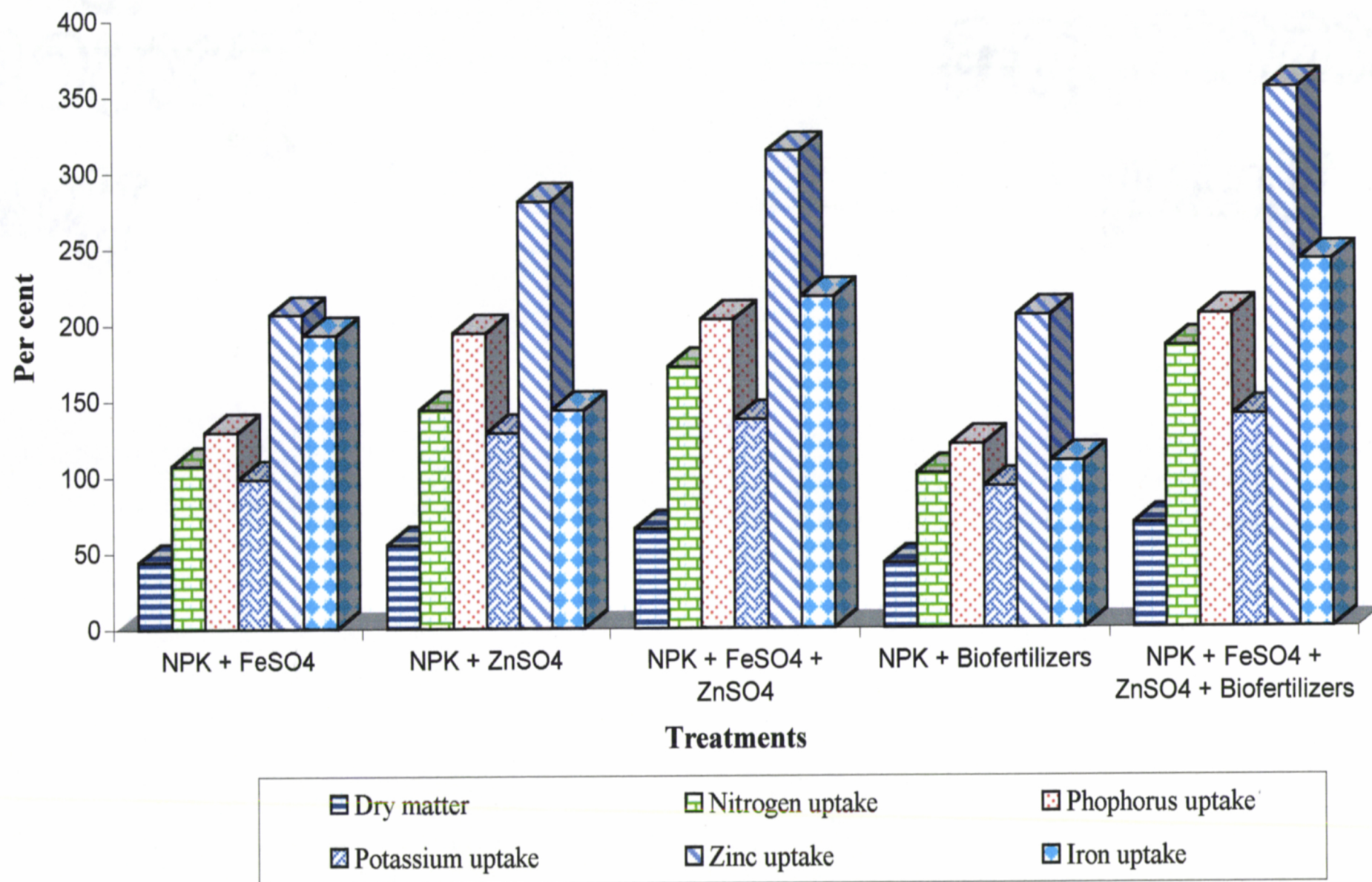


Fig. 10. Per cent use efficiency of fertilizers as influenced by integrated nutrient management

4.9.4 Potassium uptake

It could be seen from Fig. 10 that there was 139.66 per cent increase in potassium uptake by sugarcane when recommended dose of NPK + FeSO_4 + ZnSO_4 + biofertilizers were applied with FYM. The recommended dose + ZnSO_4 with FYM had 128.45 per cent more potassium uptake over recommended dose only.

4.9.5 Zinc uptake

It is interesting to note that the per cent fertilizer use efficiency (Fig. 10) was raised upto 354.52 when integration of fertilizers was with FYM. Application of recommended dose + ZnSO_4 with FYM had 280.47 per cent efficiency.

4.9.6 Iron uptake

The efficiency was observed to be raised upto 241.12 when FYM was one of the components in an integration (Fig. 10). The FeSO_4 with FYM had iron uptake registered 193.05 per cent iron uptake. In general, all these parameters showed that inclusion of organic manure (FYM) in the integrated nutrient management programme of sugarcane played promising role in increasing the uptake of nutrients and thereby the cane yield in saline sodic soil.

These results elucidated the importance of integration of inorganic and organic nutrient sources along with biofertilizers for better growth of sugarcane crop. There should exist optimum relationship between macronutrients (NPK) and the micronutrients (Fe and Zn) for harvesting optimal production of sugarcane in saline

sodic soils. However, the results have also indicated that this relationship can vary within appreciable limits depending upon the nature and extent of salinity and/or sodicity and also with the extent of integration existed in the rhizosphere of the growing sugarcane crop.

In order, therefore, to correct the deficiencies of micronutrients (Zn and Fe) and to maintain a satisfactory yield level of sugarcane grown in saline sodic soil, integrated use of fertilizers, manures and biofertilizers be followed under close monitoring of crop management.

Chapter Opener Page

SUMMARY AND CONCLUSIONS

5. SUMMARY AND CONCLUSIONS

The nutrient release pattern in saline sodic soil under integrated nutrient management for sugarcane was studied by conducting an incubation study and pot culture experiment with different sources of nutrient elements viz., urea, single superphosphate, ZnSO_4 , FeSO_4 , biofertilizer and organic manure (FYM) during 2000-2001 at the Department of Agril. Chemistry and Soil Science, M.P.K.V., Rahuri. The research information generated during the course of investigation is summarised briefly and concluded precisely in this chapter.

1. The conjoint use of urea, FYM and *Azotobacter* was effective to reduce the pH of the saline sodic soil. The total soluble salts (EC) of saline sodic soil were remained unaffected by conjoint use of urea, FYM and *Azotobacter*.
2. The ammonical nitrogen content of saline sodic soil was increased upto 20 days of incubation by the conjoint use of urea, FYM and *Azotobacter*. Whereas, nitrate nitrogen was increased up to 120 days of an incubation. The ammonical and nitrate nitrogen contents of saline sodic soil had negative relation with each other.
3. The combined use of urea, FYM and *Azotobacter* was beneficial for available phosphorus, DTPA zinc and iron in saline sodic soil.

4. The application of single superphosphate along with FYM and phosphate solubilizer decreased the soil pH and increased the electrical conductivity of saline sodic soil.
5. The conjoint use of single super phosphate with FYM and phosphate solubilizers showed positive effect on ammonical and nitrate nitrogen in saline sodic soil.
6. The phosphorus release was significantly higher in application of single superphosphate in conjunction with FYM and phosphate solubilizing bacteria, irrespective of their incubation period followed by single superphosphate + FYM. The application of single superphosphate alone released the least amount of phosphorus as compared to other single superphosphate treatments.
7. The application of single superphosphate, FYM, PSB alone and their combined use, significantly increased the DTPA Zn in saline sodic soil.
8. The integrated use of single superphosphate, FYM and phosphate solubilizers recorded the highest DTPA Fe in saline sodic soil.
9. The pH of saline sodic soil significantly decreased, whereas, electrical conductivity increased due the application of micronutrients viz., FeSO_4 + ZnSO_4 either alone or with FYM.

10. The availability of phosphorus in saline sodic soil significantly increased with micronutrient application along with FYM and *Thiobacillus ferrooxidans*.
11. The application of $\text{FeSO}_4 + \text{ZnSO}_4$ with FYM and FYM + *Thiobacillus ferrooxidans* significantly increased the ammonical and nitrate nitrogen in saline sodic soil.
12. The treatments of micronutrients and micronutrients + *Thiobacillus ferrooxidans* were significant in influencing the zinc and iron availability in saline sodic soil.
13. The integrated use of urea, single superphosphate, $\text{FeSO}_4 + \text{ZnSO}_4$, FYM, biofertilizers (*Azotobacter*, phosphate solubilizers, *Thiobacillus ferrooxidans*) significantly decreased the pH and increased the electrical conductivity of saline sodic soil.
14. The integrated nutrient management for saline sodic soil significantly increased the ammonical and nitrate nitrogen. The release of ammonical nitrogen was initially more upto 20 days and reduced thereafter. The nitrate nitrogen was increased after 30 days of an incubation. The application of FYM as one of the components of integration had significant effect on release of ammonical and nitrate nitrogen.
15. The integrated nutrient management of saline sodic soil showed that the application of FYM with inorganic and biofertilizers significantly increased the available phosphorus. The application of single superphosphate in combination with

FYM had beneficial effect on availability phosphorus in saline sodic soil.

16. The DTPA-Zn and Fe were released significantly in saline sodic soil due to integral use of urea, single superphosphate, FeSO_4 + ZnSO_4 and biofertilizers.
17. The integral use of recommended dose of NPK, micronutrients (Fe and Zn) and biofertilizers with and without farmyard manure significantly influenced the shoot and root dry matter of sugarcane in saline sodic soil.
18. The application of farmyard manure was significantly superior in the production of higher biomass and root dry matter of sugarcane in saline sodic soil.
19. The uptake of N, P, K, Fe and Zn was significantly increased due to integral use of nutrient elements along with FYM in saline sodic soil.
20. The use efficiency of nutrients applied through inorganic fertilizers was enhanced by the conjoint use of inorganic fertilizers with organics in saline sodic soil.
21. The microbial population was significantly increased due to application of FYM in saline sodic soil.

In general, the experimental results reveal that the conjoint use of recommended dose of NPK, FeSO_4 , ZnSO_4 , biofertilizers along with farmyard manure in saline sodic soil for

sugarcane crop is necessary to increase the shoot-root, biomass and nutrient uptake.

Conclusions

From the present investigations on integrated nutrient management of sugarcane grown on saline sodic soil, it is concluded that the use efficiency of fertilizers in saline sodic soils can sufficiently be increased by adoption of integrated nutrient management practice. The inorganic fertilizers showed better response in the presence of FYM. The ameliorative influence of fertilizers along with FYM in saline sodic soil is attributable to neutralization of alkalinity, improvement in salt tolerance of sugarcane crop and restoration of bio-physicochemical properties.

The integration of recommended dose of NPK, FeSO_4 , ZnSO_4 , FYM and biofertilizers resulted in higher sugarcane biomass production. This indicated that the judicious use of FYM, mineral fertilizers and biofertilizers were proved itself to be potential tool for sustaining the productivity of sugarcane grown on saline sodic soil.

These inferences were based on laboratory studies and pot culture experiment. Hence, the investigation needs to be tested under field conditions for the confirmation of results.

Future research needs

Studies on integrated nutrient management are rather scanty especially in saline sodic soil where sugarcane is mainly grown. A significant knowledge gap exists in this area. Some broad

research needs, with special reference to integrated nutrient management of sugarcane are outlined here.

- * Specific nutrient deficiencies including that of micronutrients in different parts of the sugarcane growing zones need to be identified, along with other constraints and yield levels with native nutrient supply systems determined in relation to soil physical and chemical characteristics.
- * Specific studies to be worked out integrated nutrient requirements of crop on concepts of precision agronomy would provide a base for efficient management of the system.
- * Strategies need to be worked out for harnessing biological nitrogen fixation in sugarcane and its integration with adequate supplies of other nutrients for sugarcane.
- * The role of nature and composition of salts and their dynamics in fertility build-up of saline and alkali soils should be critically studied. The function of organic matter and associated microbial community in soil alleviating the salinity and alkalinity problems also needs in depth study.
- * Stress need to be given on nitrogen fertility level and nitrogen nutrition of sugarcane grown under saline and alkali environment. Since most of the salt affected soils are deficient in nitrogen and the use efficiency of N fertilizers is poor under such soil-water-plant relationship, this has special significance.
- * Influence of salts on uptake and balance of nutrients in sugarcane need to be studied in detail with reference to nature and quality of salts in soil/crop tolerance and agronomic management.

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LITERATURE CITED

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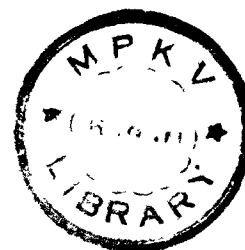
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Chapter Opener Page

VITA

7. VITA

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A candidate for the degree

of

DOCTOR OF PHILOSOPHY (AGRICULTURE)

2002

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