

**“EFFECT OF DIFFERENT MOISTURE REGIMES,  
LEVELS AND SOURCES OF PHOSPHORUS AND  
FYM ON THE AVAILABILITY OF NUTRIENTS  
IN THE SOIL OF WHEAT-GROWING AREA  
OF BHAL (GUJARAT)”**

**A THESIS  
SUBMITTED TO THE  
GUJARAT AGRICULTURAL UNIVERSITY  
IN PARTIAL FULFILMENT OF THE REQUIREMENTS  
FOR THE AWARD OF THE DEGREE**

**OF  
Master of Science  
( AGRICULTURE )**

**IN  
AGRICULTURAL CHEMISTRY AND SOIL SCIENCE**

Dr. M D Patel Regional Library  
GAU. Anand



TH41861

**BY  
V. S. PATEL**

**B. Sc. (Agri.)**

**DEPARTMENT OF AGRICULTURAL CHEMISTRY AND SOIL SCIENCE  
B. A. COLLEGE OF AGRICULTURE,  
GUJARAT AGRICULTURAL UNIVERSITY  
ANAND CAMPUS, ANAND.**

**APRIL, 1988.**



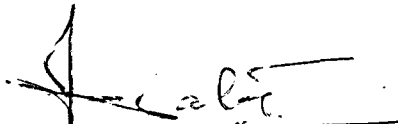
Dr. J. C. Patel  
Associate Professor and  
I/c. Professor and Head  
Department of Agril. Chem. & Soil Sci.  
B.A.College of Agriculture  
Gujarat Agricultural University  
Anand Campus  
ANAND-388 110

CERTIFICATE

This is to certify that the thesis entitled "EFFECT OF DIFFERENT MOISTURE REGIMES, LEVELS AND SOURCES OF PHOSPHORUS AND FYM ON THE AVAILABILITY OF NUTRIENTS IN THE SOIL OF WHEAT-GROWING AREA OF BHAL (GUJARAT)" submitted by Shri Vinubhai S. Patel in partial fulfilment of the requirements for the award of the degree of Master of Science (Agriculture) in Agricultural Chemistry and Soil Science of the Gujarat Agricultural University is a record of bonafide research work carried out by him under my personal guidance and supervision and the thesis has not previously formed the basis for the award of any degree, diploma or other similar title.

ANAND

Date : April 11 ,1988

  
(J. C. Patel)  
Major Advisor

# ABSTRACT

## ABSTRACT

"EFFECT OF DIFFERENT MOISTURE REGIMES, LEVELS AND SOURCES OF PHOSPHORUS AND FYM ON THE AVAILABILITY OF NUTRIENTS IN THE SOIL OF WHEAT-GROWING AREA OF BHAL (GUJARAT)"

Name of the student

V. S. Patel

Major Advisor

Dr. J. C. Patel

Department of Agricultural Chemistry and Soil Science  
B. A. College of Agriculture  
Gujarat Agricultural University  
Anand Campus, Anand

A laboratory incubation study was conducted during the year 1987, to evaluate the effect of different moisture regimes viz., 40, 30, 20, 10 and 40 (rewetting) per cent simulated due to depletion in moisture from flooded soil and again rewetting in presence (13.5 t/ha)/absence of FYM and different levels of P (0, 4.87 and 9.74 ppm) applied through dicalcium phosphate and diammonium phosphate on the availability pattern of P, K, Fe, Mn, Zn, Cu and the changes in soil pH in a clay loam soil of wheat-growing area (Bhal).

The study revealed that the value of soil pH was increased from 7.54 to 7.57, 7.61 and 7.66 when moisture depleted from 40 ( $M_1$ ) to 30 ( $M_2$ ), 20 ( $M_3$ ) and 10 ( $M_4$ ) per cent, respectively. Application of FYM markedly decreased the soil pH from 7.73 to 7.40. The availability of P and K in the soil was decreased significantly when the moisture was

depleted from 40 to 10 per cent. Again on rewetting the soil, availability of nutrients was restored. Application of diammonium phosphate at higher level significantly increased the availability of P in the soil over dicalcium phosphate. Application of FYM significantly increased the available P and K contents in the soil.

The contents of DTPA-extractable Fe and Mn significantly decreased with depletion in moisture from 40 to 10 per cent, however, the reverse was true for Zn and Cu. Again on rewetting the soil, availability of nutrients was restored. Application of P at higher level significantly decreased the availability of Fe, Zn and Cu, while reverse was true for Mn. The magnitude of adverse effect of P on the availability of Fe, Zn and Cu was significantly reduced when it was applied through DAP over DCP, while the availability of Mn was significantly enhanced by DAP over DCP. The availability of Fe, Mn, Zn and Cu was significantly increased due to FYM application.

The results of the present investigation clearly showed that at higher moisture level, application of FYM significantly enhanced the availability of different nutrients. DAP was observed a better source in increasing the Olsen's P and maintaining the micronutrients availability as compared to DCP. The pattern of nutrient availability also remained more or less same on rewetting the treated soil.

## ACKNOWLEDGEMENT

This memorable occasion provides me with a unique privilege to express my sincere and profound gratitude to my Major Advisor Dr. J.C. Patel, M.Sc., Ph.D.; Associate Professor and I/c. Professor and Head, Agricultural Chemistry and Soil Science Department, B.A. College of Agriculture, Gujarat Agricultural University, Anand Campus, Anand for his keen and continued interest, valuable guidance and thought provoking advice during the course of this investigation and the preparation of this manuscript.

I convey my sincere thanks to Prof.B.M.Zala, Director of Campus, Gujarat Agricultural University, Anand Campus, Anand; Dr.B.G. Jaisani, Principal, B.A.C.A., Anand; Dr. C.A. Patel, Ex-Professor and Head of Agricultural Chemistry and Soil Science Department and Dr.R.T. Dangarwala, Senior Soil Scientist, AICRP (Micronutrients) for providing the necessary facilities for my research work.

I am also thankful to the members of my advisory committee Sarvashri Dr.C.A.Patel, Ex-Professor and Head, Dept. of Agril. Chem. and Soil Sci., Dr. H.M. Mehta, Agronomist, AICRP on Weed Control and Dr. M.R. Vaishnav, Professor and Head, Department of Agricultural Statistics, B.A. College of Agriculture, Anand Campus, Anand for their helpful counsels and guidance.

My heartily thanks to Dr.N.A.Patel, Research Scientist (Tobacco), B.T.R.S., Anand for his valuable suggestions and going through the manuscript of the present investigation.

I also take this opportunity to express my thanks to staff members of Agril. Chem. and Soil Science Department, Shri Z.N. Patel, K.P. Patel (Biogas Project), Jashubhai, Khushvadan, Arvind and Pravin for their kind co-operation throughout the course of the present investigation.


My thanks are also due to Shri Ghanshyambhai for his persistent effort in typing out this thesis within the stipulated time.

Last but not least, I must express my deep sense of gratitude to my wife and my two kids namely Vimal and Kamal for their generous sacrifices and keenness during the period of my study.

I express my heartfelt gratitude and indebtedness to my parents and brothers for their constant inspiration and encouragement during the period of my post graduate study.

Date : April 11, 1988

ANAND - 388 110

  
( V. S. Patel )

## CONTENT

CHAPTER		PAGE NO.
I	INTRODUCTION ...	1
II	REVIEW OF LITERATURE ...	9
	2.1 Effect of moisture regimes and FYM on soil pH ...	10
	2.2 Effect of moisture regimes on availability of P and K in soil	14
	2.3 Effect of moisture regimes on availability of Fe, Mn, Zn and Cu in soil. ...	26
	2.4 Effect of organic matter on availability of P and K in soil	41
	2.5 Effect of organic matter on availability of Fe, Mn, Zn and Cu in soil ...	48
	2.6 Effect of phosphorus application on availability of P, Fe, Mn, Zn and Cu in soil ...	52
III	MATERIALS AND METHODS ...	63
	3.1 Description of soil ...	63
	3.2 Collection and preparation of the soil sample: ...	64
	3.3 Experimental details ...	66
	3.4 Incubation study ...	67
	3.5 Periodic soil analysis ...	67
	3.6 Statistical analysis ...	68
IV	RESULTS AND DISCUSSION ...	69
	4.1 Effect of moisture regimes and FYM on soil pH ...	69

CHAPTER	PAGE NO.
4.2 Effect of moisture regimes, levels and sources of P and FYM on the availability of P in soil ...	71
4.3 Effect of moisture regimes, levels and sources of P and FYM on the availability of K in soil ...	78
4.4 Effect of moisture regimes, levels and sources of P and FYM on the availability of Fe in soil ...	83
4.5 Effect of moisture regimes, levels and sources of P and FYM on the availability of Mn in soil ...	88
4.6 Effect of moisture regimes, levels and sources of P and FYM on the availability of Zn in soil ...	95
4.7 Effect of moisture regimes, levels and sources of P and FYM on the availability of Cu in soil ...	101
V SUMMARY AND CONCLUSION ...	108
REFERENCES ...	i to xxvii
APPENDICES ...	i to ii

## LIST OF TABLES

TABLE NO.	TITLE	PAGE NO.
3.1	Important physico-chemical characteristics of the soil ...	67
4.1	Effect of moisture regimes, levels and sources of phosphorus and FYM on soil pH	69
4.2	Effect of moisture regimes, levels and sources of phosphorus and FYM on the availa- bility of P (ppm) in the soil ...	72
4.3	Effect of moisture regimes, levels and sources of phosphorus and FYM on the availa- bility of K (kg/ha) in the soil ...	79
4.4	Effect of moisture regimes, levels and sources of phosphorus and FYM on the availa- bility of Fe (ppm) in the soil ...	84
4.5	Effect of moisture regimes, levels and sources of phosphorus and FYM on the availa- bility of Mn (ppm) in the soil ...	89
4.6	Effect of moisture regimes, levels and sources of phosphorus and FYM on the availa- bility of Zn (ppm) in the soil ...	96
4.7	Effect of moisture regimes, levels and sources of phosphorus and FYM on the availa- bility of Cu (ppm) in the soil ...	102

## LIST OF FIGURE

FIGURE NO.	TITLE	AFTER PAGE NO.
4.1	Average effect of moisture regimes and FYM on soil pH ...	69
4.2(A)	Average effect of moisture regimes, levels and sources of P and FYM on the availability of P in soil ...	73
4.2(B)	Available P in soil as influenced by the interaction effect of moisture regimes, levels and sources of P and FYM	73
4.3(A)	Average effect of moisture regimes, levels and sources of P and FYM on the available K in soil ...	80
4.3(B)	Available K in soil as influenced by the interaction effect of moisture regimes, levels and sources of P and FYM ...	80
4.4(A)	Average effect of moisture regimes, levels and sources of P and FYM on the DTPA- extractable Fe in soil ...	86
4.4(B)	DTPA-extractable Fe in soil as influ- enced by the interaction effect of moisture regimes, levels and sources of P and FYM ...	86
4.5(A)	Average effect of moisture regimes, levels and sources of P and FYM on the DTPA- extractable Mn in soil ...	91
4.5(B)	DTPA-extractable Mn in soil as influenced by the interaction effect of moisture regimes, levels and sources of P and FYM	91

FIGURE NO.	TITLE	AFTER PAGE NO.
4.6(A)	Average effect of moisture regimes, levels and sources of P and FYM on the DTAP-extractable Zn in soil	99
4.6(B)	DTPA-extractable Zn in soil as influenced by the interaction effect on moisture regimes, levels and sources of P and FYM	... 99
4.7(A)	Average effect of moisture regimes, levels and sources of P and FYM on the DTPA-extractable Cu in soil	... 105
4.7(B)	DTPA-extractable Cu in soil as influenced by the interaction effect of moisture regimes, levels and sources of P and FYM	... 105



# INTRODUCTION

## I. INTRODUCTION

The availability of the native and the applied nutrient and its subsequent utilization by the growing crop is governed by number of factors such as soil moisture, soil pH, concentration of the nutrient, its relationship with the other nutrients, oxidation-reduction reactions and the presence of organic matter. Among these factors, the soil moisture and organic matter have a profound effect on the availability and transformations of the different nutrients. The higher moisture regime, particularly the submergence, causes the changes in the properties of the soil because of physical reactions between the soil and water and also biological and chemical properties set in motion. The higher moisture leads to the depletion of oxygen and the accumulation of reduction products. This brings about significant changes in soil pH. The pH of the flooded acid soils rises and that of alkaline soils falls.

Crop growing in the field usually lives in a water suction regime fluctuating in water availability that may range from soil saturation to extreme drought. When the flooded rice fields become dry, the reduced constituents of soil are reoxidized with concomitant rise in soil Eh and lowering in pH. As a result, the soluble ferrous phosphate gets oxidised to insoluble ferric phosphate in dry soil.

It may, therefore, cause a reduction in the solubility of native soil phosphorus.

Paul and Delong (1949) observed that drying a soil subsequent to flooding generally decreases the solubilities of both native and added phosphate. The biological reduction of iron during the flooding phase followed by reoxidation during the drying phase results in the enhanced reactivity of the sesquioxide fraction of the soil, leading to an increase in the phosphate fixing capacity and hence to a decrease in the solubility of phosphate.

The soil maintained at higher moisture regimes such as saturation and flooding also tremendously affect the transformation and availability of other nutrients like iron, manganese, copper and potassium. After submergence of a soil, zinc deficiency in low land rice field is caused due to the formation of insoluble compounds like carbonates, hydroxides and sulphides under reduced conditions (Patrick and Reddy, 1977 and Katyal, 1977). After submergence of a soil, Fe(III) oxide hydrates are reduced to Fe(II) compounds (Ponnamperuma, 1972 and Gotoh and Patrick, 1974). The availability of manganese also increases many fold due to increased moisture content in soil (Subrahmanyam and Mehta, 1975 and Mandal and Mitra, 1982). The reduction of higher oxides of Mn, chiefly Mn(IV) takes place almost simultaneously with denitrification (Ponnamperuma, 1965). The reduction may also result from

those compounds functioning as electron acceptors in the respiration of micro-organisms and chemical oxidation-reduction products. Like zinc, the availability of copper in soil, in general, has been found to decrease with increasing moisture content of the soil (Ponnamperuma, 1977 and Haldar and Mandal, 1979).

The potassium availability in soil, in general also increases with increasing moisture content of the soil, but is also governed by the presence of the expanding type of clay minerals such as montmorillonite, illite and vermiculite (Volk, 1934; Mortland, 1961 and Sharma et al., 1977).

The availability of the applied nutrient in the soil is higher in the earlier period of incubation or crop growth and thereafter steadily diminishes either due to conversion into its insoluble compounds or the fixation by the clay colloids (Hulagur et al., 1975b; Patra et al., 1981 and Singh and Singh, 1981).

The importance of soil organic matter in relation to soil fertility and physical conditions is widely recognized. Besides being a source of nutrients for the plants, the presence of humus in soil exerts a pronounced influence on the physical, chemical and biological activities of the soil. In the formation of a fertile soil, organic substances play a direct role, as they are the sources of plant nutrients which are liberated in available form during

mineralization. A large quantity of carbon dioxide and organic acids produced during the microbial decomposition of organic matter, temporarily decreases the soil pH and thereby increases the rate of release of elements such as phosphorus, boron, zinc, iron and manganese as a result of the dissolution of certain primary soil minerals, particularly under neutral and alkaline conditions.

Organic matter also affects the phosphorus availability (Bradley and Sieling, 1953; Yu and Liu, 1965) either directly by displacement of phosphate from iron and/or aluminium phosphate, or by influencing (a) the decrease in redox potential and (b) pH changes. Nowadays it is fairly well established that though there is some fixation of phosphorus at relatively high pH (Gaur, 1969), yet not only the organic matter but also specifically humus is of positive influence of phosphorus availability (Srivastava et al., 1969; Adhikari and Ganguli, 1971; Vyas and Motiramani, 1971; Sinha, 1972 and Brams, 1973). On the other hand, humus combines with iron or aluminium to form chelates thereby decreasing the chance of inorganic phosphate fixation (Kononova, 1966). Savant and Ellis (1964) also observed that soil moisture, with or without organic matter, definitely influences availability of both native and applied phosphorus.

In long-term field studies, Prasad et al. (1983) for 6 years and Muthuvel et al. (1977) for 65 years observed that application of farm yard manure (FYM) alone or in combination with NPK markedly increased the available K status in red loam and acidic sandy loam soils. Application of FYM (12.5 t/ha/year) markedly increased the available K content (Anonymous, 1977-78).

Mann et al. (1978) reported that application of FYM by and large improved the availability of all the micro-nutrients. Similar results also have been reported by Singh and Prasad (1982), Maurya and Ghosh (1972), Hansraj (1986), Srivastava and Sethi (1981). A high positive correlation between organic matter content in soil and extractable micro-nutrients has been reported by several workers (Khetawat and Vashishtha, 1977; Misra and Pande, 1975; Misra and Pandey, 1976; Misra et al., 1976; and Vittal and Gangawar, 1974).

The addition of any nutrient obviously improves its availability in soil, but simultaneously it also affects the availability or the balance of other nutrients. The effect may be either synergistic or antagonistic. Iron exists in soil as oxides, hydroxides as well as in ionic forms and all these are capable of reacting with native and applied P in soil and reduce their solubility by chemical precipitation. Studies conducted by Das and Datta (1967, 1968, 1969) revealed that interaction of phosphates in

black, brown, red, laterite, alluvial and calcareous soil usually produced colloidal and amorphous Fe-Al phosphate with other reaction products especially when P was applied as monocalcium phosphate. Dev and Mann (1972) reported that increasing level of P application significantly decreased the available Fe in a loamy sand soil.

There is a possibility of an antagonistic relationship between Zn and P in soil and its contribution to the P induced Zn deficiency which can not be totally overlooked (Kalyansundram and Mehta, 1970). Deb and Zeliang (1976) observed that application of P at 50 kg/ha significantly reduced the available Zn content in an alluvial soil after the harvest of rice but such effect was not significant after wheat crop.

Hulagur et al. (1975 b) in an incubation experiment involving interaction between Zn, Cu and P observed that these three elements individually suppressed the availability in soil of other two elements. Maximum fixation occurred in the case of Cu, intermediate in P and least in zinc.

Application of higher doses of P at times has been reported to increase the availability of Mn in soils. The beneficial effect is stated to be due to the precipitation of  $Mn^{+2}$  as manganous phosphate which does not permit the oxidation of  $Mn^{+2}$  to higher oxides and maintains a constant, though a small supply of divalent Mn to plants (Steckel

et al., 1948). Pathak et al. (1972) also reported significantly increased availability of P and Mn at increasing levels of soil fertility under submerged conditions.

In wheat-growing area of Bhal, most of the soils are clay to clay loam in texture. In the soil profiles, surface layers are less saline but salinity and alkalinity increased with the depth (Patel, 1984). The farming practices in the Bhal area (Ahmedabad district) are critically dependent on the rainfall distribution. Durum wheat is grown in this area with the help of residual moisture conserved in the soil during the monsoon. Generally, farmers apply nitrogenous fertilizer (urea) only to durum wheat while sowing. Though the availability of Olsen's P in most of the soils is low, ranging from 0.8 to 15.8 kg P<sub>2</sub>O<sub>5</sub>/ha (Motiramani et al., 1987), the P-deficiency symptoms are not noticed on wheat crop. The DTPA-extractable Zn in the soil is also marginal (Patel and Patel, 1984). In this context, it was thought worthwhile to study the nutrient supplying capacity of the soil at different moisture regimes simulated due to its depletion from flooded soil with the passage of time in presence/absence of FYM and different phosphatic fertilizers and its residual effect on rewetting.

Hence, an incubation study was undertaken in the laboratory using a soil (0-20 cm) of wheat-growing area of Bhal with following main objectives.

- (1) To study the availability of phosphorus and other nutrients at various moisture regimes simulated due to depletion in moisture from flooded soil with the passage of time, different levels of P applied through various sources and FYM.
- (2) To study the residual effect in next season on the availability of P and different nutrients due to rewetting the treated soil.

**REVIEW OF  
LITERATURE**

## II. REVIEW OF LITERATURE

The soil moisture regimes and farm yard manure have a profound effect on the availability and transformation of various mineral nutrients in the soil. In dry farming area, after monsoon (flooding), depletion of soil moisture takes place with the passage of time, creating condition markedly different from those of a well drained irrigated soil or sub-merged paddy soil. The purpose of this chapter is to examine the research work done on various aspects related to the effect of moisture regimes, FYM and phosphorus application on availability pattern on P, K, Fe, Mn, Zn, Cu and changes in soil pH. The literature pertaining to these aspects only has been reviewed in this chapter and presented under following different sub headings.

- 2.1 Effect of moisture regimes and FYM on soil pH.
- 2.2 Effect of moisture regimes on availability of P and K in soil.
- 2.3 Effect of moisture regimes on availability of Fe, Mn, Zn and Cu in soil.
- 2.4 Effect of organic matter on availability of P and K in soil.
- 2.5 Effect of organic matter on availability of Fe, Mn, Zn and Cu in soil.
- 2.6 Effect of phosphorus application on availability of P, Fe, Mn, Zn and Cu in soil.

## 2.1 Effect of moisture regimes and organic matter on soil pH :

### 2.1.1 Effect of moisture :

The soil pH is a very important electro-chemical property which governs many other physico-chemical properties of the soil and availability of essential mineral nutrients in the soil. The moisture has marked effect on the pH of the soil. The depletion of oxygen, accumulation of carbon dioxide and onset of reduction process markedly influence the pH value of saturated soil. Generally, pH of acid soil increases and sodic soil decreases after submergence, resulting the values remaining around 7.0.

By applying the thermodynamic approach to both pure chemical and soil systems, it was concluded that the change of pH in submerged soil is regulated fundamentally by three systems.

1.  $\text{Na}_2\text{CO}_3 - \text{CO}_2 - \text{H}_2\text{O}$  - for sodic soils
2.  $\text{CaCO}_3 - \text{CO}_2 - \text{H}_2\text{O}$  - for calcareous soils
3.  $\text{Fe}(\text{OH})_3 - \text{Fe}^{2+}$  - for ferruginous soils

The first two systems control the decrease of pH in alkaline soils. The third, an oxidation-reduction system, regulates increase of pH and its stabilization at 6.5 to 7.0 particularly in acid soils (Ponnamperuma, 1967, 1972).

Mahapatra (1968) carried out a study using twenty Louisiana soils (pH 4.7 to 8.2) and found that the pH values of the

soils incubated for 60 days under waterlogged conditions, varied between 6.4 and 7.7. He further observed that the pH of acid soils increased and alkaline soils decreased after waterlogging and tended to shift near neutral point.

Ponnamperuma et al. (1966) conducted an experiment with 35 air dried lowland rice soils from Philippines, Tiwan and Vietnam. They observed that soil properties markedly influenced the magnitude of pH changes caused by submergence of the soils. The pH values of alkali soils (7.6 to 9.4) decreased upto 6.7 to 7.2, after six weeks of flooding. Flooding thus, changed the pH values of alkaline soils to near neutral point.

Shanthamallaiiah et al. (1976) conducted an experiment in the rice soil at Dharwar having pH value of 7.9. They observed that the pH reached to near neutral point after 40 days under submerged condition. They further noted that there was a significant difference between saturation and submergence at 40th day after start and not at other periods.

In a laboratory study Rahmatullah et al. (1976) indicated that submergence reduced pH from 8.5 and 8.3 to 7.8 and 7.5 by second week for the Hafizabad and Miranpur (Pakistan) soils, respectively. No further reduction was observed during subsequent period. It was further noted

that drying of soils to field capacity after seventh week had no effect on pH of the two soils.

Sharma et al. (1977) carried out an incubation study using silty loam soil with three moisture regimes viz., field capacity, saturation and flooding. They observed that the pH of the soil decreased from 8.3 to near neutral reaction after 15 days, irrespective of moisture levels, but the decrease was more pronounced under flooding than saturation and field capacity.

From the incubation studies of different type of soil, it has been reported that flooding of the acid soil (pH 5.4 to 6.6) resulted in an increase in pH and it attained near neutral reaction within 21 to 45 days of submergence and remained more or less similar for the remaining period of submergence (Chakravarti and Kar, 1970; Mukherjee and Basu, 1971; Ghosh et al., 1976; Mandal and Mitra, 1982; Rao et al., 1984; and Kumar et al., 1981). However, Bora and Goswami (1980) studied the electro-chemical properties of rice growing soils of Assam and concluded that within 10 to 15 days of submergence, the pH of the soils increased from 5.3 to an almost neutral soil condition.

#### 2.1.2 Effect of organic matter :

A large quantity of carbon dioxide (carbonic acid in water) and some organic acid evolved during microbial

decomposition of organic matter brings about a decrease in soil reaction temporarily (Singh and Lal, 1976).

The quality and quantity of manuring over the period of time has been known to affect the soil pH. The prolonged use of FYM and fertilizers in long term cropping has influenced the soil pH to a variable extent in different soils. The effect is largely controlled by the basic soil type and the source of the fertilizer nutrient. While studying the effect of long term application of manures and fertilizers on phosphorus status of vertisol (calcareous soil), Rahate et al. (1979) reported that high dose of FYM alone or in combination with ammonium sulphate, lowered the pH of the soil which could be attributed to the decomposition of organic matter. Sharma et al. (1977) also observed that addition of organic matter play a very important role in the reduction of pH in a alkaline soil.

Modi (1986) reported that application of green manure and FYM for twenty five years significantly lowered the pH of sub-surface soil (22.5 to 45.0 cm).

Contrary to this, Sahu and Nayak (1971), Shinde and Ghosh (1971) and Bandyopadhyay et al. (1969) reported that pH of medium black, alluvial and lateritic (sandy loam) soils did not change by the long term (10 to 17 years) application of lime, compost, ammonium sulphate or FYM. These results were in conformity with Ghosh and Kanzaria (1964).

Murthy and Poonamperuma (1986) studied the association of different soil characteristics of the soil samples from rice growing area in the Philippines. They found that soil pH (6.5 to 8.1) was positively correlated with organic carbon ( $r = 0.62$ ).

## 2.2 Effect of moisture regimes on availability of P and K in soil :

### 2.2.1 Availability of phosphorus :

The availability of phosphorus in soil increases with increasing moisture content of the soil. The effect is more pronounced in case of submergence as compared to saturation and field capacity. The increased availability of phosphorus with higher moisture regimes is mainly due to reduction of ferric phosphate to ferrous phosphate, although other changes like hydrolysis of aluminium phosphate and the dissolution of calcium phosphate resulting from the accumulation of carbon dioxide are also involved. These changes are also accompanied by the changes in the pH of the soil (Ponnamperuma, 1972). The increase in availability of P with increase in moisture levels depended on the concentration of P in the form of  $Fe^{+3}$  i.e. the soils which were originally rich in Fe-P fraction showed an increase with increase in moisture content (Chauhan et al., 1972; Prabhakar et al., 1972). Contrary to these, soils dominating in Ca-P fraction or the calcareous soils have showed

practically least increase in the availability (Savant and Ellis, 1964; Chauhan et al., 1972; Prabhakar et al., 1972, 1974 and Mali et al., 1979).

From a research study, Mandal (1964) reported that the monocalcium phosphate in soil increased upto the 60th day after waterlogging and thereafter gradually decreased.

Prabhakar et al. (1974) conducted an experiment on red sandy loam (pH 7.7), alluvial (pH 7.4) and black clay loam (pH 6.7) soils with three moisture levels viz., 50, 100 and 200 per cent field capacity. They observed the maximum P availability when the soils were incubated at 200 per cent field capacity level, as compared to 100 and 50 per cent field capacity moisture levels. Availability of P was increased by 30 and 4 per cent in red sand loam, 14 and 1 per cent in black clay loam and 19 and 2 per cent in alluvial soil at 200 and 100 per cent field capacity, respectively over that of 50 per cent field capacity level.

In an incubation study, Rao and Venkateswarlu (1974) reported that the phosphorus availability increased after two weeks of submergence from 16.4 to 20.0 ppm in red sandy loam soil and from 3.2 to 11.6 ppm in heavy loam soil and thereafter it decreased upto 8th week of submergence in both the soils.

Vyas and Motiramani (1971) carried out a laboratory study on black and alluvial soils (pH 7.8 to 8.2) with five

moisture levels viz., 0, 10, 20, 40 and 60 per cent. They reported that there was an increase of 19.95 and 19.50 ppm  $P_2O_5$  at 60 per cent moisture level over 10 per cent in case of black and alluvial soil, respectively. Thus, minimum fixation was found at 60 per cent and maximum at 10 per cent moisture level.

Satyanarayana et al. (1970) carried out an experiment on black clay (pH 8.0), red sandy loam (pH 7.9) and reddish brown sandy loam soil (pH 6.0) with three moisture levels viz., (i) continuous flooding, (ii) constant moisture regime and (iii) alternate wetting and drying. They found that the available  $P_2O_5$  content of the black soils increased from 29 to 70 ppm with increasing moisture levels. While it varied from 20 to 44 ppm in case of reddish brown soil and 38 to 92 ppm in case of red soil.

Patel (1975) indicated that submergence of heavy clay soil of Navagam (Gujarat) resulted in an increased availability of native phosphorus. The average increase in the available P was 16.6, 26.7 and 33.4 per cent after 7, 14 and 28 days of incubation, respectively.

Mandal and Khan (1975) observed that repeated cycles of alternate waterlogged and saturated conditions lowered the Bray's and Truog's extractable P, irrespective of the soils, however, continuous waterlogged condition appeared to be beneficial for the release of soil native

phosphorus in acidic soils. In very slightly acidic or almost neutral soils neither continuous waterlogged nor saturated condition could influence much the availability of native soil phosphorus.

Mahapatra (1969) conducted a laboratory experiment by continuously flooding the soil samples in 1:1 soil : water ratio and observed a considerable increase in the amount of available phosphorus ranging from 30.3 ppm (air dry) to 76.9 ppm (waterlogged).

Shanthamallaiyah et al. (1976) studied the phosphorus availability under saturation and submergence and found the maximum release of phosphorus (42 ppm) on 32nd day in submerged condition, whereas it was the highest on 40th day in case of saturation condition. The increase in phosphorus due to submergence was attributed to the resultant favourable soil pH.

De Datta et al. (1966) conducted an experiment at IRRI with six low land rice soils (pH 5.1 to 7.7) of Philippines and concluded that flooding of the soils for 3.5 months increased the extractable P content in all the soils by 2.5 to 15 times over that of initial content of air dry soils.

Mandal and Khan (1976) concluded that the soil at field capacity could maintain a higher amount of added P in the water soluble, saloid bound and Truog's

available P in the canning soil which was neutral to slightly alkaline in reaction, but no such effect was found in Shriniketal soil having acidic nature.

Savant and Ellis (1964) conducted an incubation study with silt loam soils (pH 6.2 to 7.6) with 3 moisture regimes viz., (i) field capacity, (ii) twice the field capacity and (iii) submergence. They observed that the P availability was the highest at submergence followed by twice field capacity and field capacity.

In an incubation study with a clay loam soil (pH 5.7), Singh et al. (1976) noted that available phosphorus under waterlogged condition increased appreciably at 10 days of incubation and then decreased at 20 days of incubation, but increased thereafter. The increased P availability with waterlogging was mainly due to increase in Fe-P.

Bradley et al. (1984) reported that P sorption values showed a significant increase with time of waterlogging. Bray's extractable P significantly increased upto 90 days of waterlogging and declined thereafter.

Khalid et al. (1977) indicated that the more native soil P was released under reduced condition than under oxidized condition and the concentration of P adsorbed under reduced condition was highly significantly correlated with Bray's extractable P.

Rajukannu and Ravikumar (1978) reported that among the moisture regimes, flooding increased the Fe-P to a large extent and the values were nearly double in flooded soils as compared to air-dried soils. As the submergence period increased, the Fe-P increased. There was an increase in Al-P in both the moisture regimes, but flooding had a significant effect than field capacity.

Sahi et al. (1979) studied the availability of phosphorus in calcareous soil at field capacity and waterlogged conditions and found that the available P tremendously increased on 40th day of incubation. The P availability after 60 days of incubation fell down from 58.2 to 5.5 ppm, recording nearly eleven fold reduction. Akbari et al. (1981) conducted an incubation study at Junagadh using clayey soil (pH 7.4) with three moisture regimes viz., saturation, field capacity and 50 per cent field capacity. They reported that moisture levels showed significant effect on P availability at each incubation period. The mean available P due to saturation was 13.7 and 36.0 per cent higher over those at field capacity and 50 per cent field capacity, respectively. It was further noted that field capacity and saturation treatments were at par upto 35 days of incubation period.

Mandal and Khan (1977) studied the influence of three moisture regimes, viz., (i) continuous submergence,

(ii) continuous saturation and (iii) alternate submergence and saturation on the availability of phosphorus in alluvial rice soils (pH 5.4) of West Bengal. They observed that the continuous saturation moisture condition could maintain a higher amount of applied P in the saloid bound and Bray's available form, as compared to other two moisture conditions. They further reported that the P availability increased upto 40th day of incubation (from 174 to 243 ppm P) and thereafter it decreased.

Savant et al. (1981) conducted an experiment using laterite and medium black soil of Konkan region with three moisture regimes, viz.,  $M_1$  - half the WHC,  $M_2$  - equal the WHC and  $M_3$  - twice the WHC. The available  $P_2O_5$  content was found to be the maximum under  $M_2$  moisture level corresponding to soil saturation, as compared to that of  $M_1$  and  $M_3$  moisture levels in laterite soil. While in medium black soil the  $P_2O_5$  availability gradually increased with increasing moisture levels, being maximum at  $M_3$  level (submerged condition).

Crop growing in the field usually lives in a water suction regimes fluctuating on water availability that may range from soil saturation to extreme drought. When the flooded rice fields become dry, the reduced constituents of soil are reoxidized with concomitant rise in soil Eh and lowering in pH. As a result, the soluble ferrous phosphate

get oxidised to insoluble ferric phosphate in dry soil. It may, therefore, cause a reduction in the solubility of native soil phosphorus. Paul and Delong (1949) observed that drying a soil subsequent to flooding generally decreased the solubilities of both native and added phosphates. The biological reduction of iron during the flooding phase followed by reoxidation during the drying phase results in the enhanced reactivity of the sesquioxide fraction of the soil, leading to an increase in the phosphate fixing capacity and hence to a decrease in the solubility of phosphate.

Babayan and Gasparyan (1962) reported that air drying generally increased the easily soluble phosphate content of non-calcareous soils and decreased it in calcareous soils. Moistening air dry soil to field capacity usually increased the easily soluble phosphorus content.

Zachariah (1962, 1964) studied the effect of drying in twenty submerged soils of Kerala on the availability of phosphorus and observed an appreciable fall in pH and marked increase in the available phosphorus on drying. The increases were greater in oven-dried soils than in sundried ones.

Savant et al. (1970) observed that submergence followed by drying of soil prior to re-submergence increased the availability of native phosphorus to rice in acid soils of Maharashtra.

Grechin (1961) and Smith (1969) however, remarked that short periods of waterlogging followed by drying may markedly depress the availability of recently applied phosphate to plants.

### 2.2.2 Availability of K :

From the earlier studies, Volk (1934) reported that the clay minerals chiefly responsible for the fixation and release of potassium were of the expanding types such as illite, montmorillonite and vermiculite. The mechanism that has been considered to be active in this process was the trapping of K ions between the lattice unit sheets of the expanding lattice when these were treated with soluble K. Some of the clay minerals such as illite could fix K under moist conditions and others such as montmorillonite could fix appreciable amount of potassium only on drying, as drying helped in contracting the lattice.

Kadrekar and Kibe (1973) studied the effect of hydration and drying on the release of exchangeable K in soils of Dapoli, Poona and Dongargaon and observed that the release of exchangeable K over initial status was 3.6, 2.6 and 3.6 per cent at one half moisture equivalent and 1.8, 2.3 and 2.9 per cent at wetting and drying in Dapoli, Poona and Dongargaon soil, respectively.

Studying the K fixation in a sandy clay loam soil at field capacity and alternate wetting and drying

condition, Ramanathan et al. (1977) observed that the fixation of K was maximum under alternate wetting and drying condition. From their studies on potassium fixation in different soil types of India, Mitra et al. (1958) found, on an average 12.97 per cent fixation in arid and semi arid soils of Karnal, Summerpur, Delhi, Saurashtra and Belgaon. The humid region soils of Marateru, Raipur, Nagpur, Karjat, Orissa and Pusha had a fixation capacity of 17.0 per cent. The potassium fixing capacity of the per-humid region soils of Always, Tripura and Assam was to the extent of 17.3 per cent and for red, black and alluvial soils it was 10.90, 14.55 and 14.90 per cent, respectively.

Savant et al. (1981) indicated that as the moisture regimes increased from one half WHC (field capacity) to twice WHC (flooding), the potassium availability decreased. From this study, they concluded that one half WHC moisture regime was most conducive to potassium availability in soil, while the submergence markedly reduced the K availability in soil. Datta and Kalbande (1963) studied the K release at 35°C and 45°C temperature in conjunction with 3 moisture regimes viz., WHC, one half WHC and air-drying and observed the maximum release of potassium in the soils under one half WHC at 35°C temperature.

Mathuvel and Krishnamoorthy (1981) conducted an experiment using red and black soils of Tamil Nadu with three moisture regimes viz., 100 and 50 per cent ASM and field capacity. They observed that the available K content of soils was not influenced by the soil moisture regimes, though alternate cycles of wetting and drying were found to enhance the potassium fixing power of the soils.

Sharma et al. (1977) reported that the concentration of exchangeable K under field capacity was found to decrease with time and it reached to 27.0 ppm from the initial 106.9 ppm after 60 days, while under saturation it decreased only upto 30 days and increased thereafter under flooding after sudden decline on 2nd day, the value showed a continuous increase upto 60 days.

In a green house study with laterite soils (pH 6.2) of West Bengal, Nad and Goswami (1981) reported that there was a higher release of soil potassium and its greater availability to rice under both the moisture regimes viz., continuous submergence and alternate wetting and drying. The effect was more prominent under continuous submerged condition.

Ahmed and Davis (1970) studied the effect of moisture regimes (10, 30 and 40 per cent moisture content) in Trinidad soil and found that there was a decrease in exchangeable K with increase in moisture content. From

their studies on potassium fixation in different clay colloids under different moisture conditions, Richards and Mclean (1963) concluded that (i) potassium fixed under moist condition resulted from illite or minerals containing mica as an impurity (ii) K fixed due to air-drying resulted from vermiculite or other minerals containing expanding type of mica such as beidellite and illite and (iii) soil clay fractions of mixed mineral compositions fixed more K in a dry-rewet sequence than similar mixture of standard clay minerals due to greater weathering.

Mortland (1961) studied the dynamic character of potassium release and fixation in soil and reported that the potassium release and fixation could occur simultaneously in a system containing a heterogeneous group of 2:1 minerals not in equilibrium with each other. The rate of K fixation was found to be inversely proportional to the initial K content of the clay minerals.

Grewal and Kanwar (1967) studied the potassium fixation in the soils of Punjab, Haryana, and Himachal Pradesh and observed higher K fixation after drying the soils at different temperature. Alternate wetting and drying showed the highest K fixation. The fixation capacity increased with a rise in pH from 4.0 to 10.0 and nearly 80 per cent K was fixed in one day and the equilibrium was established in 7 days.

Khanna and Datta (1968) incubated the soil at one-fourth and one-half moisture equivalent and at 18°, 34° and 45°C temperature equivalent and reported that the effect of moisture was more pronounced than that of temperature on the release of K. With an increase in moisture content, there was an increase in exchangeable K at a definite temperature.

### 2.3 Effect of moisture regimes on availability of Fe, Mn, Zn and Cu in soil :

It is well known that soil maintained at higher moisture levels such as saturation and flooding results in more available iron than soils kept at lower moisture level. After submergence of a soil, Fe (III) oxide hydrates are reduced to Fe (II) compounds. As a result, the soil colour changes from brown to grey and large amount of Fe (II) enters into solution phase. The concentration of water soluble Fe may vary from 0.1 ppm shortly after submergence to as high as 600 ppm. In acid sulphate soils the concentration may be as high as 5,000 ppm within a few weeks after submergence (Ponnamperuma, 1976).

Based on their studies with 26 soils, Redman and Patrick (1965) reported that the  $Fe^{+2}$  concentration after flooding ranged from 567 to 2230 ppm. Similarly Mahapatra (1968) conducted an experiment with 20 Louisiana soils (pH 4.7 to 8.2) of varying texture and found that the

$\text{Fe}^{+2}$  and  $\text{Fe}^{+3}$  concentration in soil increased to a greater amount after 60 days of submergence. Jaggi and Russel (1973) reported that the concentration of ferrous iron in the 0 to 5 cm surface clay loam soil receiving organic matter and surface flooding attained its maximum value of 2000 ppm after 6 weeks of flooding and thereafter it gradually declined.

Gotoh and Patrick (1974) studied the iron transformation in a waterlogged Crowley silt loam soil of Louisiana. They observed that both pH and Eh had marked effects on Fe transformation in waterlogged soil. Water soluble and exchangeable Fe increased with decrease in both pH and Eh. Dissolution of soil Fe compounds ranged from no detectable Fe at the highest pH and Eh (pH = 8.0 and Eh = + 300 mv) to a marked release at the lowest pH and Eh (pH = 5.0 and Eh = -250 mv).

Misra and Pande (1976) studied the behaviour of native iron in waterlogged rice soils (pH 6.9 to 8.9) of Allahabad and found that a greater amount of  $\text{Fe}^{2+}$  was present in the waterlogged rice soils and the samples on drying showed smaller amount of  $\text{Fe}^{2+}$ , but rewaterlogging of dried soils resulted in an appreciable increase at 60 days over dry samples. It has been concluded that waterlogged soils contained a greater amount of  $\text{Fe}^{2+}$  due to anaerobic condition.

Tiwari et al. (1976) indicated that the available Fe content of the black clayey soil (pH 7.7) of Kanpur was significantly higher under waterlogged condition (165 ppm) as compared to field capacity (81.0 ppm).

Babaria and Patel (1980) conducted an incubation study using medium black clayey calcareous soil of Saurashtra with three moisture regimes viz., 50 per cent field capacity, field capacity and saturation. They observed that there was a progressive increase in the available Fe with increasing incubation period under all the moisture regimes upto 42 days and decreased thereafter. There was three fold increase in available Fe content of soil when the moisture content of soil was raised from 50 per cent field capacity to saturation (from 1.90 to 6.06 ppm).

Kumar et al. (1981) indicated that the soils of Kunaon and Garhwal region (Uttar Pradesh) showed continuous increase in  $Fe^{+2}$  activity in soil solution under submerged condition.

Gupta et al. (1982) conducted an experiment using sandy clay loam soil (pH 8.0) of Uttar Pradesh with two moisture regimes viz., field capacity and waterlogging. They found that the exchangeable Fe tended to increase marginally with time upto 30 days and then declined upto 90 days under both the moisture regimes, however, the reducible Fe recorded a considerable increase upto 60 days.

Sharma and Banerjee (1983) conducted an incubation study using rice growing soils (pH 4.9 to 6.1) of West Bengal with two moisture regimes viz., 50 per cent WHC and waterlogging. They observed that the ammonium acetate extractable Fe in 50 per cent WHC treatment increased with incubation time, but at a very slow rate. While under waterlogged condition the rate was very high and attained its maximum values upto 30 days of incubation and declined thereafter.

Sadana and Takkar (1985) conducted an experiment using sandy loam soil (pH 7.4) of Rohi (Punjab) and reported that the Fe concentration in soil increased with increasing period of submergence and the maximum Fe concentration (15.8 ppm) was obtained at 14 days of submergence and thereafter it declined gradually upto 70 days, but there were only minor changes in Fe concentration.

Moisture regime has a profound effect on the availability of manganese in soil. The available Mn content of the soil tremendously increases with higher moisture levels such as saturation and flooding. In flooded soils the reduction of the higher oxides of Mn, chiefly Mn (IV), takes place almost simultaneously with denitrification (Ponnamperuma, 1965). The reduction may also result from these compounds functioning as (i) electron acceptors in the respiration of microorganisms and (ii) chemical oxidation

reduction products. Manganese is more readily reduced and rendered soluble than iron. The release of Mn into the soil solution, therefore precedes that of iron.

Suman and Anderson (1978) conducted a greenhouse experiment using eight soils of Georgia (U.S.A.) with 3 pH levels viz., 5.8, 6.4 and 6.8. They observed that there were greater differences in extractable Mn among soil types and pH levels. Exchangeable Mn was correlated with clay content but not correlated with silt and organic matter content. The extractable Mn decreased as soil pH increased.

From an incubation study with a sodic soil (pH 9.6) with two moisture regimes viz., field capacity (moist) and submergence, Anand Swarup (1979) observed that the exchangeable Mn increased with time and the increase was more during 14 and 28 days of incubation and thereafter it remained either constant or declined under submerged condition. Under moist condition, the exchangeable Mn decreased with length of incubation, probably due to oxidation of  $Mn^{+2}$  to higher oxides of low solubility.

Gill and Sinha (1981) conducted an experiment with saline sodic soils (pH 8.8 to 10.7) of Sangrur district of Punjab and found that the water soluble Mn increased with increasing period of submergence upto the end of the experiment (28 days).

Mandal (1961) studied the transformation of Fe and Mn in waterlogged rice soils (pH 6.8) of West Bengal and reported that there was a sharp rise in insoluble, inorganic  $\text{Fe}^{+2}$  with waterlogging of the soil upto the end of the experiment (78 days). The reducible Mn comprising of higher oxides such as  $\text{MnO}_2$ ,  $\text{Mn}_2\text{O}_3$  and  $\text{Mn}_3\text{O}_4$  showed a decrease upto 14 days of waterlogging and then began to increase to a level that was higher than at the start.

Pathak et al. (1972) studied the effect of waterlogging on the availability of Fe and Mn in sandy clay loam rice soil (pH 7.5) of Kanpur (U.P.). They observed that the available Fe and Mn content increased upto 70th day from 10.0 to 14.5 ppm and 12.5 to 38.0 ppm, respectively and thereafter decreased from 14.5 to 8.5 ppm and 38.0 to 25.0 ppm, respectively from 70 to 90 days. Olomu et al. (1973) conducted an incubation study using six Manitoba (Canada) soils (pH 7.8) and concluded that the concentration of Fe and Mn in the extracts was either very low or negligible after 1 week of flooding, but it increased with time of flooding and remained relatively high after 4 weeks of incubation.

Rao and Venkateswarlu (1974) observed that the Mn content in submerged red sandy loam soil increased sharply from 12.5 to 24.5 ppm within a week. Whereas in black clay loam soil, the Mn content remained more or less the same.

The increase in Fe content during eight weeks was from 14.7 to 48.0 ppm in red sandy loam soil and from 3.9 to 12.2 ppm in black clay loam soil.

Subrahmanyam and Mehta (1975) indicated that the available Fe and Mn in the paddy soil (pH 7.6) of Nawagam (Gujarat) were maximum under flooding followed by saturation and field capacity. The available Fe content under these conditions was 591.1, 345.7 and 129.1 ppm, respectively, whereas, that of Mn was 90.6, 42.7 and 4.0 ppm, respectively.

Brar and Sekhon (1976) reported that the available Fe and Mn were higher in a Laungowal loam soil (Punjab) under flooding than in unflooded soil. The increase in available Mn due to flooding was considered to be associated with both microbial and chemical reductions of higher oxides of Mn such as  $MnO_2$ ,  $Mn_2O_3$  and  $Mn_3O_4$ .

Ghosh et al. (1976) conducted a field trial on sandy loam soil (pH 6.40) of Durgapur (West Bengal) and noted that the submergence of the soil lead to an increase in exchangeable Fe and Mn in first 30 days followed by a gradual decrease with time upto 72 days of submergence.

Sharma et al. (1977) found that the water soluble and exchangeable Mn content of a silty loam soil (pH 8.3) of Nainital Terai region remained unchanged under field capacity and it increased with increasing moisture levels and the availability was maximum (145 ppm) on 60th day under

saturation and on 15th day under flooding (458 ppm).  $Fe^{2+}$  concentration continuously increased upto 15 days under saturation and flooding and upto 30 days under field capacity, but it decreased thereafter irrespective of moisture levels.

Rao et al. (1978) conducted an experiment with different soil groups of Tamil Nadu and found that under submergence, almost all the soils (alluvial, black and red soils) recorded more of available Fe. The available Mn increased immediately after submergence and it came into solution much earlier than Fe. Among the various soil groups, Mn did not show much variation.

Singh and Ram (1979) in their incubation study with rice growing soils (pH 6.6 to 8.1) of Eastern Uttar Pradesh, noted that the water soluble  $Fe^{+2}$  in alluvial soil increased with the advancement of incubation time, while in red soils it increased upto 7 weeks of submergence and thereafter, there was a greater reduction in  $Fe^{+2}$  content of soil. The water soluble and exchangeable Mn increased after submergence and attained the highest values at 2 weeks, afterthat it tended to decrease.

Patil and Patil (1981) conducted an incubation study using clayey soils (pH 7.6) with 5 moisture regimes viz., 100, 80, 60, 40, and 20 per cent available soil moisture (ASM). They observed a proportionate decrease in the available Fe with progress of incubation time at all the

moisture regimes and a positive relationship was observed between ASM and available Fe. The Mn availability increased with decreased levels of ASM at all the periods of incubation (75 days), but the effect was more pronounced after 30 days.

Pulford and Duncan (1981) noted that waterlogging of the Brown hilly soil of Glasgow (U.K.) over a period of 16 weeks resulted in the release of both Fe and Mn from the organic and oxide bound reservoirs to the soluble and exchangeable forms, but it lowered the soluble exchangeable and organically bound Cu in soil.

Mandal and Mitra (1982) conducted a laboratory experiment using different rice-growing soils (pH 5.65 to 7.45) of West Bengal with three moisture regimes viz., (i) continuous saturated, (ii) alternate waterlogged and saturated and (iii) continuous waterlogged. They found that the water soluble and exchangeable Fe and Mn under the continuous saturated and alternate waterlogged and saturated moisture regimes were always much lower as compared to that of continuous waterlogged.

Bandyopadhyay and Bandyopadhyay (1984) studied the effect of submergence of Fe and Mn transformation in coastal saline soil of West Bengal. They found that there was a significant increase in the available Fe and Mn content in the initial stage of submergence (upto 20 days)

and thereafter it showed a decreasing trend. Similarly Rao et al. (1984) also noted that the ammonium acetate extractable Fe and Mn in alluvial, laterite and black soils of Orissa increased rapidly within 10 to 20 days of flooding beyond which it decreased gradually.

Siewkee and Bloomfield (1962) conducted an incubation study using different textured soils (Rothamsted) and observed that the water soluble Fe increased upto the end of the experiment (25 days) under flooded condition. The water soluble Cu increased upto 15 days of incubation and declined thereafter.

Reddy and Perkins (1974) indicated that the bentonite fixed significant quantities of Zn under wetting and drying condition, as compared to Kaolinite clay mineral. The Zn fixation was found to be directly related to pH and added Zn and the highest fixation occurred at pH 8.8 by both the bentonite and illite clay minerals.

From their incubation study with loamy sand soil (pH 7.4), Hulagur et al. (1975b) reported that the Zn availability at field capacity level increased upto 56th day, recording 22.4 per cent increase in Zn availability. Subrahmanyam and Mehta (1975) carried out an incubation study using paddy soil (pH 7.6) of Navagam (Gujarat) to know the effect of three moisture regimes on Zn availability. They found that the Zn availability was maximum under saturation

(3.68 ppm) followed by flooding (3.56 ppm) and field capacity (3.45 ppm).

Brar and Sekhon (1976) conducted an incubation study with Laungowal loam soil from Sungrur district of Punjab. They tried four levels of Zn (0, 2.5, 5.0 and 10.0 ppm) with flooded and unflooded (near to field capacity) conditions. They found that the DTPA-extractable Zn was higher under unflooded than flooded condition. The DTPA-Zn decreased within 15 days of incubation and continued to decrease with increasing period of incubation (3.58 to 1.54 ppm Zn). The decrease in available zinc was attributed to the adsorption and fixation of added Zn by the soil colloids and  $\text{CaCO}_3$  and possibly the formation of zinc carbonate and zinc hydroxide.

The moist soil condition, particularly the submergence of soil has been observed to decrease the Zn availability. The decrease in Zn content in submerged soil may be due to (i) precipitation of  $\text{Zn(OH)}_2$  as a result of increased pH after flooding (ii) precipitation of  $\text{ZnCO}_3$  due to  $\text{CO}_2$  accumulation and (iii) precipitation of ZnS under very reduced soil conditions (Patrick and Reddy, 1977).

Takkar and Sidhu (1979) conducted an experiment using different rice growing soils of Punjab and concluded that zinc concentration in soil solution decreased with the period of submergence. The rate of zinc transformation was

rapid during the first 10 days in calcareous sodic soils and 21 days in calcareous alkaline soils, but the rate of Zn transformation after these periods was slow and less pronounced upto 72 days of submergence.

In an incubation study with black soil, Kanagaraj and Ramanathan (1980) observed that the available zinc content was the highest at 50 per cent depletion of available soil moisture (ASM) followed by 75 per cent depletion of ASM. Higher moisture regimes such as flooding recorded lower values. As regards the incubation periods, there was no clear trend, though at 5th week significantly higher values of available Zn were recorded.

Shuman (1980) conducted an experiment using different rice growing soils (pH 7.2 to 7.7) of Georgia with three moisture levels viz., 5, 1/3 and 0 bar. He indicated that the general trend for Zn was to decrease in extractability with increasing moisture levels.

Singh and Prasad (1982) conducted an incubation study using a calcareous soil of North Bihar with 4 moisture regimes viz., 2/3 field capacity, field capacity, saturation and flooding. They observed that the availability of Zn decreased after 3 days of incubation was due to fixation in calcareous soil. The mean values of available Zn range from 2.10 ppm under flooded conditions to 2.76 ppm under 2/3 field capacity and it decreased linearly with increasing

moisture levels. The extent of reduction, when compared to 0 to 56 days of incubation was maximum (35 %) in flooded soil and minimum (19 %) in 2/3 field capacity. The reduction in the availability of zinc under flooding was considered probably due to high partial pressure of  $\text{CO}_2$  which could precipitate Zn as  $\text{ZnCO}_3$ .

Sadana and Takkar (1985) conducted an experiment using Ghabdan (loamy soil, pH 10.09) and Langrian (sandy clay loam soil, pH 9.79) series of sodic soils of Punjab. They found that the Zn concentration in soil solutions increased markedly with the addition of Zn @ 10 ppm as  $\text{ZnSO}_4 \cdot 7\text{H}_2\text{O}$ , but it decreased with prolongation of submergence and approached less than 0.13 ppm after 84 days of submergence. The decrease was sharp upto 14 days of submergence and gradual thereafter.

The availability of copper in soil in general decreased with increasing moisture content of the soil (Ponnampuruma, 1972 and Haldar and Mandal, 1979).

Hulagur et al. (1975b) conducted an incubation study using a loamy sand soil (pH 7.4) of Anand (Gujarat) by maintaining the moisture level at 60 per cent of the field capacity and reported that the incubation period had no significant effect on the availability of Cu in soil. The maximum Cu availability (0.52 ppm) was observed on 28th day of incubation, thereafter it decreased.

Sims and Patrick (1978) noted that the water soluble Cu of a Mhoom silty clay loam soil (U.S.A.) was directly related to pH but inversely to Eh although greater amount of exchangeable and organically bound Cu was found at low pH and Eh values than at high pH or Eh.

In a incubation study with alluvial rice soils of West Bengal, Haldar and Mandal (1979) observed that the extractable Cu content in soils recorded a marked decrease with increase in incubation time under all the moisture regimes but it was most prominent under continuous saturated condition followed by waterlogged and alternate waterlogged and saturation conditions.

Kanagaraj and Ramanathan (1980) observed that low moisture regimes such as 70 per cent depletion of ASM recorded significantly higher value of available Cu (1.31 ppm) as compared to 50 per cent depletion of ASM (0.51 ppm). It was further noted that with the passage of incubation, there was regular and consistent decrease in available Cu content.

Rahmatullah et al. (1976) conducted a laboratory study using Hafizabad (pH 8.5) and Miranpur soil (pH 8.3) of Pakistan. They observed that the available iron under flooded condition in both the soils increased with time except at 4th week in Hafizabad and 5th week in Miranpur soil where a decrease in Fe content was observed. The

available Mn gradually increased over the whole incubation period (8 weeks) but the submergence had no effect on the available Cu content of the soils. Drying of the soils at field capacity drastically reduced the available Fe and Mn in both the soils. Whereas the available Cu strongly enhanced in Hafizabad soil on drying, but it had no effect in the Miranpur soil.

Mandal and Haldar (1980) reported that the available Fe content of clay loam soils (West Bengal) was found to be the maximum on 70th day after flooding and thereafter decreased, probably due to the hydrolysis of  $\text{Fe}^{+2}$  and its subsequent oxidation to  $\text{Fe}(\text{OH})_3$  due to decrease in partial pressure of  $\text{CO}_2$ . In case of Mn, the maximum availability was observed on 45th day, thereafter it decreased. A gradual decrease in extractable Cu was observed with the progress of incubation time under submerged condition.

Shuman (1980) indicated that the moisture levels during incubation caused little differences in the extractable Fe and Mn between 5 and 1/3 bar, but 0 bar moisture level of samples that were very wet during incubation had extremely high amount of extractable Fe and Mn for both Dyke and Cecil soils (Georgia). There was not significant difference between 5 and 1/3 bar moisture levels in the amount of extractable Cu, but Cu extracted at 0 bar was significantly higher than 1/3 and 5 bar levels.

Patra et al. (1981) reported that the extractable Fe and Mn content of a Gangetic alluvial soil (pH 7.8) of West Bengal increased with progress of incubation, attained its maximum value after 10 days of incubation and thereafter it gradually declined. Similarly with the increase of incubation period, the extractable Cu decreased.

Chatterjee et al. (1983) indicated that the DTPA-extractable Fe and Mn recorded an increase upto 15 days of incubation under waterlogged condition and thereafter it declined. The initial rise in Fe content was considered due to reduction of higher oxide of Fe<sup>+3</sup> to soluble Fe<sup>+2</sup> compounds. The DTPA-extractable Cu recorded a sharp decline just after waterlogging, but during later periods of incubation it remained more or less constant.

#### 2.4 Effect of organic matter on the availability of P and K in soil :

##### 2.4.1 Availability of P :

Organic matter affects the phosphorus availability (Bradley and Sieling, 1953; Yu and Liu, 1965) either directly by displacement of phosphate from iron and/or aluminium phosphate, or by influencing (a) the decrease in redox potential and (b) pH changes. Nowadays it is fairly well established that though there is some fixation of phosphorus at relatively high pH (Gaur, 1969), yet not only the organic matter but also specifically humus is

of positive influence in phosphorus availability (Srivastava et al., 1969; Adhikari and Ganguli, 1971; Sinha, 1972 and Brams, 1973). On the other hand, humus combines with iron or aluminium to form chelates thereby decreasing the chance of inorganic phosphate fixation (Kononova, 1966). Savant and Ellis (1964) also observed that soil moisture, with or without organic matter definitely influences availability of both native and applied phosphorus.

An incubation study was conducted by Mukhopadhyay and Mandal (1969) to investigate the effect of 3 pre-submergence moisture regimes and FYM applied @ 1 per cent (weight basis) on the release of P from the native source and applied superphosphate in two acidic soils. In general, FYM treated soil showed higher amount of available P than the no FYM treatment.

Vyas and Motiramani (1971) reported that application of organic matter @ 1.0 g (10,000 ppm), silicate @ 0.1 g (1,000 ppm) and ammonium sulphate @ 0.3 g per 100 g to shallow and medium black and alluvial soils, proved to be effective in increasing the available phosphorus from native as well as added phosphorus.

In an incubation study at field capacity, Prabhakar et al. (1972) observed that addition of organic manures in the form of compost and Glyricidia maculata increased the availability of native phosphorus by 46 and 37 in red

sandy loam, 35 and 26 in black clay loam and 42 and 27 per cent in alluvial paddy soils respectively over control.

Datta and Goswami (1962) studied the effect of three levels of organic matter (0, 10 and 20 tones of FYM per acre) and four levels of moisture (50, 75, 100 and 125 per cent moisture equivalent of the soils) on the availability of P and its uptake by wheat from soil and fertilizer phosphorus using four Indian soils having quite different physical and chemical properties in the laboratory and pot experiments by radiotracer technique. They reported that in both pot culture and laboratory studies, availability of phosphorus in the soil increased with increase in organic matter levels.

Vyas (1964) studied the influence of four moisture levels, viz., 100, 125, 150 and 175 per cent, three organic matter levels, viz., 0, 10 and 20 t/acre and superphosphate supplied as a basal dose of 80 lb  $P_2O_5$ /acre at Varanasi to wheat crop. He observed that application of organic matter increased the available phosphorus content in all soils. The percentage phosphorus fixation capacity decreased with increase in organic matter and moisture levels.

Mandal and Mandal (1973) reported that application of organic matter (starch, 0.25 g/100 g soil) greatly reduced the P fixation as iron phosphate in all the soils

(Gayeshpur, Kalimpong and Midnapore) but this effect was most pronounced in the case of laterite soil (Midnapore). Application of organic matter did not bring about any important change in P fixation as calcium phosphate.

Rahate et al. (1979) reported that application of normal doses of fertilizers used in combination with a small dose of 5 tonnes of FYM/ha over a long period of eleven years gave 25 to 30 per cent higher crop yields than those obtained by use of fertilizer alone. There is little variation in soil pH and the organic matter status of the soil by normal use of fertilizers for a long period. However, organic matter status of the soil can be built up gradually by use of even a small quantity of FYM (1 to 5 t/ha) every year. Comparing the results obtained with application of one tonne of FYM/ha, the highest available P content (73.0 ppm) was recorded with NPK fertilizers followed by NP fertilizers (69.7 ppm) at normal levels. This showed that the requirement of available P for higher crop yields is fairly met by the continuous use of even a very small dose of FYM (1 t/ha). Application of 1 and 5 t FYM/ha have increased the organic P, 4 to 5 times higher over control.

In an experiment conducted on two soils, one red soil (pH 6.6) and the other karail soil (pH 7.4) of Uttar Pradesh to examine the effect of phosphorus and

FYM under submerged condition, Singh and Patiram (1977) reported that addition of FYM increased the availability of native Fe-P in red soil and Ca-P in karail soil due to increase in their solubilities by CO<sub>2</sub> and organic acid produced during the decomposition of organic matter. The maximum P uptake by paddy crop (Jaya) observed when applied with FYM and it was highly pronounced in the case of red soil.

In a laboratory experiment under the influence of added organic matter in different type of soils of Uttar Pradesh, on the transformation of inorganic phosphorus in soil, Singh and Hariram (1977) reported that application of organic matter (starch) @ 2 per cent was superior to 1 per cent level in reducing the conversion of added P in to Al-P, Fe-P and Ca-P. They further noted that organic matter treatment reduced the transformation of added P as Fe-P in all the soils. The decomposition of added organic matter might have created an intense anaerobic condition causing reduction of ferric to ferrous compounds and consequent lowering of the transformation as Fe-P considerably. Decomposition of organic matter might have also produced organic compounds capable of chelating Fe (Chiang, 1963 and Mandal and Chatterjee, 1972).

Incubation studies on the effect of soil moisture on P solubility, Murty (1987) indicated that application of

P alongwith FYM was highly beneficial in increasing the P availability. Soil moisture increased the P availability only when FYM and/or phosphorus was applied.

In long-term (8 to 9 years) experiments, organic matter (FYM) alongwith phosphatic fertilizers resulted in increase in available P content of Punjab soils (Kanwar and Prihar, 1962); sandy loam soil of Delhi (Biswas et al., 1967 and Havanagi and Mann, 1970) and fine sandy loam soil (Maurya and Ghosh, 1972). Patel and Patel (1979) also reported that application of FYM or NPK fertilizers for 17 years to Goradu soil of Gujarat, markedly increased the soil available P content.

Singh et al. (1983) observed that a nine years application of FYM in a sandy loam soil under wheat-maize rotation significantly increased the available P content in surface soil. Similarly application of FYM for twelve years to a coarse sandy loam soil under maize-wheat rotation, significantly increased the available P content in surface soil (Venkata Reddy et al., 1983).

#### 2.4.2 Availability of K :

Generally, farm yard manure contains about 0.5 per cent  $K_2O$ , which can obviously increase the available potash in the soil considerably (50 to 75 kg  $K_2O/ha$ ) when it is incorporated in soil @ 10 to 15 t/ha.

In long-term field studies, Prasad et al. (1983) for 6 years and Muthuvel et al. (1977) for 65 years observed that application of FYM alone or in combination with NPK markedly increased the available K status in red loam and acidic sandy loam soils.

In sandy loam soil of Gujarat, available K significantly increased after 17 years application of NPK chemical fertilizers. On the other hand application of FYM (12.5 t/ha/yr) also markedly increased the available K content (Anonymous, 1977-78). Contrary to this, Patel et al. (1963) reported that 17 year application of FYM containing 99 kg K<sub>2</sub>O/ha did not result in any appreciable increase in available K content of alluvial sandy loam soil, probably due to luxury consumption of K by the plants.

While studying the effect of continuous manuring and cropping on soil fertility in the old and new permanent manurial experiments in progress at Pusa (Bihar) on calcareous soil under rainfed condition, Ghosh and Kanzaria (1962) reported little difference in available K content in the soils in the old manurial series, while in New series some of the differences (including FYM and rape cake) were found to be significant.

Brar and Sekhon (1987) noted positive significant correlation ( $r = 0.51$  to  $0.81$ ) between organic carbon and exchangeable K of five benchmark soil series of Northern

India. They also observed the influence of texture and organic carbon on the ammonium acetate extractable K of soil. Having the same texture, the K content differed with the organic carbon content of the soil.

#### 2.5 Effect of organic matter on availability of Fe, Mn Cu and Zn in soil :

In the formation of a fertile soil, organic substances play a direct role, as they are the sources of plant nutrients which are liberated in available form during mineralization. A large quantity of carbon dioxide and organic acids produced during the microbial decomposition of organic matter, temporarily decreases the soil pH and thereby increases the rate of release of elements such as phosphorus, boron, zinc, iron and manganese as a result of dissolution of certain primary soil minerals, particularly under neutral and alkaline conditions (Singh and Lal, 1976).

A high positive correlation between organic matter content and extractable micronutrients has been reported by several workers (Khetawat and Vashishtha, 1977; Misra and Pande, 1975; Misra and Pandey, 1976; Misra et al., 1976 and Vittal and Gangawar, 1974). This parallels the prevalence of micronutrient deficiencies on low organic matter soils. On the contrary, in high organic matter soils, the available micronutrients, particularly Cu, were inversely related to organic matter contents (Rajagopal et al., 1974).

In a green house experiment with wheat crop conducted in a Zn deficient loamy sand soil using FYM, dhaincha and wheat straw (0, 5, 10 and 20 t.ha<sup>-1</sup>) in combination with Zn (0, 2.5, 5.0 and 10.0 ppm), Hansraj (1986) observed the highest DTPA-extractable Zn with FYM followed by dhaincha, while wheat straw did not show any important effect on Zn extractability. Content and uptake of Fe and Mn were also increased with the application of 10 t.ha<sup>-1</sup> FYM and dhaincha.

Nayyar et al. (1982) observed a significant positive relationship of organic carbon with available Zn, Cu, Fe and Mn in soils of Gurdaspur district (Punjab).

While conducting field experiments with maize and wheat crops of Fatehpur loamy sand soil (Ustipsamments) deficient in Zn, Cu, B and marginal to adequate in Mo, Fe and Mn, Mann et al. (1978) reported that application of FYM and micronutrients to soil significantly increased the availability of micronutrients. Further they observed that the response on yield was higher in treatments that received FYM as compared to those that did not.

In the Pusa permanent manurial experiment in North Bihar, Maurya and Ghosh (1972) observed the superiority of farm yard manure (FYM) on the average wheat and barley yields for the last four decades under rainfed system of cropping on the alluvial calcareous soil. FYM application

resulted in an increase in the exchangeable Mn status. Significant and positive correlation also has been observed between organic carbon and easily reducible Mn.

Srivastava and Sethi (1981) reported that application of FYM (upto 45 t/ha) containing 70 ppm Zn once or twice a year to an airidisol resulted in increases in the levels of DTPA-extractable Zn in soil and in the uptake of Zn by wheat or pearl millet.

Kanwar et al. (1984) reported that DTPA-extractable Fe and Zn were positively correlated with organic carbon in case of soils from wheat-growing valleys of Himachal Pradesh, while Cu showed no significant correlation. In an incubation study, Singh and Prasad (1982) reported that application of paddy straw (2.39 g/200 g) and FYM (1.09 g/200 g) to calcareous soils of North Bihar increased the availability of Zn from 2.26 to 2.68 ppm and 1.68 to 2.07 ppm, respectively between 7 and 56 days incubation. After 56 days of incubation, the decrease in available Zn was found to be maximum in control (30 %) and minimum in FYM treatment (4 per cent).

While studying the effect of P, K and farm yard manure and three phases of manuring in the zinc content of the soil, Zn concentration and uptake by maize and wheat crops, Sharma and Meelu (1975) reported that available Zn status of the soil, and its uptake were significantly increased with the application of FYM.

Trehan and Grewal (1983) studied the role of organic matter, inorganic fertilizers and cropping sequence proved more effective on micronutrient status (DTPA - extractable Zn, Mn, Fe and Cu) in two different soils. The results revealed that FYM was effective in maintaining available micronutrient levels in acid hill soils of Simla, where single crop of potato was taken in a year. Annual addition of FYM @ 30 t/ha increased the available Zn, Cu, Mn and Fe to other fertilizer treatments even after four years. Further they reported that incorporation of green manure in a cropping sequence proved more effective than farm yard manure in improving the status of micronutrients.

Sakal et al. (1985, 1986) reported that the available Zn, Cu, Mn and Fe were significantly (positively) correlated with the organic carbon in the soil whereas, Rawat and Mathpal (1981) reported that organic carbon positively correlated with available Fe and Mn and negatively correlated with available Cu, Zn, Mo and B.

While equilibrating copper sulphate with seddon V. (0-4") and seddon V. (4-8") soils, Kanwar (1954) noticed that the higher absorption and lower exchange of Cu in the former as well as in its separates, as compared with the latter and its separates mainly due to the organic matter.

## 2.6 Effect of P-sources on the availability of P, Fe, Zn, Cu and Mn in soil :

### 2.6.1 Availability of P :

The application of P to a soil increases its availability but the magnitude of increase is controlled by the form in which it is added. Chauhan *et al.* (1972) studied the effect of superphosphate, diammonium phosphate and dicalcium phosphate on availability of P (Olsen-P) in four soils from Chambal command area. They found the order : super phosphate > diammonium phosphate > ammonium phosphate > dicalcium phosphate. The higher availability of P with respect to super phosphate was explained on the basis of acidic nature of the fertilizer on dissolution.

Naphade and Dhua (1972, 1973) have also observed similar effect of super phosphate > ammonium phosphate > sulphonic nitrophosphate > sulphala. The availability of P for the same source has been found to depend on accompanying fertilizers also. Prabhakar *et al.* (1972) studied the effect of single super phosphate (alone), single super phosphate + ammonium sulphate and single super phosphate +  $\text{KNO}_3$  on availability of Olsen-P in three soils from Dharwar. The treatment of single super phosphate + ammonium sulphate showed the highest availability due to formation of two molecules of sulphuric acid at the end of nitrification reaction and consequent dissolution of P from native Cu-P forms.

Banerjee and Mandal (1965) studied the influence of physico-chemical composition of pond soils on the rate of disappearance of added phosphate from water and the nature and magnitude of its transformation in acidic, neutral and alkaline soils. They observed that phosphate concentration in water declined rapidly in all the three soils and the concentration of soluble phosphate in water was higher in acid soil than in neutral or alkaline soil. The total amount of phosphorus fixed was maximum in alkaline soil and minimum in neutral soil.

Dravid and Apte (1975) studied the effect of various phosphatic fertilizers on the availability of phosphorus in black and alluvial soils of Madhya Pradesh. They observed that the availability of phosphorus was more in alluvial soils as compared to black soil. Motiramani et al. (1964) also stated that higher percentage of clay increased the phosphate fixation capacity of soil (M.P.). Similar results were also obtained by Krishnamorthy et al. (1963).

Seshagiri Rao et al. (1972) from inorganic P fractionation study in black and red soils after treating them separately with ammonium phosphate and super phosphate found that in both the soils Fe-P was more than the other forms, while Al-P was found only in soils treated with super phosphate.

Mandal and Chatterjee (1972) have stated that, added phosphorus remaining in solution in equilibrium with

the soils declined sharply, the rate being comparatively lower in soils poor in free iron oxide and native iron phosphate contents. On an average, Cu-P was 6 to 12 per cent of the added amount, while 10 to 30 per cent of the added amount was transformed into reductant soluble iron phosphate.

Bapat and Bedekar (1965) studied the fixation and distribution of different phosphatic fertilizer with varying amount of calcium carbonate and on different pH values in three different soils. It was observed that about 80 per cent of the added phosphorus was retained by these soils. In soil rich in  $\text{CaCO}_3$  most of the retained phosphorus was bound to calcium irrespective of the nature of fertilizer, whereas it was predominantly bound to aluminium and iron in the soil poor in  $\text{CaCO}_3$  content.

Bagchi et al. (1974) showed that calcareous soils (pH greater than 7) fixed the applied phosphate mostly in the form of Ca-P. Soils having pH less than or equal to 7, fixed phosphate more in the Fe-P and Al-P forms. Minimum and maximum fixation was found in soils having pH 7.0 and 8.4, respectively.

Mahapatra and Patrick (1969) reported that phosphate added to soils as  $\text{AlPO}_4 \cdot 2\text{H}_2\text{O}$ ,  $\text{FePO}_4 \cdot 2\text{H}_2\text{O}$  or  $\text{Ca}(\text{H}_2\text{PO}_4)_2 \cdot \text{H}_2\text{O}$  was recovered after incubation, almost completely in the Al-P and Fe-P fractions, regardless

of whether the soils were incubated under optimum moisture or waterlogged conditions. A small amount of added phosphorus was present as water soluble and loosely bound phosphorus under optimum moisture conditions.

Mandal and Khan (1976) studied the influence of three moisture regimes namely (i) air-dried, (ii) submerged, and (iii) at field capacity, prior to flooding on the transformation of applied P in soils and its availability to rice plants. They found that the moisture could maintain a higher amount of added phosphorus in the water soluble and saloid bound phosphate in coastal saline which was neutral to slightly alkaline soils as compared to alluvial and laterite soils, but their effects were not observed in acidic soil.

The availability of phosphorus from single super phosphate, diammonium phosphate, uramphos (28 : 28) and suphala (15 : 15 : 15) in calcareous clayey soils of Parbhani was examined in a laboratory incubation study by Mali et al. (1979). They reported that the availability of phosphorus increased with time and rate of application and it was maximum at 60 days irrespective of rate and source. Super phosphate was found superior to all other fertilizers. Diamonium phosphate and uramphos proved nearly equal in phosphorus availability and both of these were superior to suphala.

Immobilization of monocalcium phosphate (MCP) and diammonium phosphate (DAP) as affected by wetting and drying cycles and moisture tension, was investigated by Fathi Amer et al. (1980) in an alluvial (4.1 %  $\text{CaCO}_3$ ) and desert (39 %  $\text{CaCO}_3$ ) soils in the laboratory. They reported that in soil columns, soluble P increased with the depth for DAP, while for MCP it depended on moisture tension, the lower the tension the higher the solubility. DAP and MCP were equally effective in the alluvial soil but MCP was superior in the highly calcareous desert soil, especially when combined with organic matter application.

#### 2.6.2 Availability of Fe :

Iron exists in soil as oxides, hydroxides as well as in ionic forms and all these are capable of reacting with native and applied P in soil and reduce their solubility by chemical precipitation.

Studies conducted by Das and Datta (1967, 1968, 1969) revealed that interaction of phosphates in black, brown, red, laterite, alluvial and calcareous soils produces different types of reaction products of which colloidal and amorphous Fe-Al phosphate were universally present especially when P was applied as monocalcium phosphate. Partial substitution of  $\text{Al}^{+3}$  by  $\text{Fe}^{+3}$  seemed to have taken place in the structure of taranakite. Yadav and Mistry (1977) also obtained similar results. The formation

of these reaction products are responsible for the decrease in the availability of native and applied P in soil. Dev and Mann (1972) reported that increasing level of P application significantly decreased the available Fe in a loamy sand soil.

According to Mandal and Chatterjee (1972), the rate of disappearance of applied water soluble P in soil under flooded condition was very slow in soils poor in free iron oxide and iron phosphate compounds. Formation of Fe-phosphate compounds was also related to these forms already present in soil. About 10 to 30 per cent of added P was transformed into reductant soluble iron phosphate.

Basu and Mukherjee (1969) observed that iron phosphates were the least available forms of phosphate reaction products in soil and the availability varied with the nature and age of reaction product and was in the order : colloidal Fe-P > freshly precipitated Fe-P > digested Fe-P (strengite). Ageing decreased the availability of Ca and Al-P compounds in soil. Waterlogging, however increased the availability of P from iron phosphates.

A progressive release of P from Fe-phosphate was observed upto 20 weeks by Chakravarty and Ghosal (1969) when kept in contact with acidic soils. Presence of Ca-P reduced the availability of Fe-P in soil. The availability of freshly prepared iron phosphate was studied in

four soils having pH varying from 4.7 to 5.6 by Kar (1973) under submerged condition. It was observed that Fe-P application increased the available P content in soil. The results of Sacheti and Saxena (1972) indicated that strengite type of compounds are not available to maize and urd crops and their performance was comparable to that apatite in soils of Rajasthan.

### 2.6.3 Availability of Zn :

Kalyansundram and Mehta (1970) reported that possibility of an antagonistic relationship between Zn and P in soil and its contribution to the P induced Zn deficiency can not be totally overlooked.

Badamur and Venkata Rao (1973) reported that though the build-up of P in red sandy loam acid soil reduced the available soil Zn by 22 to 38 per cent, yet its level did not go below the critical limit for plant growth.

Sen and Deb (1975) observed that application of P at 25 ppm level reduced the leaching loss of applied Zn in an alluvial sand from 22 to 8.5 per cent beyond the root zone (30 cm depth).

Sharma and Meelu (1975) recorded a significant decrease in the available Zn content even to a deficient range in the soil samples collected from a long term field trial involving direct, residual and cumulative effects of two levels of P at Punjab Agricultural University, Ludhiana.

Deb and Ziliang (1976) observed that application of 50 kg P/ha significantly reduced the available Zn content in an alluvial soil after the harvest of rice but such effect was not significant after wheat crop. They however, observed that Zn application did not affect the available P content in soil under both the management conditions.

Rajagopal and Mehta (1971), Reddy *et al.* (1973), Hulagur *et al.* (1975 a) and Takkar *et al.* (1976) observed that the application of P or Zn in soil had no effect on the availability of Zn or P suggesting that the depressing effect of P on the Zn content of plant was not in the soil but in the plant itself. Sanyal and Deb (1975) observed that placement of P and Zn together in soil did not show any antagonism on their absorption by barley crop as well as on the A values of the soils.

#### 2.6.4 Availability of Cu :

Consideration of the mechanisms responsible for the reduced availability of Cu as a result of P-Cu interaction presents several explanations.

- (i) Low supply of Cu on account of precipitation as copper phosphate,
- (ii) Inhibition of Cu uptake by excess  $H_2PO_4$  in the substrate,
- (iii) Microbial tie-up and
- (iv) Immobilization of Cu within the plant.

Bingham and Garber (1960) did not find any evidence of the reduced amount of Cu from analysis of water-extracts.

Hulagur et al. (1975 b) in an incubation experiment involving interaction between Zn, Cu and P observed that these three elements individually suppressed the availability in soil of other two elements. Maximum fixation occurred in the case of Cu, intermediate in P and least in Zn.

Badamur and Venkata Rao (1973) recorded reductions in available Cu, Zn and Mn to the extent of 8.1 to 60.6, 21.8 to 38.3 and 6.5 to 26.5 per cent, respectively on account of heavy build up of P in soil through repeated heavy application of phosphatic fertilizers on a slightly acidic red sandy loam soil. The relationship between total P and available contents of three micronutrients were negative and significant with value of -0.80, -0.75 and -0.96 for Cu, Zn and Mn, respectively.

#### 2.6.5 Availability of Mn :

Application of P at higher doses at times has been reported to increase the availability of Mn in soils. However, instances are not lacking when build up of P in soils is associated with decreased availability of Mn to plants. Some of the explanations offered

to interpret the results of the interaction of P-Mn in soil by various workers (Steckel et al., 1948; Spencer, 1960) are :

- (i) Precipitation of  $Mn^{+2}$  as manganous phosphate which does not permit the oxidation of  $Mn^{+2}$  to higher oxides and maintains a constant, though a small supply of divalent Mn to plants.
- (ii) Slight acidic reaction of super phosphate in soils. The fertilizer carries about 60 per cent of gypsum which is known to exert a depressing effect on soil pH,
- (iii) Accumulation of calcium phosphate presumably hydroxyapatite which can retain Mn against leaching through adsorption on its surface.

According to Misra and Misra (1968), presence of phosphate decreased the retention of Mn. Addition of phosphate reduced the exchangeable and reducible forms of Mn except in alkali soil. Decrease in available Mn as a result of continuous and heavy dressings of P has been reported by Badamur and Venkata Rao (1973). They found a significant negative correlation ( $r = -0.96$ ) between total P and available Mn content of the soil.

Walsh et al. (1950) observed that toxicity symptoms of Mn were reduced with P application. Water soluble P sources proved more effective in reducing the

Mn content of Swedes than less water soluble sources, however, Morris (1948) did not notice any effect of heavier application of P fertilizers to acid soils on the water soluble Mn concentration of these soils.

Pathak et al. (1972) reported increased availability of P and Mn at increasing levels of soil fertility under submerged conditions. Significant positive correlation was recorded between available soil P and Mn.

**MATERIALS**  
**&**  
**METHODS**

### III. MATERIALS AND METHODS

The present investigation was undertaken with a view to study the effect of different moisture regimes, phosphorus application through various sources and farm yard manure on the availability of phosphorus, potassium, zinc, iron, copper, manganese and changes in soil pH. The details of the materials used and the analytical procedures adopted during the course of present investigation are presented in this chapter.

#### 3.1 Description of soil :

The soils of Bhal area appear to consist mainly of recent marine sediments deposited by the muddy water of the gulf of Cambay. The marine sediments have been deposited in a pattern of islands, originally separated by wide and deep creeks and later on the creeks were filled up. On the islands, vertisols have been formed which are related to the zonal black cotton soils. They are heavy montmorillonitic clays with very pronounced swelling and shrinking <sup>behaviour</sup>. In the creek fillings very saline, incipiently developed soils (Halaquepts order : inceptisols) are found (Nedeco, 1968). The marine sediments show differences in texture and structure from one place to another, while creek-fillings have usually light textured soils. The finely bedded sediments have a very low permeability. Due to the marine origin, salts

are interlocked in soils (Patel, 1984). However, where natural desalinization of top soils has taken place, the farmers are using the lands for aerable farming. The farming practices in this area are critically dependent on rainfall (400 to 800 mm) distribution. When khharif crop like cotton/jowar is not possible due to flooding<sup>of</sup> the soil, wheat (dry) as a rabi crop is grown on the conserved moisture. Some of the important physico-chemical properties of the surface soil (0 to 20 cm) under investigation alongwith the methods adopted for their estimations are given in Table 3.1.

The soil was clay loam in texture and can be considered as deficient in nitrogen and phosphorus and marginal in zinc availability, whereas it was sufficient in available potash. The soil has slight salinity and alkalinity and medium CEC.

### 3.2 Collection and preparation of the soil sample :

The bulk soil sample from a depth of 20 cm was collected from a farmer's wheat (dry) field near Arnej village (Dholka taluka). The soil was collected from the random spots and composited. The composite soil sample was then brought to the laboratory, air dried and powdered with a wooden mortar. It was passed through a 2 mm sieve and mixed thoroughly. The necessary precautions were taken to avoid any contamination from extraneous sources.

Table 3.1 : Important physico-chemical characteristics of the soil

1.	Mechanical composition (Piper, 1950) :		
-	Coarse sand (%)	...	2.99
-	Fine sand (%)	...	27.15
-	Silt (%)	...	23.08
-	Clay (%)	...	36.33
-	Textural class	...	Clay loam
2.	Maximum water holding capacity (Piper, 1966)		49.50
3.	pH (1 : 2.5 Soil:Water)(Jackson, 1968)		7.6
4.	EC (1 : 2.5 Soil:Water) $\text{dSm}^{-1}$ at 25 °C (Jackson, 1968)		0.9
5.	$\text{CaCO}_3$ (%) (Richards, 1954)	...	9.34
6.	Organic matter (%) (Piper, 1950)	...	0.65
7.	Total N (%) (Jackson, 1967)	...	0.04
8.	Total P (%) (Jackson, 1967)	...	0.20
9.	Available P (ppm) (Olsen <u>et al.</u> , 1954)		5.00
10.	Available K(kg/ha) (Jackson, 1967)	...	254.7
11.	CEC ( $\text{c mol}(\text{p}^+)\text{kg}^{-1}$ ) (Chapman, 1965)		33.27
12.	Exchangeable Ca + Mg ( $\text{c mol}(\text{p}^+)\text{kg}^{-1}$ )		25.98
13.	Exchangeable K ( $\text{c mol}(\text{p}^+)\text{kg}^{-1}$ )(Jackson,1967)		0.91
14.	Exchangeable Na ( $\text{c mol}(\text{p}^+)\text{kg}^{-1}$ ) (Jackson, 1967)	...	6.38
15.	DTPA-extractable Zn (ppm) (Lindsay and Norvell, 1969)	...	0.52
16.	DTPA-extractable Cu (ppm) (Lindsay and Norvell, 1969)	...	1.82
17.	DTPA-extractable Fe (ppm) (Lindsay and Norvell, 1969)	...	10.36
18.	DTPA-extractable Mn (ppm) (Lindsay and Norvell, 1969)	...	11.52

### 3.3 Experimental details :

#### 3.3.1 Treatments :

Sixty treatments, arising from combination of five moisture regimes, three levels of phosphorus applied through two sources and two levels of farm yard manure were tested in the present incubation study for the availability of different nutrients. A common dose of 25 kg N/ha (urea/DAP) was also given in the form of solution. The details are given below :

#### I. Regimes of moisture :

Soils under each treatment were flooded and incubated for three weeks and then allowed for depletion in moisture at desired level.

(i)  $M_1$  - 40 per cent moisture

(ii)  $M_2$  - 30 per cent moisture

(iii)  $M_3$  - 20 per cent moisture

(iv)  $M_4$  - 10 per cent moisture

(v)  $M_5$  - After three weeks incubation

under flooding, the soil was allowed to air-dry. Again it was flooded and incubated for three weeks and brought to 40 per cent moisture.

#### II. Level of phosphorus :

(i)  $P_0$  - 0.00 ppm P (0 kg  $P_2O_5$ /ha)

(ii)  $P_1$  - 4.87 ppm P (25 kg  $P_2O_5$ /ha)

(iii)  $P_2$  - 9.74 ppm P (50 kg  $P_2O_5$ /ha)

III. Sources of phosphorus :

- (i) Dicalcium phosphate (AR grade)
- (ii) Diammonium phosphate (AR grade)

IV. Levels of farm yard manure (FYM) :

- (i)  $F_0$  - 0.0 t/ha
- (ii)  $F_1$  - 13.5 t/ha

3.3.2 Design of the experiment :

A factorial completely randomized design with two replications was employed in the experiment.

3.4 Incubation study :

The study was conducted in the laboratory at room temperature during the period from November to February, 1986-87. Plastic containers (250 ml) were filled with 150 g of air dried soil and treated with phosphorus through the solutions (100 ml) of AR grade  $\text{Ca}(\text{H}_2\text{PO}_4)_2$  and  $(\text{NH}_4)_2 \text{HPO}_4$  and farm yard manure as per the treatments. The soils were kept flooded for three weeks by adding required quantity of distilled water. The samples were stirred on alternate day to have uniform distribution of P and FYM. The moisture from the soil was allowed to deplete to a desired level. A blank was also run along with the set in the laboratory.

3.5 Periodic soil analysis :

The wet soil samples at different moisture levels were immediately used for the analysis of available phosphorus, potassium, DTPA-extractable zinc, iron, manganese, copper

and soil pH. Simultaneously soil samples were also drawn from each container for the moisture determination so as to work out the nutrient status on oven-dry basis. The chemical methods employed for the estimation of different nutrients are given below.

(1) pH :

It was determined in 1 : 2.5 soil:water suspension by glass electrode Perkin-elmer pH meter (Coleman, 1980).

(2) Phosphorus :

M/2  $\text{NaHCO}_3$  (pH 8.5) was used as an extractant and P concentration determined by Olsen's method (Olsen et al., 1954).

(3) Potassium :

The available potassium was determined by extracting soil with neutral N ammonium acetate and using flame photometer (Jackson, 1967).

(4) Micronutrients (Zn, Fe, Mn and Cu) :

Micronutrient concentrations in soil extract with DTPA solution (0.005 M diethelene triamine penta-acetic acid, 0.01 M calcium chloride and 0.1 M triethanolamine, pH 7.3), as suggested by Lindsay and Norvell (1969) were estimated by Atomic Absorption Spectrophotometer (Varian Tectron, AA-120).

### 3.6 Statistical analysis :

The statistical analysis of variance (including values of 'F' test and critical difference) for factorial completely randomized design was made on computer (PC/AT).

**RESULTS**  
**&**  
**DISCUSSION**

#### IV. RESULTS AND DISCUSSION

The present investigation was undertaken to study the effect of different moisture regimes, levels and sources of P and FYM application on the availability pattern of P, K, Fe, Mn, Zn, Cu and changes in soil pH in medium black calcareous soil of wheat-growing area of Bhal (Ahmedabad district). The results related to various aspects of the studies alongwith their discussion are presented in this chapter under different sub-headings.

##### 4.1 Effect of moisture regimes and FYM on soil pH :

The data on soil pH as influenced by the moisture regimes and FYM are given in Table 4.1 and graphically presented in Fig. 4.1.

Table 4.1 : Effect of moisture regimes, levels and sources of phosphorus and FYM on soil pH

Moisture levels	No. FYM			FYM			Mean
	P <sub>0</sub>	P <sub>1</sub>	P <sub>2</sub>	P <sub>0</sub>	P <sub>1</sub>	P <sub>2</sub>	
M <sub>1</sub>	7.69	7.70	7.72	7.38	7.39	7.40	7.55
M <sub>2</sub>	7.71	7.72	7.74	7.41	7.42	7.43	7.57
M <sub>3</sub>	7.73	7.76	7.77	7.47	7.48	7.49	7.62
M <sub>4</sub>	7.75	7.77	7.78	7.52	7.56	7.57	7.66
M <sub>5</sub>	7.69	7.70	7.72	7.37	7.38	7.39	7.54
Mean	7.73			7.40			

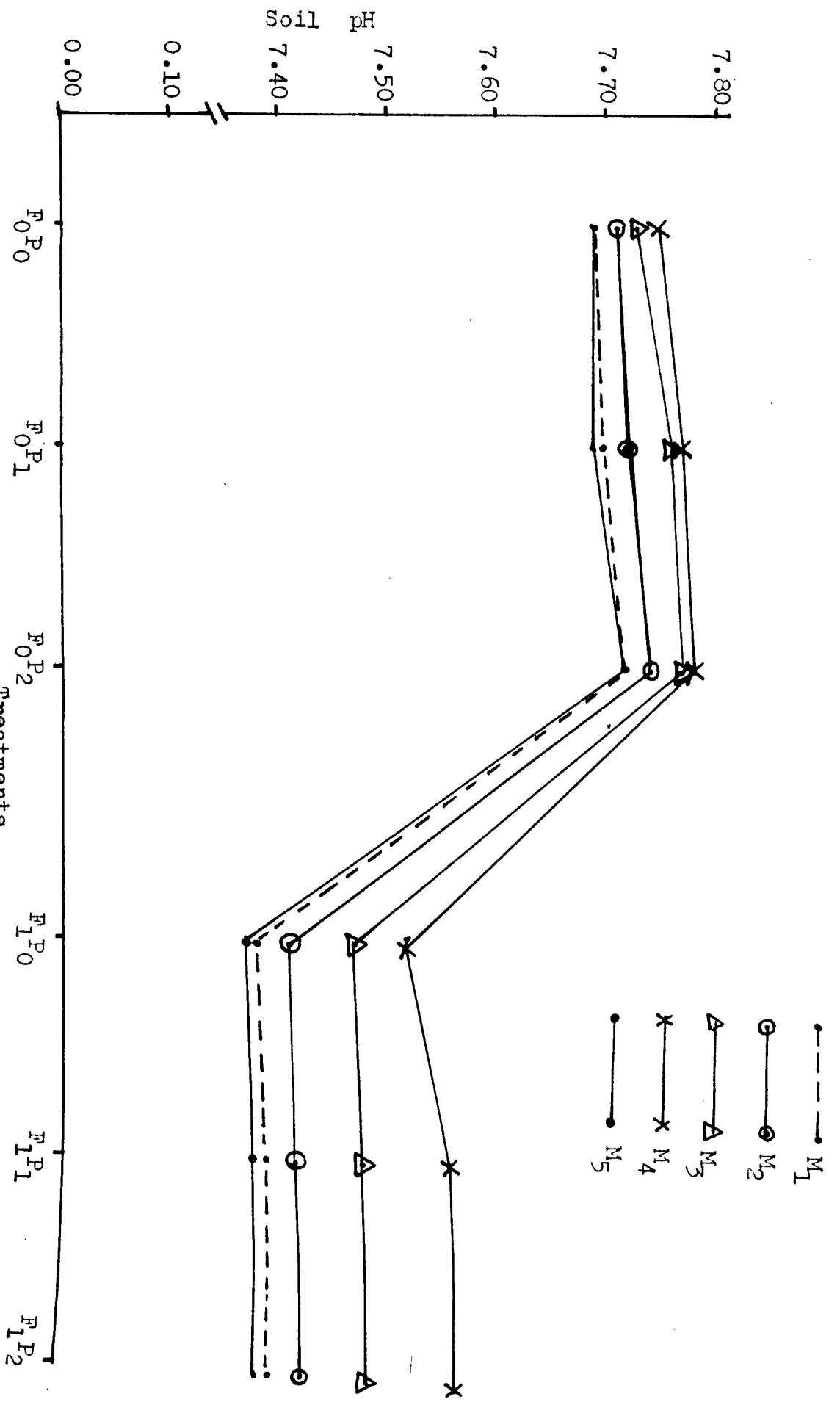


Fig. 4.1 : Average effect of moisture regimes and FYM on soil pH

It is observed that the pH value increased when the moisture was depleted from 40 ( $M_1$ ) to 10 ( $M_4$ ) per cent. No much difference in soil pH was observed between moisture regimes  $M_1$  and  $M_5$ . The overall increase in soil pH value due to various moisture regimes was from 7.54 to 7.57, 7.62 and 7.66 under  $M_2$ ,  $M_3$  and  $M_4$ , respectively. Application of FYM markedly decreased the soil pH from 7.73 to 7.40. The different treatment combinations of moisture regimes with phosphorus did not show any marked effect on soil pH. The results clearly indicated the role of moisture and organic matter in decreasing the soil pH. The reduction in soil pH at higher moisture level could be attributed to the depletion of oxygen, accumulation of carbon dioxide and the reduction reactions taking place under higher moisture level and due to partial pressure of  $CO_2$  in alkaline and calcareous soils (Ponnamperuma, 1977). The decrease in soil pH due to FYM application could be attributed to large quantity of carbon dioxide and some organic acids produced during the microbial decomposition of organic matter (Singh and Lal, 1976).

Rahate et al. (1979) also reported that high doses of FYM alone or in combination with ammonium sulphate lowered the pH of the soil due to decomposition of organic matter. Similar results were also reported by Murthy and Ponnamperuma (1986) and Modi (1986).

#### 4.2. Effect of moisture regimes, levels and sources of P and FYM on the availability of P in the soil :

##### 4.2.1 Effect of moisture regimes :

The data on availability of P due to various treatments are presented in Table 4.2. The data revealed that the effect of moisture regimes on the availability of P in the soil was found to be significant. It is clearly seen from the results that the available P content was significantly decreased when the moisture was depleted from 40 to 10 per cent.

The data also indicated that the effect of  $M_1$  (9.68 ppm P) and  $M_5$  (9.63 ppm P) on the available P content in the soil was at par. Thus, the availability of P was restored on rewetting the soil ( $M_5$ ). The depletion in moisture from 40 ( $M_1$ ) to 10 per cent ( $M_4$ ) resulted in as high as 72.9 per cent decrease in the available P content in the soil. Similarly the decrease in value of P at  $M_2$  (20 %) and  $M_3$  (30 %) was 26.2 and 51.3 per cent, respectively.

Further the data (Table 4.2) revealed that the effect of P levels and its interaction with moisture regimes (P x M) was also found to be significant. The significantly higher available P content was observed with the increase in the levels of P application at each moisture regimes over  $P_0$ . However, with the depletion in moisture under each level of P application, the availability of P decreased. The



maximum availability of P was observed under P<sub>2</sub> level at each moisture level.

Average and interaction effects of various treatments on the P availability are also depicted in Figs. 4.2 (A) and 4.2(B), respectively. The maximum availability of P was observed at 40 per cent moisture level, then it decreased with the depletion in moisture. At both moisture regimes viz., M<sub>1</sub> (40 %) and M<sub>5</sub> (40 % rewetting) alongwith FYM, the P availability was higher as compared to M<sub>2</sub>, M<sub>3</sub> and M<sub>4</sub> irrespective of levels and sources of P. The decreased availability of phosphorus with the depletion in moisture could be attributed to the oxidation of more soluble ferrous phosphate to insoluble ferric phosphate and also due to precipitation of calcium phosphate under reduced concentration of CO<sub>2</sub>. It could also be due to increase in pH (Table 4.1) and fixation of P (Appendix-I) with depletion in soil moisture.

Ponnamperuma (1967, 1972) reported that the increased availability of P with higher moisture regimes is mainly due to reduction of ferric phosphate to ferrous phosphate, although other changes like hydrolysis of aluminium phosphate and dissolution of calcium phosphate resulting from the accumulation of CO<sub>2</sub> are also involved. The changes are also accompanied by the changes in the pH of the soil. Similar results are also reported by number of research workers for wide range of soils (Mandal, 1964; Mahapatra, 1969; Satyanarayana et al., 1970; Rao and Venkateswarlu, 1974; Mandal and Khan, 1975;

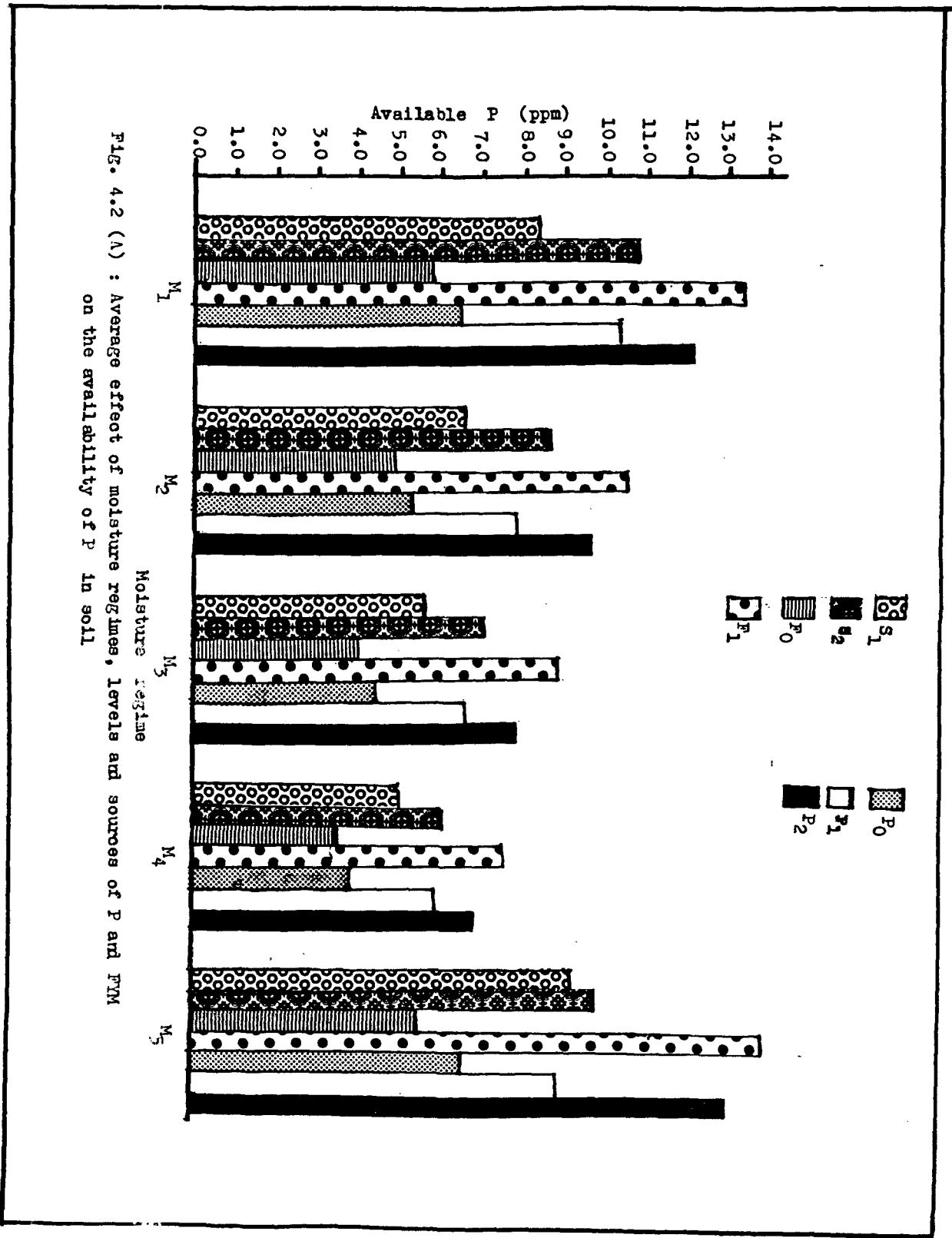


Fig. 4.2 (A) : Average effect of moisture regimes, levels and sources of P and PTM on the availability of P in soil

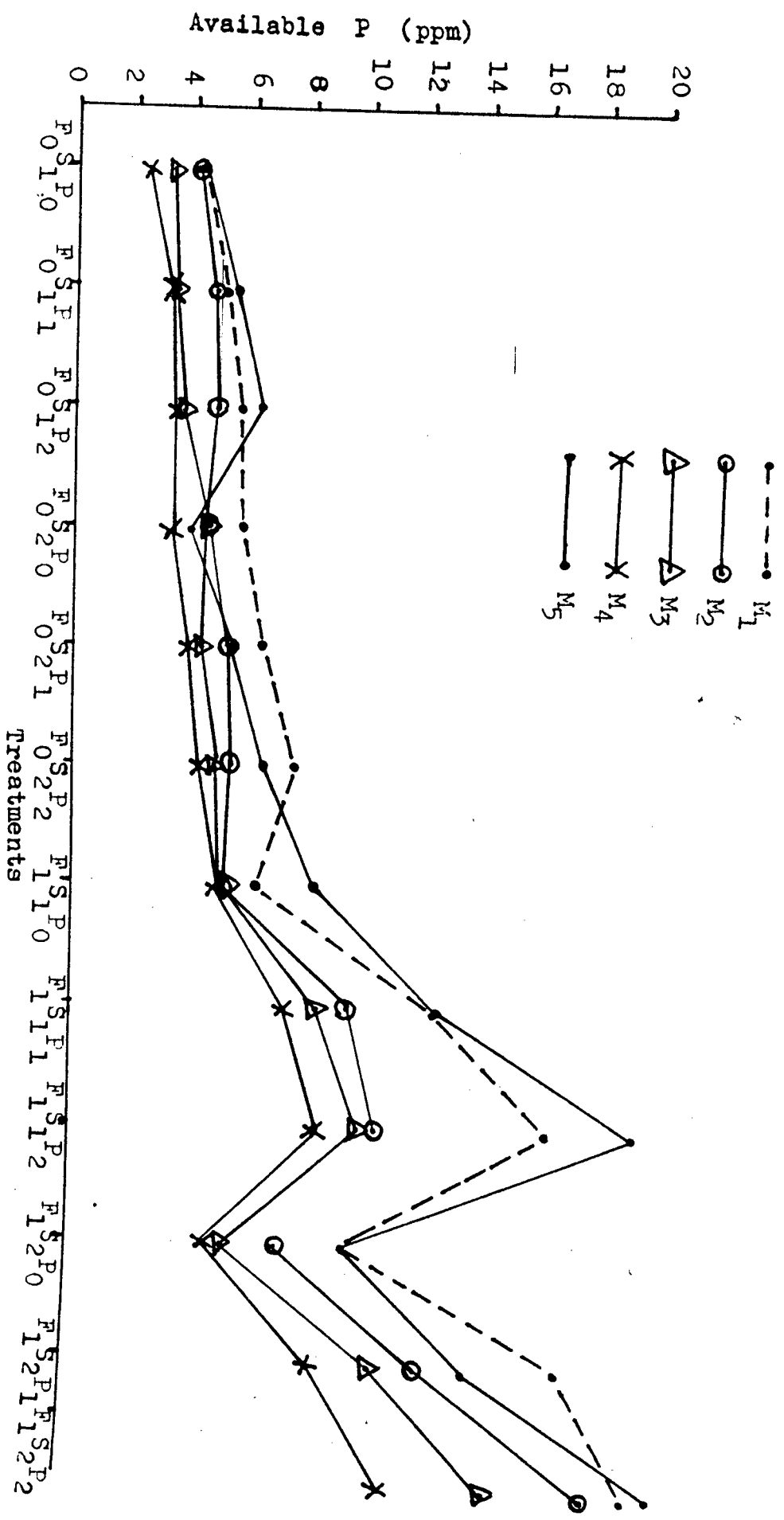


Fig. 4.2 (B) : Available P in soil as influenced by the interaction effect of moisture regimes, levels and sources of P and FYM

Shanthamallaiyah et al., 1976; Mandal and Haldar, 1980; Akabari et al., 1981; Bradley et al., 1984 and Vekaria, 1985).

#### 4.2.2 Effect of levels and sources of phosphorus :

The results revealed that the application of phosphorus was found to be significant in increasing the availability of P in the soil. There was significant increase of available P content in the soil with the increase in the level of phosphorus application over control. The maximum P availability (10.0 ppm) was observed with P<sub>2</sub> treatment followed by P<sub>1</sub> (8.01 ppm) and P<sub>0</sub> (5.38 ppm). The increase was as high as 48.9 and 85.9 per cent under P<sub>1</sub> and P<sub>2</sub> treatments over P<sub>0</sub>, respectively.

Similarly source of phosphorus was also found to be significant. It is clear from the data given in Table 4.2 that when phosphorus application was made through S<sub>2</sub> source (diammonium phosphate), the available P content in the soil was found significantly higher than that of S<sub>1</sub> source (dicalcium phosphate). The increase in the available P content with S<sub>2</sub> source (8.58 ppm) was 22.2 per cent higher as compared to S<sub>1</sub> source (7.02 ppm).

The data also indicated that the interaction of P x S was found to be significant. The P application through S<sub>2</sub> source was significantly superior to S<sub>1</sub> source in increasing the availability of P in the soil. The

maximum available P content was observed with  $P_2S_2$  treatment combination (11.11 ppm) which was significantly higher (more than double) over rest of the treatments.

Average and interaction effects of various treatments on the P availability are depicted in Figs. 4.2 (A) and 4.2 (B), respectively. Application of P @ 9.74 ppm ( $P_2$ ) through DAP produced higher available P content in the soil as compared to  $P_1$  and  $P_0$  irrespective of moisture regimes. Similarly the same treatment ( $P_2S_2$ ) produced maximum available P in the soil when P was applied alongwith FYM.

An attempt was made to calculate the per cent available P of the applied phosphorus through DCP and DAP in presence or absence of FYM under different moisture regimes. The values of per cent available and fixed P are given in Appendix-I. It was observed that the per cent P availability was higher under P application ( $P_2$ ) through DAP (14.5) as compared to  $P_1$  level (13.9), while the trend was reverse in case of P application through DCP. It is interesting to note that the availability of P increased to the tune of 79.8 ( $P_1$ ) and 70.0 ( $P_2$ ) per cent when P was applied through DCP along with FYM whereas in case of DAP, the values for the same increased further to the extent of 109.3 ( $P_1$ ) and 93.8 ( $P_2$ ) per cent. In general, the per cent availability of P was higher at higher moisture regimes, and it decreased with the depletion in moisture from 40 to 10 per cent. Data also revealed that at higher moisture regimes

alongwith FYM application, resulted in more than 100 per cent P availability. It indicated the role of FYM in preventing the P fixation and even releasing the native P in the soil.

The higher availability of P in the soil with DAP as compared to DCP application can be ascribed to the higher solubility of DAP than DCP. Chauhan *et al.* (1972) also found the order of Olsen's P as : super phosphate > diammonium phosphate > ammonium phosphate > dicalcium phosphate.

#### 4.2.3 Effect of farm yard manure :

Application of FYM @ 13.5 t/ha significantly increased the available P content (10.81 ppm) in the soil over no FYM (4.79 ppm). In general, the P availability with FYM was found more than double. The data also revealed that the effect of P x F interaction was found to be significant. The available P content was significantly higher at all the levels of P application alongwith FYM than that of P without FYM. It indicated that even the availability of P was significantly increased (58.9 %) with only FYM application (6.61 ppm P) in absence of P and FYM (4.16 ppm P). Similarly, the increase was even more than double with  $P_1F_1$  (11.22 ppm P) and about three times more with  $P_2F_1$  (14.59 ppm P) treatments over that of  $P_1F_0$  (4.80 ppm P) and  $P_2F_0$  (5.40 ppm P), respectively.

The average and interaction effects of various treatments on the availability of P are also depicted in

Figs. 4.2(A) and 4.2(B), respectively. Application of FYM @ 13.5 t/ha produced higher available P content in soil over no FYM irrespective of moisture regimes. The effect of higher moisture levels in increasing the availability of P was more pronounced in presence of FYM. Similarly, the availability of P was also found to be maximum under  $S_2P_2$  or  $S_1P_2$  treatment combination in presence of FYM and minimum under the same treatment combinations without FYM indicating the role of FYM in preventing the fixation of P in the soil (Appendix - I).

The increased availability of P on FYM application may be due to either directly by replacement of phosphorus from iron and/or aluminium phosphate or by influencing (i) the decrease in redox potential and (ii) pH changes as given in Table 4.1 (Bradley and Sieling, 1953; Yu and Liu, 1965). Sinha (1972) also reported the possible mechanisms involved in the mobilization of insoluble P in the soil as (i) complex formation between Fe and fulvic acid and (ii) the possible formation of soluble fulvic iron phosphate complexes. Positive influence of organic matter on P availability has also been reported by many research workers (Srivastava *et al.*, 1969; Adhikari and Ganguli, 1971; Sinha, 1972; Brans, 1973 and Kononova, 1966). The results regarding the role of FYM in preventing the fixation of P in the soil are also reported

by Prabhakar et al. (1972), Vyas and Motiramani (1971) and Vyas (1964).

#### 4.3 Effect of moisture regimes, levels and sources of P and FYM on the availability of K in the soil :

##### 4.3.1 Effect of moisture regimes :

The data on availability of K due to various treatments are presented in Table 4.3. The moisture regimes had significant effect on available K content in the soil. The maximum available K content (kg/ha) was observed at  $M_1$  moisture regime (340.1) followed by  $M_2$  (323.6),  $M_3$  (282.7) and  $M_4$  (252.1). Thus, it clearly indicated the significant decrease in the available K content in the soil with the depletion in moisture from 40 to 10 per cent. The values of available K content were significantly decreased by 5.1, 20.3 and 34.9 per cent with the decrease in moisture from 40 to 30, 20 and 10 per cent, respectively. However, no any significant change in available K was observed under moisture regimes  $M_1$  and  $M_5$ .

The interaction effect of M x S on availability of K in soil was found to be significant. The maximum availability of K (341.2 kg/ha) under  $M_1S_1$  which was significantly higher over  $M_4S_1$  treatment (250.5 kg/ha). Similarly M x F interaction was also found to be significant. At all the moisture levels, application of FYM significantly increased available K content in soil over  $F_0$  treatment.

Table 4.3 : Effect of moisture regimes, levels and sources of phosphorus and FYM on the availability of K (kg/ha) in the soil (oven dry basis)

Levels of Moisture	F <sub>0</sub>		F <sub>1</sub>		Levels of Moisture								
	S <sub>1</sub>	S <sub>2</sub>	Mean	S <sub>1</sub>	S <sub>2</sub>	M <sub>1</sub>	M <sub>2</sub>	M <sub>3</sub>	M <sub>4</sub>	M <sub>5</sub>	Mean		
<u>M x P x F x S</u>													
M <sub>1</sub>	P <sub>0</sub>	318.09	314.28	316.18	356.74	339.35	348.04	332.11	315.98	275.41	249.46	331.15	300.82
	P <sub>1</sub>	318.72	316.72	317.72	359.09	365.58	362.83	340.28	324.16	284.26	251.78	336.59	307.41
	P <sub>2</sub>	329.95	320.31	325.13	364.82	376.60	370.71	347.92	330.54	288.31	255.16	343.99	313.19
	Mean	322.25	317.10	319.68	360.22	360.84	360.53	340.10	323.56	282.66	252.13	337.24	307.14
M <sub>2</sub>	P <sub>0</sub>	304.74	301.63	303.18	333.08	324.49	328.78						
	P <sub>1</sub>	308.35	303.18	305.76	335.38	349.75	342.56						
	P <sub>2</sub>	314.17	308.18	311.17	338.08	361.75	349.91						
	Mean	309.09	304.33	306.71	335.51	345.33	340.42						
M <sub>3</sub>	P <sub>0</sub>	264.70	273.81	269.25	280.24	282.88	281.56						
	P <sub>1</sub>	273.39	278.24	275.82	290.81	294.61	292.71						
	P <sub>2</sub>	283.05	282.51	282.78	292.57	295.13	293.85						
	Mean	273.71	278.19	275.95	287.87	290.87	289.37						
M <sub>4</sub>	P <sub>0</sub>	236.38	236.77	236.57	260.35	264.34	262.34						
	P <sub>1</sub>	240.07	239.32	239.70	261.74	265.99	263.87						
	P <sub>2</sub>	240.29	244.44	242.36	264.39	271.53	267.96						
	Mean	238.91	240.18	239.54	262.16	267.29	264.72						
M <sub>5</sub>	P <sub>0</sub>	311.54	303.45	307.49	355.02	354.59	354.80						
	P <sub>1</sub>	315.60	304.81	310.20	364.04	361.90	362.97						
	P <sub>2</sub>	320.87	312.52	316.69	371.28	371.30	371.29						
	Mean	316.00	306.92	311.46	363.45	362.59	363.02						
<u>P x F x S</u>													
	P <sub>0</sub>	287.09	317.09	302.09	285.99	313.13	299.56						
	P <sub>1</sub>	291.23	322.21	306.72	288.45	327.77	308.11						
	P <sub>2</sub>	297.66	326.23	311.95	293.59	335.26	314.43						
	Mean	291.99	289.34	306.92	289.34	325.38	307.36						
<u>F<sub>0</sub></u>													
	P <sub>0</sub>	302.09	299.56	300.83	286.54	315.11	300.83						
	P <sub>1</sub>	306.72	308.11	307.41	289.84	324.99	307.41						
	P <sub>2</sub>	311.95	314.43	313.19	295.63	330.74	313.19						
	Mean	306.92	307.36	307.14	299.67	323.61	307.14						

Source	S.E.m. ±	C.D. at 5%
Moisture (M)	1.071	3.029
Source (S)	0.677	NS
FYM (F)	0.677	1.916
Phosphorus (P)	0.830	2.346
M x S	1.515	4.284
M x F	1.515	4.284
M x P	1.855	NS
S x F	0.958	2.709
S x P	1.173	NS
F x P	1.173	3.318
C. V. %	1.708	

However, the availability of K under  $M_1F_1$  and  $M_5F_1$  treatments was significantly higher over rest of the treatments.

From the Figs. 4.3(A) and 4.3(B) it can be clearly stated that higher moisture levels had significant role in increasing the K availability in the soil as compared to other treatments. The soil used for the study exhibits considerable swelling and shrinkage properties on wetting and drying (Nedeco, 1968). The decreased availability of K with depletion of moisture in the soil could be attributed to fixation of K in the lattice of the montmorillonitic Bhal- soil (Savant et al., 1981). Grewal and Kanwar (1967) also observed higher K fixation after drying the soils of Punjab, Haryana and Himachal Pradesh. Potassium fixation due to drying resulted from vermiculite or other minerals containing expanding type of mica such as beidellite and illite has also been reported by Ahmed and Davis (1970). Vekaria (1985) also observed the significant decrease of available K at lower moisture level.

#### 4.3.2 Effect of levels and sources of phosphorus :

The data revealed that the application of phosphorus significantly increased the availability of K in the soil. The maximum available K content was observed at  $P_2$  level (313.2 kg/ha) followed by  $P_1$  (307.4 kg/ha) over no phosphorus application (300.8 kg/ha).

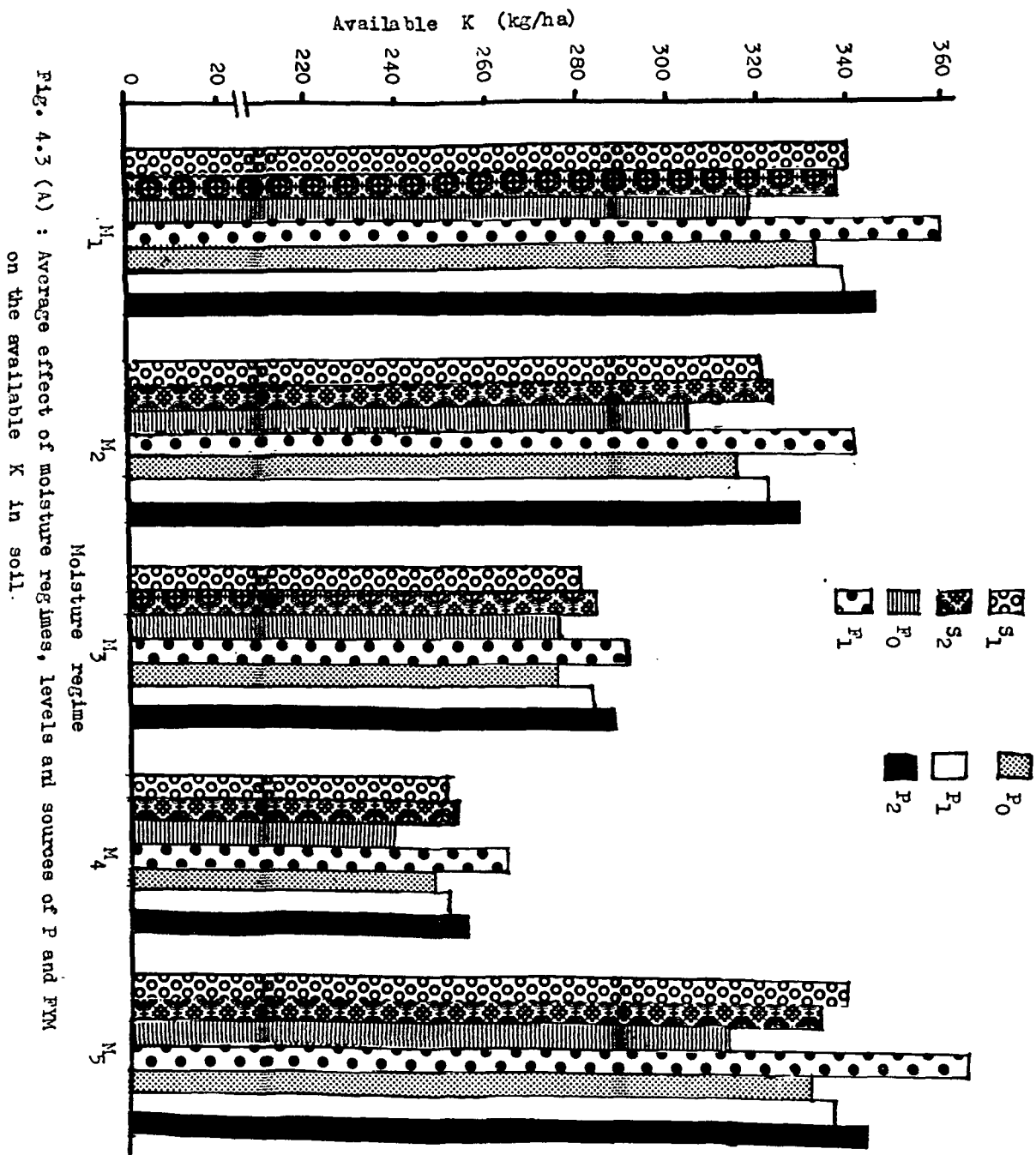


Fig. 4.3 (A) : Average effect of moisture regimes, levels and sources of P and FYM on the available K in soil.

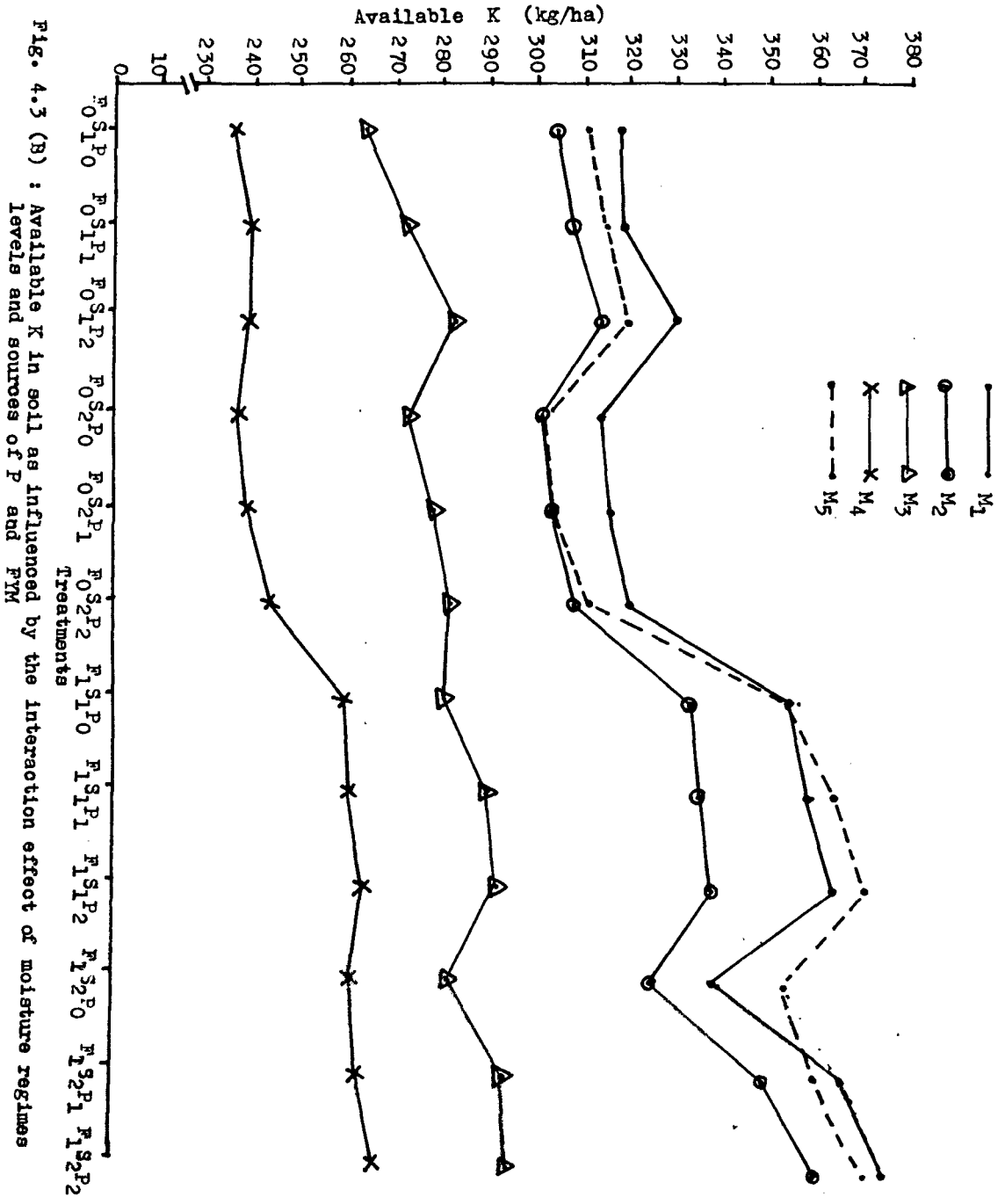


Fig. 4.3 (B) : Available K in soil as influenced by the interaction effect of moisture regimes levels and sources of P and FYM

However, the increase was very meagre, being 2.2 and 4.1 per cent with  $P_1$  and  $P_2$  levels, respectively. This can also be seen from the Figs. 4.3(A) and 4.3(B). The effect of source of P was found to be non significant. Similarly the effect of interaction between the levels of P and its source (P x S) as well as P x M was also found to be non significant.

#### 4.3.3 Effect of farm yard manure :

The availability of K was significantly higher with the application of FYM @ 13.5 t/ha (323.6 kg/ha) than that of no FYM (290.7 kg/ha). In general, the increase in K availability with FYM application, it was 11.3 per cent higher over no FYM. The data given in Table 4.3 revealed that the effects of FYM and treatments in combination with P application were found to be significant. The availability of K in the soil was also significantly increased with FYM application at all the levels of P application than that of no FYM treatments. However, the increase was significantly higher with the increase in level of P application. The maximum K availability with  $P_2F_1$  was 330.7 kg/ha and minimum under  $P_0F_0$  (286.5 kg/ha), respectively. Similarly interaction of F x S was found to be significant. The maximum availability of K was observed under  $F_1S_2$  (325.4 kg/ha) and minimum under  $F_0S_2$  (289.3 kg/ha).

From the average and interaction effects as depicted in Fig. 4.3(A) and 4.3(B), it could be said that FYM application plays a significant role, particularly at higher moisture levels in releasing the K in montmorillonitic soil of Bhal area.

Generally, farm yard manure contains about 0.5 per cent  $K_2O$ , which can obviously increase the available potash in the soil considerably when it gets decomposed. While studying the effect of continuous manuring and cropping on soil fertility in the old and new permanent manurial experiments in progress at Pusa (Bihar) on calcareous soil under rainfed condition, Ghosh and Kanzaria (1962) reported little difference in available K content in the soils in the old manurial series, while in new series some of the differences (including FYM and rape cake) were found to be significant. Brar and Sekhon (1987) noted positive significant correlation ( $r = 0.51$  to  $0.81$ ) between organic carbon and exchangeable K of five bench mark soil series of Northern India. They also observed the influence of texture and organic carbon on the ammonium acetate extractable K of the soil. Having the same texture, the K content differed with the organic carbon content of the soil. Similar results are also reported elsewhere (Anonymous, 1987-88).

#### 4.4 Effect of moisture regimes, levels and sources of P and FYM on the availability of Fe in the soil :

##### 4.4.1 Effect of moisture regimes :

The data on the available Fe content in the soil as influenced by various treatments are presented in Table 4.4. Effect of moisture regimes was found to be significant. There was significant decrease in the DTPA-extractable Fe content in soil with the decrease in moisture content. Moisture regime  $M_1$  (40 %) produced on an average 17.11 ppm of available Fe content in the soil which was significantly higher than rest of the moisture regimes including  $M_5$  (rewetting). The minimum available Fe content (10.05 ppm) was observed at  $M_4$  (10 %) moisture regime, whereas the  $M_2$  (30 %) and  $M_3$  (20 %) treatments produced 13.43 and 11.93 ppm of DTPA-extractable Fe contents in soil, respectively. Thus, it indicated that with the depletion in moisture in soil from 40 to 30, 20 and 10 per cent, the decrease in available Fe content was 27.4, 43.4 and 70.2 per cent, respectively. The same decrease with  $M_5$  (rewetting) treatment was only by 6.4 per cent as compared to  $M_1$ . Thus, the effect was not so pronounced as was observed in case of the treatments applied at lower moisture regimes. The importance of moisture in releasing the Fe in soil at  $M_1$  and  $M_5$  level can also be seen from the Fig. 4.4(A).



The effect of interactions between the sources of P (M x S) and levels of P (M x P) on availability of Fe in soil was found to be non significant.

The decrease in the available Fe with the depletion in moisture could be due to the oxidized condition created on drying through which ferrous phosphate gets converted into ferric phosphate, the more insoluble compound. It appeared that  $Fe^{+2} \longrightarrow Fe(OH)_3$  system regulated the conversion (Paul and Delong, 1949). Ponnampereuma (1972, 1976) also reported an increase in the availability of Fe due to submergence of soil as regulated by redox system :  $Fe(OH)_3 \longrightarrow Fe^{+2}$ . The decrease in available Fe content could also be due to increase in soil pH from 7.69 to 7.78 as observed in the present study (Table 4.1). The increase in available Fe with the increase in moisture content in soil has also been observed by Babaria and Patel (1980) and Mandal and Mitra (1982). Patil and Patil (1981) also observed a proportionate decrease in the available Fe with progress of incubation time at all the moisture regimes (viz., 100, 80, 60, 40 and 20 % ASM) and positive relationship was observed between ASM and available Fe. Similar results have also been reported by Rahmatullah et al. (1976) and Vekaria (1985).

#### 4.4.2 Effect of levels and sources of phosphorus :

A significant decrease in the DTPA-extractable Fe in the soil was observed with the increase in the levels of P application. Maximum available Fe content of 14.92 ppm was observed under  $P_0$  treatment followed by  $P_1$  (13.68 ppm) and  $P_2$  (12.56 ppm). Thus, the decrease was 9.1 and 18.8 per cent with  $P_1$  and  $P_2$  levels, respectively over no P application. The effect of source used for the P application was also found to be significant. In general, the P application made through diammonium phosphate ( $S_2$ ) gave DTPA-extractable Fe content of 13.88 ppm which was significantly higher than that of dicalcium phosphate (13.56 ppm). The increase at  $S_2$  was about 2.4 per cent more than  $S_1$  treatment. The data also revealed that the interaction effect of P x S was found to be non significant. The average and interaction effects of levels and sources of P on the Fe availability have also been depicted graphically in Figs. 4.4 (A) and 4.4 (B).

The decrease in DTPA-extractable Fe with the application of phosphorus can be attributed to the formation of insoluble reaction products like colloidal and amorphous Fe-phosphate in the soil (Das and Datta, 1967, 1968, 1969). Similar results on availability of Fe with P application have also been reported by Yadav and Mistry (1977) and Basu and Mukherjee (1969).

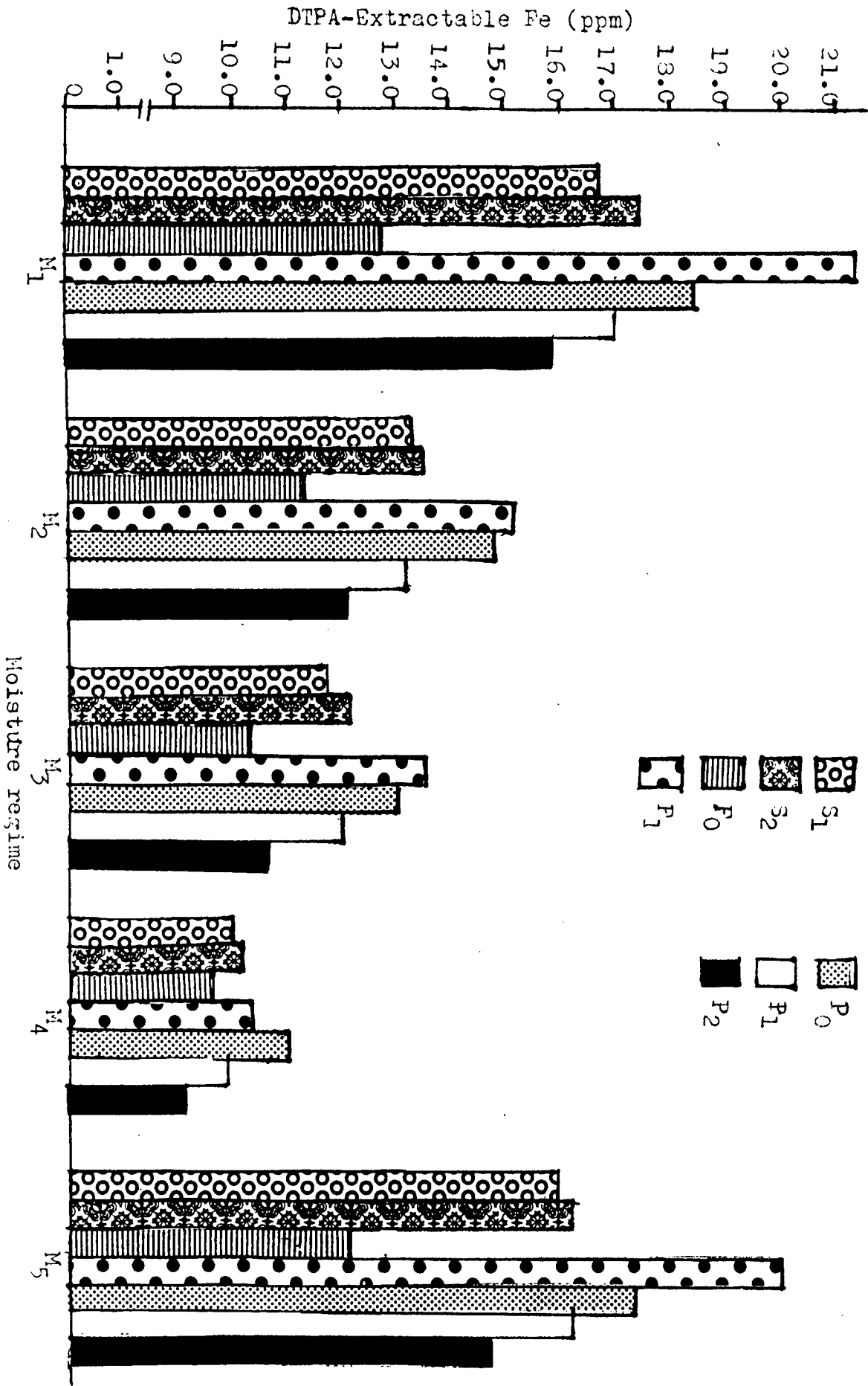


FIG. 4.4 (A) : Average effect of moisture regimes, levels and sources of P and FYM on the DTPA - extractable Fe in soil

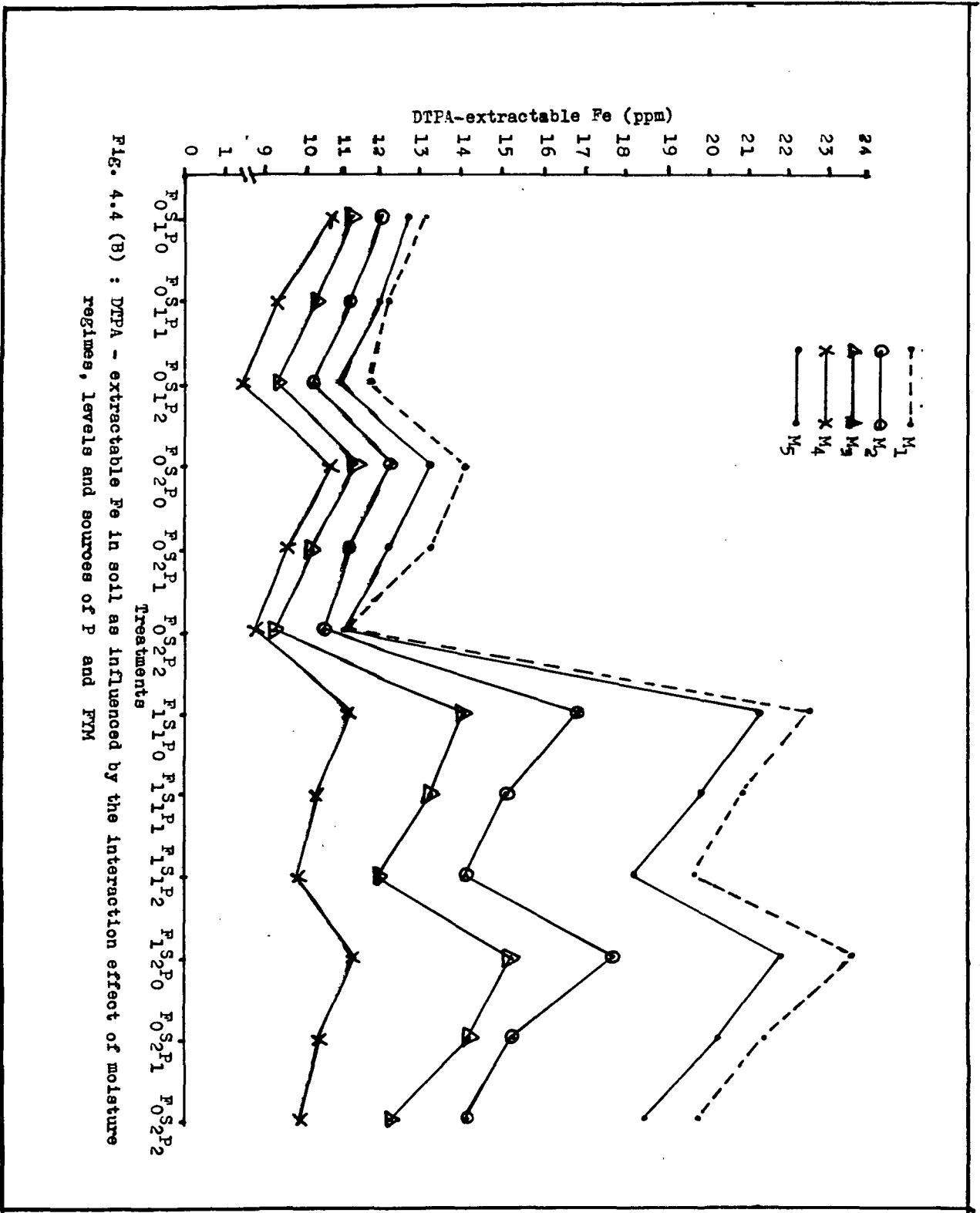


FIG. 4.4 (B) : DTPA - extractable Fe in soil as influenced by the interaction effect of moisture regimes, levels and sources of P and FYM

#### 4.4.3 Effect of farm yard manure :

The effect on FYM application was also found to be significant (Table 4.4). In general, application of FYM produced DTPA-extractable Fe of 16.19 ppm, whereas the same was 11.25 ppm under without FYM application. This showed that the treatment with FYM application raised available Fe content in soil by 43.9 per cent over the treatment no FYM.

Average and interaction effects of various treatments on the DTPA-extractable Fe in soil have also been graphically depicted in Figs. 4.4(A) and 4.4(B). Average value clearly showed the positive effect of FYM and negative effect of phosphorus on the availability of Fe in soil. Interaction effect also showed that application of FYM in combination with phosphorus tremendously increased the availability of Fe, particularly at higher moisture levels.

The data also indicated that the interaction of  $P \times F$  had significant effect on DTPA-extractable Fe content in soil, while the sources of P ( $F \times S$ ) for the same was found to be non significant. The maximum available Fe content (17.61 ppm) was produced by the treatment combination  $P_0F_1$ , whereas the minimum (10.27 ppm) was observed with the  $P_2F_0$ . This might be due to beneficial effect of FYM and adverse effect of phosphorus application.

The interaction of  $M \times F$  was found to be significant as is revealed from the Table 4.4. The maximum

DTPA-extractable Fe in soil was observed under  $M_1F_1$  treatment (21.35 ppm) as both the factors showed additive effect, while minimum value was noted with  $M_4F_0$  (9.63 ppm).

A large increase in the DTPA-extractable Fe in soil with the application of FYM could be attributed to the production of large quantity of  $CO_2$  and organic acids during its microbial decomposition with the subsequent decrease in soil pH (Table 4.1) and thereby increase the release of Fe (Singh and Lal, 1976). The decrease in pH due to application of organic matter has also been reported by several workers (Rahate *et al.*, 1969; Sharma *et al.*, 1977 and Modi, 1986). Farm yard manure itself contains considerable amount of Fe (Appendix-II) and hence, it can also increase the availability of Fe in soil. A high positive correlation between organic matter content and extractable Fe has been reported by several workers (Khetawat and Vashishtha, 1977; Misra and Pandey, 1976 and Misra *et al.*, 1976).

#### 4.5 Effect of moisture regimes, levels and sources of P and FYM on the availability of Mn in the soil :

##### 4.5.1 Effect of moisture regimes :

DTPA-extractable Mn content in the soil due to various treatments are presented in Table 4.5. The data revealed a significant effect of moisture regimes on the DTPA-extractable Mn content in the soil. It is clear from

Table 4.5 : Effect of moisture regimes, levels and sources of phosphorus and FYM on the availability of Mn (ppm) in the soil (oven dry basis)

Levels of Moisture	F <sub>0</sub>				F <sub>1</sub>				Levels of moisture					
	S <sub>1</sub>		S <sub>2</sub>		S <sub>1</sub>		S <sub>2</sub>		P x M					
	M	x	P	x	F	x	S	M <sub>1</sub>	M <sub>2</sub>	M <sub>3</sub>	M <sub>4</sub>	M <sub>5</sub>	Mean	
M <sub>1</sub>	P <sub>0</sub>	50.55	57.14	42.74	41.30	61.03	64.66	62.84	70.73	52.07	44.33	28.34	71.31	53.36
	P <sub>1</sub>	62.80	74.36	42.53	45.50	64.99	77.87	71.43	92.05	58.47	47.39	31.60	89.78	63.86
	P <sub>2</sub>	76.01	81.13	51.82	51.74	69.16	82.92	76.04	102.53	63.89	51.83	33.78	109.83	72.37
	Mean	63.11	70.87	47.68	46.18	65.07	75.15	70.10	88.44	58.14	47.85	31.24	90.30	63.20
M <sub>2</sub>	P <sub>0</sub>	39.86	42.74	42.74	41.30	61.03	64.66	62.84	70.73	52.07	44.33	28.34	71.31	53.36
	P <sub>1</sub>	42.53	42.48	42.53	45.50	64.99	77.87	71.43	92.05	58.47	47.39	31.60	89.78	63.86
	P <sub>2</sub>	51.66	51.82	51.82	51.74	69.16	82.92	76.04	102.53	63.89	51.83	33.78	109.83	72.37
	Mean	44.68	47.68	47.68	46.18	65.07	75.15	70.10	88.44	58.14	47.85	31.24	90.30	63.20
M <sub>3</sub>	P <sub>0</sub>	35.90	33.56	33.56	34.73	49.81	58.07	53.94	70.73	52.07	44.33	28.34	71.31	53.36
	P <sub>1</sub>	39.43	38.67	38.67	39.05	52.10	39.37	55.74	92.05	58.47	47.39	31.60	89.78	63.86
	P <sub>2</sub>	43.03	43.55	43.55	43.29	55.59	65.17	60.38	102.53	63.89	51.83	33.78	109.83	72.37
	Mean	39.45	38.59	38.59	39.02	52.50	60.87	56.68	88.44	58.14	47.85	31.24	90.30	63.20
M <sub>4</sub>	P <sub>0</sub>	14.24	14.81	14.81	14.52	42.64	41.68	42.16	70.73	52.07	44.33	28.34	71.31	53.36
	P <sub>1</sub>	15.60	16.37	16.37	15.99	46.74	47.62	47.21	92.05	58.47	47.39	31.60	89.78	63.86
	P <sub>2</sub>	16.50	17.22	17.22	16.86	51.25	50.14	50.70	102.53	63.89	51.83	33.78	109.83	72.37
	Mean	15.45	16.13	16.13	15.79	46.88	46.50	46.69	88.44	58.14	47.85	31.24	90.30	63.20
M <sub>5</sub>	P <sub>0</sub>	55.69	54.69	54.69	55.19	71.12	103.74	87.43	70.73	52.07	44.33	28.34	71.31	53.36
	P <sub>1</sub>	69.58	73.75	73.75	71.67	89.01	126.77	107.89	92.05	58.47	47.39	31.60	89.78	63.86
	P <sub>2</sub>	88.31	96.51	96.51	92.41	115.38	139.13	127.25	102.53	63.89	51.83	33.78	109.83	72.37
	Mean	71.19	74.98	74.98	73.09	91.83	123.21	107.52	88.44	58.14	47.85	31.24	90.30	63.20
		P x F		x S		P x F		x S						
	P <sub>0</sub>	39.25	40.59	40.59	39.92	60.73	72.87	66.80	70.73	52.07	44.33	28.34	71.31	53.36
	P <sub>1</sub>	45.99	50.33	50.33	48.16	72.23	86.88	79.56	92.05	58.47	47.39	31.60	89.78	63.86
	P <sub>2</sub>	55.10	58.04	58.04	56.57	81.78	94.56	88.17	102.53	63.89	51.83	33.78	109.83	72.37
	Mean	46.78	49.65	49.65	48.22	71.58	84.77	78.17	88.44	58.14	47.85	31.24	90.30	63.20
		P x S		F x S		P x S		F x S						
	F <sub>0</sub>	49.99	56.73	56.73	53.36	39.92	66.80	53.36	70.73	52.07	44.33	28.34	71.31	53.36
	F <sub>1</sub>	59.11	68.60	68.60	63.86	48.16	79.56	63.86	92.05	58.47	47.39	31.60	89.78	63.86
	F <sub>2</sub>	68.44	76.30	76.30	72.37	56.57	88.17	72.37	102.53	63.89	51.83	33.78	109.83	72.37
	Mean	59.18	67.21	67.21	63.20	50.00	78.17	63.20	88.44	58.14	47.85	31.24	90.30	63.20

	S. Em.	C.D. at 5 %
Moisture (M)	0.465	1.314
Source (S)	0.294	0.831
FYM (F)	0.294	0.831
Phosphorus (P)	0.360	1.018
M x S	0.657	1.859
M x F	0.657	1.859
M x P	0.805	2.276
S x F	0.416	1.175
S x P	0.509	1.440
F x P	0.509	1.440
C. V. %	3.602	

the data that there was a significant decrease in the available Mn content with the decrease in moisture regimes from 40 to 10 per cent. The moisture regime  $M_1$  (40 %) produced the maximum available Mn content (88.44 ppm) followed by  $M_2$  (58.14 ppm),  $M_3$  (47.85 ppm) and  $M_4$  (31.24 ppm) treatments. Thus, depletion in the moisture regimes from 40 to 30, 20 and 10 per cent resulted in the reduction of available Mn content in the soil by 52.1, 85.9 and 183.1 per cent, respectively. The average effect of moisture on Mn availability is also graphically shown in Fig. 4.5(A). The data further revealed that due to rewetting the soil ( $M_5$ ), the DTPA-extractable Mn in soil was increased significantly over all the moisture regimes.

Interaction between M and P was found to be significant in respect of DTPA-extractable Mn content in the soil (Table 4.5). Treatment combination  $M_5P_2$  gave the maximum available Mn content (109.83 ppm) in the soil whereas the lowest value was observed with  $M_4P_0$  treatment combination (28.34 ppm). This showed that available Mn content varied to a greater extent with different treatment combinations. Thus, data clearly indicated that the values of DTPA-extractable Mn influenced positively both by moisture and P levels.

Interaction between M and S was found to be significant for DTPA-extractable Mn in soil (Table 4.5). Treatment

combination  $M_5S_2$  exhibited maximum (99.1 ppm) available Mn in soil, whereas minimum (31.2 ppm) was found with  $M_4S_1$  treatment combination. Data clearly indicated the superiority of DAP over DCP on availability of Mn in soil irrespective of moisture levels.

Interaction between moisture and FYM (Table 4.5) on availability of Mn in soil was found to be significant. The highest (109.9 ppm) available Mn content in soil was observed at  $M_1F_1$ , while it was the lowest (15.8 ppm) at  $M_4F_0$ . Data clearly showed the beneficial additive effect of FYM and moisture on Mn availability in soil. Interaction effect of various treatments is also graphically given in Fig. 4.5(B).

The decrease in the availability of Mn in the soil with the depletion in moisture could be attributed to the unfavourable oxidizing conditions created on drying the soil. Similar behaviour of Mn is also reported by Rahmatullah et al. (1976). Ponnampereuma (1965) reported that at higher moisture regimes, the facultative anaerobes could use the oxidized compounds like  $MnO_2$  as electron acceptors and decrease the oxygen concentration thereby, increase the availability of Mn. The reduction of oxides of Mn almost simultaneously takes place with the nitrate reduction. At higher moisture level, this reduction is further accentuated by the organic matter present in the soil, ultimately resulting in further increase in its availability.

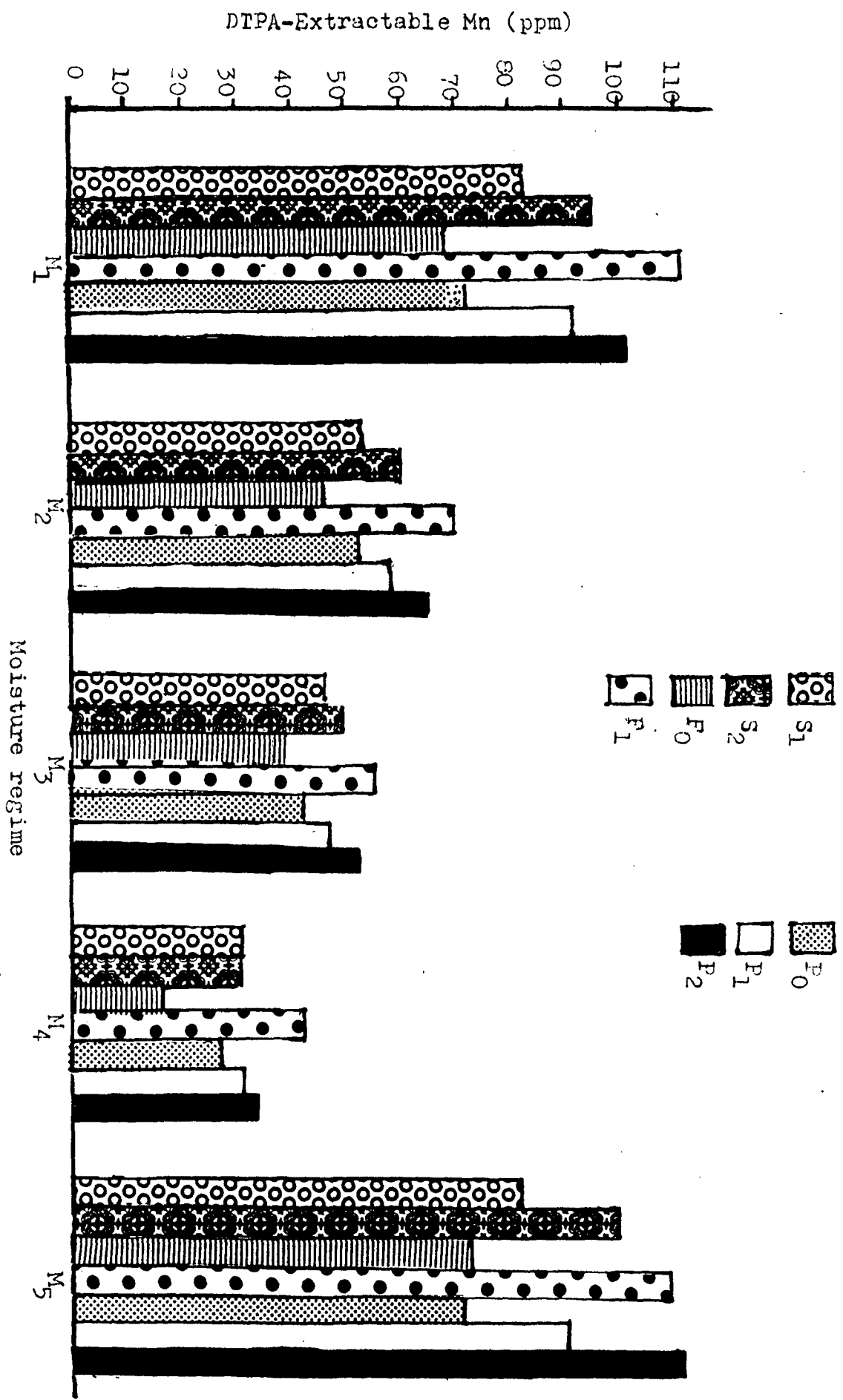


Fig. 4.5 (A) : Average effect of moisture regimes, levels and sources of F and FVM on the DTPA - extractable Mn in soil

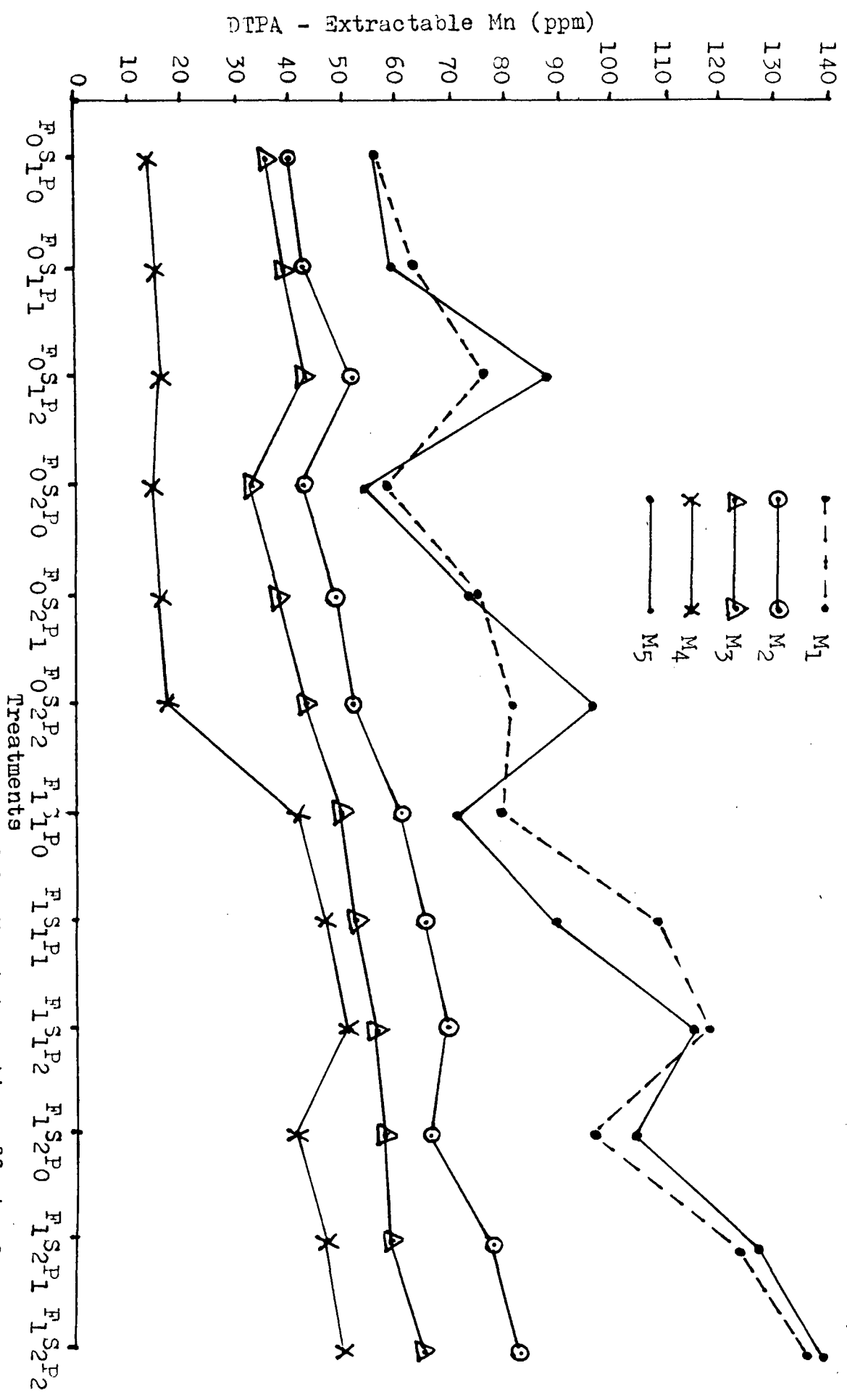


Fig. 4.5 (B) : DTPA - extractable Mn in soil as influenced by the interaction effect of moisture regimes, levels and sources of P and FYM

Such a high increase in the availability of Mn in the soil due to high moisture level has been indicated by various workers (Mandal, 1961; Pathak et al., 1972; Subrahmanyam and Mehta, 1975; Mandal and Haldar, 1980; Chatterjee et al., 1983; Bandyopadhyay and Bandyopadhyay, 1984 and Vekaria, 1985).

#### 4.5.2 Effect of levels and sources of phosphorus :

Phosphorus application showed a significant effect in raising the DTPA-extractable Mn content in the soil over no P. There was a significant increase in the available Mn content with increase in the level of P application. In general, the treatment which received 9.74 ppm P (50 kg  $P_2O_5$ /ha) produced on an average 72.37 ppm of available Mn content followed by  $P_1$  (63.86 ppm) and  $P_0$  (53.36 ppm). Thus, the phosphorus application @ 25 and 50 kg  $P_2O_5$ /ha resulted in increasing the DTPA-extractable Mn content of the soil by 19.7 and 35.6 per cent, respectively over control. However, the increase was only by 13.3 per cent when phosphorus application was increased from 25 to 50 kg  $P_2O_5$ /ha

Similarly, the effect of source of P application was also found to be significant. The data revealed that the available Mn content was significantly increased when the P application was made through  $S_2$  source (diammonium phosphate) than that of the  $S_1$  source (dicalcium phosphate).

There was also a significant effect of P x S interaction on the available Mn content in the soil as is revealed from the data given in Table 4.5. Treatment combination  $P_2S_2$  produced maximum available Mn in the soil (76.30 ppm), while it was minimum (49.99 ppm) under  $P_0S_1$ .

In general,  $S_2$  treatment raised the available Mn content from 59.18 to 67.12 ppm (3.5 %). This showed the favourable effect of  $S_2$  (DAP) source in increasing the available Mn content in the soil. The average effect of various treatments of Mn availability is also graphically depicted in Fig. 4.5 (A).

The increased availability of DTPA-extractable Mn with phosphorus application can be attributed to the fact that formation of manganous phosphate which does not permit the oxidation of  $Mn^{+2}$  to higher oxides (Mandal, 1961). Pathak *et al.* (1972) also reported increased availability of P and Mn at increasing levels of soil fertility under submerged conditions. They also recorded significant positive correlation between available soil P and Mn. Low availability of Mn with dicalcium phosphate may be due to some adsorption of Mn on the surface hydroxyapatite (DCP) (Anand Swarup, 1979).

#### 4.5.3 Effect of farm yard manure :

The effect of FYM application on the DTPA-extractable Mn content in the soil was found to be significant. The treatment with FYM (13.5 t/ha) increased the available

Mn content in the soil from 59.18 to 67.21 ppm. This increase was 13.6 per cent higher over no FYM. The treatments with higher level of P application with FYM had a significant effect in increasing the availability of Mn content in the soil as compared to the lower level of P application (Table 4.5).

The significant effect of P x F interaction also indicated that the minimum available Mn content was observed with  $P_0F_0$  (39.92 ppm) treatment combination which increased upto 88.17 ppm under  $P_2F_1$ . This showed that the increase was even more than double due to FYM and phosphorus application. This is due to their positive effects on the availability of Mn in the soil.

Interaction between FYM and sources of P on DTPA-extractable Mn in soil was found to be significant. Maximum (84.8 ppm) available Mn in soil was noted when the P was applied through DAP in presence of FYM. While it was minimum (46.8 ppm) when the P applied through DCP in absence of FYM. This clearly indicated the superiority of FYM in combination with DAP over DCP for the availability of Mn in soil.

The interaction effect of various treatments is also graphically depicted in Fig. 4.5(B). It clearly showed that the availability of Mn was higher under  $F_1S_2P_2$  treatment combination particularly at higher moisture level over

control. Effect of organic matter on the increased availability of Mn can be attributed to its effect on the reduction in pH (Table 4.1). A high positive correlation between organic matter content and extractable Mn has also been reported by several workers (Khetawat and Vashishtha, 1977; Misra and Pande, 1975; Misra and Pandey, 1976; Misra et al., 1976 and Vittal and Gangawar, 1974).

#### 4.6 Effect of moisture regimes, levels and sources of P and FYM on the availability of Zn in the soil :

##### 4.6.1 Effect of moisture regimes :

The data on DTPA-extractable Zn in the soil due to various treatments are presented in Table 4.6. Significant effect of moisture regimes was observed on DTPA-extractable Zn content in the soil. As the soil moisture depleted from 40 to 10 per cent, the available Zn content increased significantly. With a higher moisture regime of 40 per cent ( $M_1$ ), the available Zn content was 0.49 ppm whereas the same was 0.70, 0.74 and 0.76 ppm with  $M_2$  (30 %),  $M_3$  (20 %) and  $M_4$  (10 %) moisture regimes, respectively. A significant increase in the available Zn content was also observed with  $M_5$  (rewetting) treatment (0.52 ppm) over  $M_1$  only. Thus, with the depletion in moisture from 40 to 30, 20 and 10 per cent, the availability of Zn content was increased to the tune of 42.9, 51.0 and 55.1 per cent at  $M_2$ ,  $M_3$  and  $M_4$  moisture regimes, respectively. However, at  $M_5$  level (rewetting) the available Zn content was increased by 6.1 per cent over  $M_1$  (40 %).

Table 4.6 : Effect of moisture regimes, levels and sources of phosphorus and FYM on the availability of Zn (ppm) in the soil (oven dry basis)

Levels of Moisture	F <sub>0</sub>			F <sub>1</sub>			Levels of Moisture					S.E.m. ±	C.D. at 5 %
	S <sub>1</sub>	S <sub>2</sub>	Mean	S <sub>1</sub>	S <sub>2</sub>	Mean	M <sub>1</sub>	M <sub>2</sub>	M <sub>3</sub>	M <sub>4</sub>	M <sub>5</sub>		
M <sub>1</sub>	P <sub>0</sub>	0.34	0.43	0.38	0.69	0.73	0.71	0.55	0.73	0.78	0.81	0.56	0.69
	P <sub>1</sub>	0.31	0.39	0.35	0.57	0.66	0.61	0.48	0.69	0.73	0.76	0.51	0.63
	P <sub>2</sub>	0.29	0.37	0.33	0.55	0.63	0.59	0.46	0.66	0.70	0.72	0.48	0.60
	Mean	0.31	0.39	0.35	0.60	0.67	0.63	0.49	0.70	0.74	0.76	0.52	0.64
M <sub>2</sub>	P <sub>0</sub>	0.57	0.68	0.62	0.84	0.84	0.84						
	P <sub>1</sub>	0.52	0.64	0.58	0.81	0.81	0.81						
	P <sub>2</sub>	0.48	0.61	0.54	0.79	0.79	0.79						
	Mean	0.52	0.64	0.58	0.81	0.81	0.81						
M <sub>3</sub>	P <sub>0</sub>	0.63	0.69	0.66	0.86	0.93	0.90						
	P <sub>1</sub>	0.58	0.66	0.62	0.82	0.88	0.85						
	P <sub>2</sub>	0.55	0.63	0.59	0.80	0.84	0.82						
	Mean	0.59	0.66	0.62	0.83	0.88	0.85						
M <sub>4</sub>	P <sub>0</sub>	0.65	0.71	0.68	0.94	0.95	0.95						
	P <sub>1</sub>	0.60	0.68	0.64	0.85	0.92	0.88						
	P <sub>2</sub>	0.54	0.66	0.60	0.81	0.87	0.84						
	Mean	0.59	0.68	0.64	0.86	0.92	0.89						
M <sub>5</sub>	P <sub>0</sub>	0.34	0.46	0.40	0.70	0.75	0.73						
	P <sub>1</sub>	0.32	0.41	0.36	0.62	0.68	0.65						
	P <sub>2</sub>	0.30	0.39	0.34	0.60	0.65	0.63						
	Mean	0.31	0.42	0.37	0.64	0.69	0.67						
				P x F x S									
				P <sub>0</sub>	0.55	0.81	0.82						
				P <sub>1</sub>	0.51	0.73	0.76						
				P <sub>2</sub>	0.48	0.71	0.73						
				Mean	0.51	0.75	0.77						
				P x S									
				F <sub>0</sub>									
				F <sub>1</sub>	0.66	0.72	0.69	0.82	0.69				
				P <sub>1</sub>	0.60	0.67	0.63	0.76	0.63				
				P <sub>2</sub>	0.57	0.64	0.61	0.73	0.61				
				Mean	0.61	0.68	0.64	0.77	0.64				
				P x F									
				Moisture (M)				0.002	0.007				
				Source (S)				0.001	0.004				
				FYM (F)				0.001	0.004				
				Phosphorus (P)				0.002	0.005				
				M x S				0.003	NS				
				M x F				0.003	0.009				
				M x P				0.004	0.012				
				S x F				0.002	0.006				
				S x P				0.003	0.007				
				F x P				0.003	0.007				
				C. V. %				1.807					

The average values of Zn availability due to moisture regimes are also graphically given in Fig. 4.6 (A).

Interaction of M x S on availability of Zn was found to be non significant. Interaction of M x F on DTPA-extractable Zn was observed to be significant. From the data, it is clearly seen that at higher moisture regimes with FYM, the availability of Zn decreased, being maximum (0.89 ppm) with  $M_4F_1$  treatment and minimum (0.63 ppm) with  $M_1F_1$  treatment.

Interaction of M x P also had significant effect in decreasing the DTPA-extractable Zn content in the soil with the increase in P levels. There was a significant decrease in available Zn content for each level of moisture regimes, however, the maximum available Zn content was observed at each moisture regime under  $P_0$  followed by  $P_1$  and  $P_2$  levels.

An increase in the DTPA-extractable Zn in the soil with the depletion of moisture may probably be due to the favourable conditions provided for the conversion of less soluble Zn compounds into a soluble one. Mineralization of Zn-organic complexes also may probably have helped in increasing availability of Zn in the soil. According to Ponnampereuma (1972) and Patrick and Reddy (1977), the decrease in the Zn content in soil at higher moisture level is due to accumulation of  $CO_2$  which could result

in the formation of highly insoluble compounds like  $ZnCO_3$  and  $ZnS$ . Similar observation has also been made by Brar and Sekhon (1976), Haldar and Mandal (1979), Singh et al. (1983) and Vekaria (1985). The present study has also revealed that increased availability of P and Fe at higher soil moisture level can interact with Zn and reduced its availability (Halagur et al., 1975 a; Subrahmanyam and Mehta, 1975 and Patra et al., 1981).

#### 4.6.2 Effect of levels and sources of phosphorus :

The data revealed (Table 4.6) that the effect of P application on DTPA-extractable Zn content was found to be significant. In general, increasing level of P application produced the antagonistic effect on the availability of Zn content in the soil. The significant decrease in the value of available Zn content was from 0.69 ppm ( $P_0$ ) to 0.63 and 0.61 ppm with the treatments  $P_1$  and  $P_2$ , respectively. The decrease was more pronounced with  $P_1$  treatment (0.63 ppm) over control (0.69 ppm) than that of  $P_2$  (0.61 ppm) over  $P_1$  treatment (0.63 ppm).

Effect of P source in DTPA-extractable Zn content in soil was also found to be significant. The availability of Zn (0.68 ppm) was significantly higher (11.5 %) with diammonium phosphate ( $S_2$ ) than that of dicalcium phosphate (0.61 ppm).

The data given in Table 4.6 revealed that the effect of P x S interaction on DTPA-extractable Zn in soil

was found to be significant. The  $P_0S_2$  treatment combination produced the maximum available Zn content (0.72 ppm) whereas the minimum (0.57 ppm) was observed with  $P_2S_1$  treatment combination. The average effects of levels and sources of P are also graphically given in Figs. 4.6(A) and 4.6 (B). Thus, the data clearly indicated that the antagonistic effect of P on DTPA-extractable Zn content could be significantly reduced by its application through diammonium phosphate instead of dicalcium phosphate at each level of P.

The decreased availability of Zn in the soil with increase in P levels could be attributed to the formation of insoluble zinc phosphate compound. Similar results have also been reported by several research workers (Kalyansundram and Mehta, 1970; Sharma and Meelu, 1975 and Deb and Ziliang, 1976).

#### 4.6.3 Effect of farm yard manure :

The effect of FYM application on DTPA-extractable Zn in soil was also found to be significant as reported in Table 4.6. Farm yard manure application @ 13.5 t/ha produced significantly higher DTPA-extractable Zn content (0.77 ppm) in soil than that of no FYM (0.51 ppm). Thus, FYM application had a pronounced effect in increasing (51.0 %) the available Zn content in the soil.

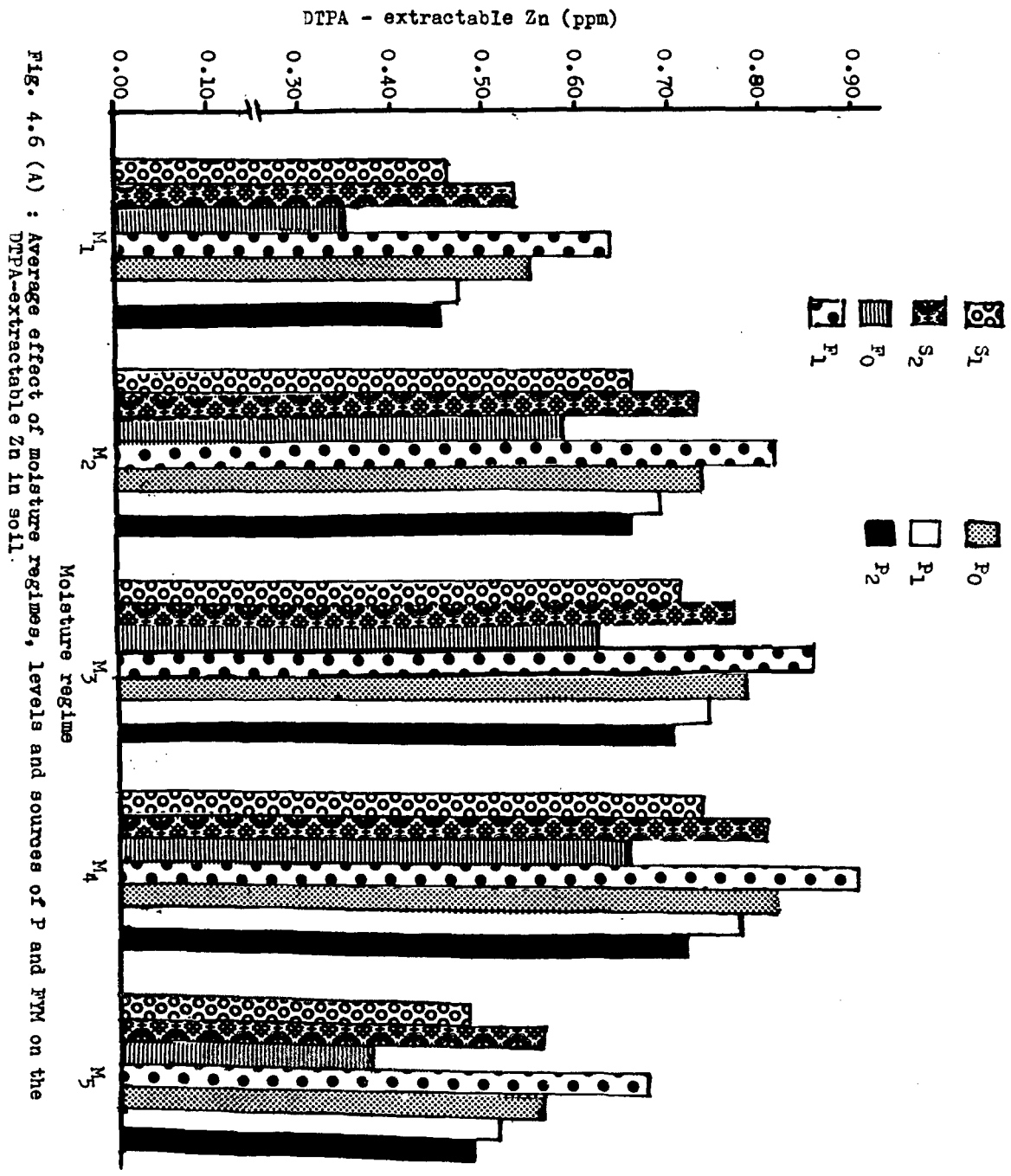


Fig. 4.6 (A) : Average effect of moisture regimes, levels and sources of P and FYM on the DTPA-extractable Zn in soil.

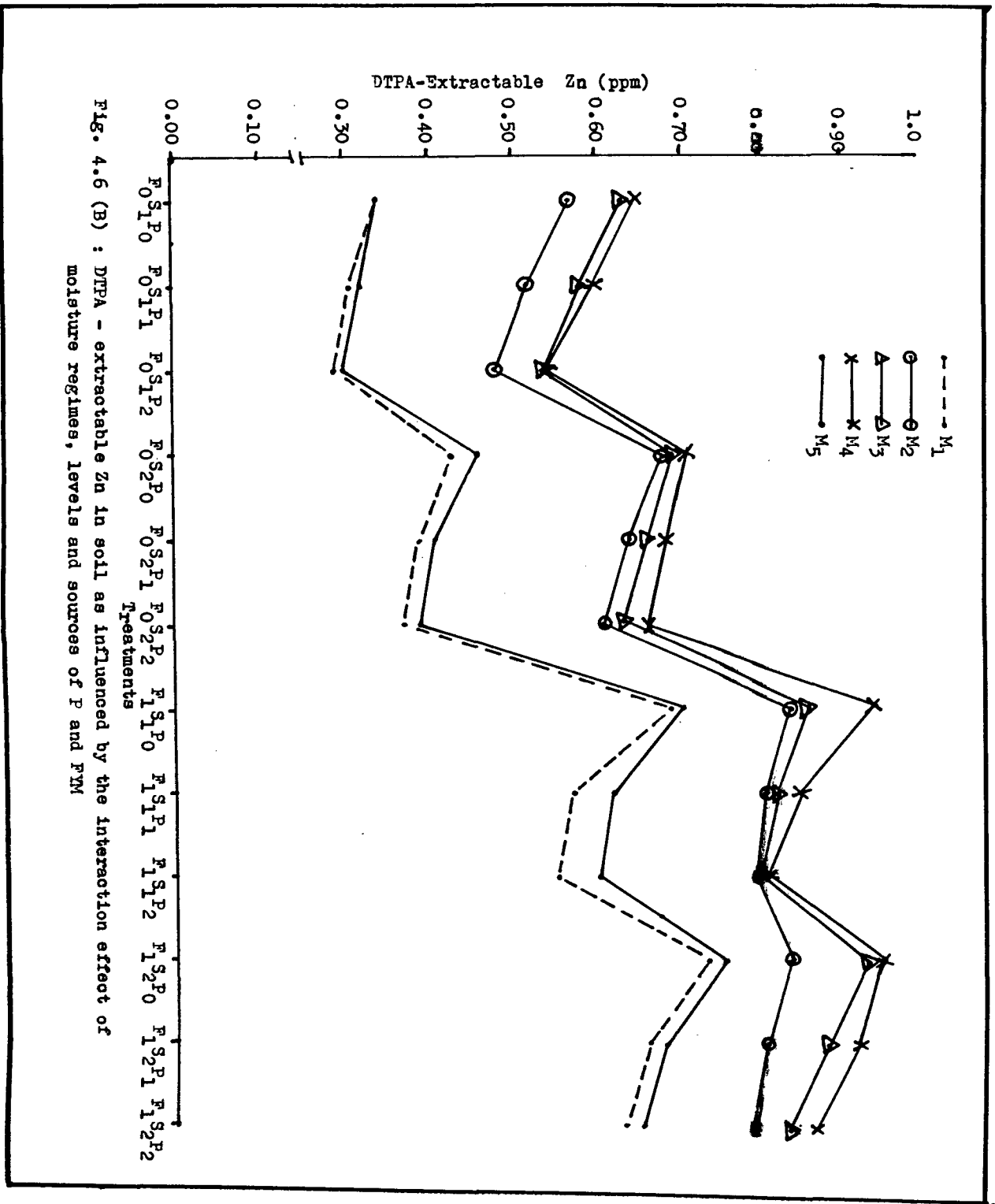


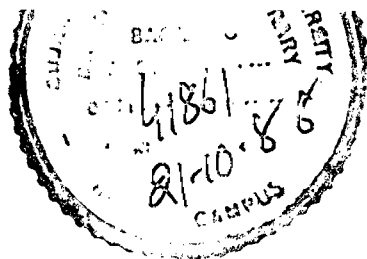
FIG. 4.6 (B) : DTPA - extractable Zn in soil as influenced by the interaction effect of moisture regimes, levels and sources of P and P<sub>2</sub>M

Interaction of FYM with phosphorus application on DTPA-extractable Zn in soil was also found to be significant. The treatment with FYM and without phosphorus application ( $P_0F_1$ ) produced the maximum available Zn content (0.82 ppm) and it was minimum (0.48 ppm) under  $P_2F_0$  treatment combination and the decrease in the available Zn content with  $P_2F_0$  treatment was ~~by~~ 70.8 per cent. Thus, the data given in Table 4.6 clearly indicated the beneficial effect of FYM application even in presence of phosphorus (at each level) in increasing the availability of DTPA-extractable Zn in the soil.

Interaction of FYM with phosphorus application through different sources on DTPA-extractable Zn was observed to be significant. Higher values of available Zn in soil were observed when phosphorus was applied through DAP in presence or absence of FYM over that of DCP.

The interaction effect of various treatments on Zn availability is also depicted graphically in Fig. 4.6 (B). Higher values of Zn availability were observed with FYM application in absence of P, irrespective of moisture levels.

This could be attributed to its effect in lowering the pH of the soil (Table 4.1) and thereby increasing the availability of Zn in the soil. A high positive correlation between organic matter content and extractable Zn content has also been reported by several workers (Shrivastava and Sethi, 1981; Kanwar et al., 1984; Sakal et al., 1985, 1986 and Hansraj, 1986).



#### 4.7 Effect of moisture regimes, levels and sources of P and FYM on the availability of Cu in the soil :

##### 4.7.1 Effect of moisture regimes :

The data on DTPA-extractable Cu in soil due to various treatments are given in Table 4.7. DTPA-extractable Cu in the soil was significantly affected by the moisture regimes as is clearly seen from the data (Table 4.7). The results revealed that the increasing levels of moisture regimes upto 30 per cent had significant effect in increasing the available Cu content in the soil. The soil kept at  $M_2$  (30 %) level produced the maximum available Cu content (2.56 ppm) followed by 2.12, 2.02, 1.96 and 1.67 ppm under  $M_5$  (rewetting),  $M_1$  (40 %),  $M_3$  (20 %) and  $M_4$  (10 %) treatments, respectively. This has further indicated that the reduction in moisture content i.e. from 30 to 20 and 10 per cent decreased the available Cu content by 30.6 and 53.3 per cent, respectively, whereas the same with  $M_5$  (rewetting) and  $M_1$  (40 %) moisture regimes it was 20.8 and 26.7 per cent, respectively. It is also seen from the Fig. 4.7(A), the availability of Cu was maximum at  $M_2$  moisture level (30 %) irrespective of any type of treatment.

The interaction of M x P on DTPA-extractable Cu in soils was also found to be significant (Table 4.7). The data in general, revealed that the treatment with higher moisture regimes upto 30 per cent in absence of P application produced significantly higher available Cu content in

Table 4.7 : Effect of moisture regimes levels and sources of phosphorus and FYM on the availability of Cu (ppm) in the soil (oven dry basis)

Levels of moisture	F <sub>0</sub>			F <sub>1</sub>			Levels of moisture					
	S <sub>1</sub>	S <sub>2</sub>	Mean	S <sub>1</sub>	S <sub>2</sub>	Mean	M <sub>1</sub>	M <sub>2</sub>	M <sub>3</sub>	M <sub>4</sub>	M <sub>5</sub>	Mean
M <sub>1</sub>	1.95	1.71	1.83	2.62	2.62	2.62	2.23	2.97	2.18	1.89	2.37	2.33
	1.75	1.68	1.71	2.50	2.48	2.48	2.10	2.52	1.98	1.64	2.12	2.07
	1.31	1.30	1.31	2.16	2.16	2.16	1.73	2.19	1.74	1.49	1.86	1.80
Mean	1.67	1.56	1.62	2.43	2.42	2.42	2.02	2.56	1.96	1.67	2.12	2.07
M <sub>2</sub>	2.30	2.68	2.49	3.50	3.41	3.46						
	2.06	2.45	2.26	3.01	2.56	2.78						
	1.86	2.30	2.08	2.30	2.32	2.31						
Mean	2.07	2.48	2.28	2.93	2.76	2.85						
M <sub>3</sub>	2.12	1.92	2.02	2.37	2.30	2.34						
	1.91	1.73	1.82	2.16	2.13	2.14						
	1.56	1.62	1.59	1.88	1.90	1.89						
Mean	1.86	1.75	1.81	2.14	2.11	2.13						
M <sub>4</sub>	1.85	1.83	1.84	1.97	1.94	1.95						
	1.54	1.51	1.52	1.74	1.80	1.77						
	1.40	1.30	1.35	1.55	1.69	1.62						
Mean	1.60	1.55	1.58	1.75	1.81	1.78						
M <sub>5</sub>	2.03	2.23	2.13	2.68	2.51	2.61						
	1.92	2.06	1.99	2.28	2.23	2.26						
	1.42	1.80	1.61	2.09	2.12	2.10						
Mean	1.79	2.03	1.91	2.35	2.29	2.32						
	2.05	2.07	2.06	2.63	2.56	2.59						
	1.83	1.89	1.86	2.34	2.24	2.29						
	1.51	1.66	1.59	2.00	2.04	2.02						
Mean	1.80	1.87	1.84	2.32	2.28	2.30						
	2.34	2.32	2.33	2.06	2.59	2.33						
	2.08	2.06	2.07	1.86	2.29	2.07						
	1.75	1.85	1.80	1.59	2.02	1.80						
Mean	2.06	2.08	2.07	1.84	2.30	2.07						

		S.E.M. ±		C.D. at 5 %	
Moisture (M)		0.025		0.07	
Source (S)		0.016		NS	
FYM (F)		0.016		0.044	
Phosphorus (P)		0.019		0.054	
M x S		0.035		0.099	
M x F		0.035		0.099	
M x P		0.043		0.121	
S x F		0.022		0.063	
S x P		0.027		0.077	
F x P		0.027		NS	
C.V. %		5.86			

the soil than the treatments  $M_1$ ,  $M_3$  and  $M_4$  alongwith higher level of P application. The maximum available Cu content observed with  $M_2P_0$  (2.97 ppm) was significantly higher (about double) than the minimum with  $M_4P_2$  treatment (1.49 ppm). The interaction of M x S on DTPA-extractable Cu in soil was found to be significant. The maximum available Cu content in soil was noticed with  $M_2S_2$  treatment combination (2.62 ppm) and minimum with  $M_4S_1$  (1.67 ppm) treatment. The adverse effect of phosphorus on the availability of Cu in the soil could be explained on the basis of their antagonistic behaviour.

Interaction effect of moisture with other treatments on the availability of Cu is also graphically depicted in Fig. 4.7(B). Availability of Cu was slightly higher in presence of DAF as compared to that with DCP. Maximum availability of Cu was found at 30 per cent moisture level irrespective of levels and sources of P application.

An increase in the DTPA-extractable Cu in the soil due to depletion of moisture may probably be due to the favourable conditions provided for conversion of less soluble Cu compounds into a soluble one. Mineralization of Cu-chelates also may probably have helped in increasing the availability of Cu in the soil. Kanagaraj and Ramanathan (1980) observed that low moisture regimes as 70 per cent depletion of ASM recorded significantly higher value of Cu (1.31 ppm) as

compared to 50 per cent depletion of ASM (0.51 ppm). Similarly Rahmatullah et al. (1976), noted strong enhancement in the availability of Cu in Hafizabad soil upon drying. The decrease in available Cu in soil at higher moisture level has been attributed to formation of highly insoluble compounds like  $\text{CuCO}_3$  and  $\text{CuS}$  (Halidar and Mandal, 1979) and microbial immobilization or antagonistic effect of increased concentration of Fe and Mn (Chatterjee et al., 1983). Similar results were also reported by Vekaria (1985).

#### 4.7.2 Effect of levels and sources of phosphorus :

Significant effect of phosphorus application was observed on DTPA-extractable Cu content in the soil (Table 4.7). The data showed that the effect was significant in decreasing the available Cu content with the increase in phosphorus levels. Application of phosphorus at  $P_1$  (4.87 ppm) and  $P_2$  (9.74 ppm) levels decreased the available Cu content by 12.3 and 29.2 per cent over  $P_0$ , respectively. This is also graphically shown in Fig. 4.7 (A).

Although the phosphorus application had antagonistic effect on DTPA-extractable Cu content in the soil, its source of application was found to be non significant (Table 4.7). The available Cu contents in soil with  $S_1$  (dicalcium phosphate) and  $S_2$  (diammonium phosphate) were 2.06 and 2.08 ppm, respectively. While the source of P application was found to be non significant, its interaction with the levels

of P (P x S) had significant effect on DTPA-extractable Cu content in the soil (Table 4.7). The results showed that the maximum available Cu content (2.34 ppm) in the soil was observed at  $P_0$  over rest of the treatment combinations. The increase in level of P application irrespective of its source, resulted in significant decrease in the available Cu content in the soil. However, the decrease was significantly higher at  $F_2$  level (1.75 ppm) when applied through  $S_1$  (dicalcium phosphate) source than that made through  $S_2$  (diammonium phosphate) source (1.85 ppm).

Interaction effect of P x S in absence or presence of FYM is also graphically depicted in Fig. 4.7(B). It is seen from the Figure that availability of Cu was slightly higher in presence of DAP ( $S_2$ ) as compared to that with DCP ( $S_1$ ) in presence or absence of FYM.

The decrease in the DTPA-extractable Cu content in the soil with the phosphorus application could be attributed to the precipitation of Cu as insoluble copper phosphate. These results are well corroborated with the findings of Hulagur et al. (1975 b) and Badamur and Venkata Rao (1973).

#### 4.7.3 Effect of farm yard manure :

Application of FYM was found to be significant in increasing the DTPA-extractable Cu content in the soil (Table 4.7). Application of FYM @ 13.5 t/ha raised the available Cu content in the soil from 1.34 ppm ( $F_0$ ) to

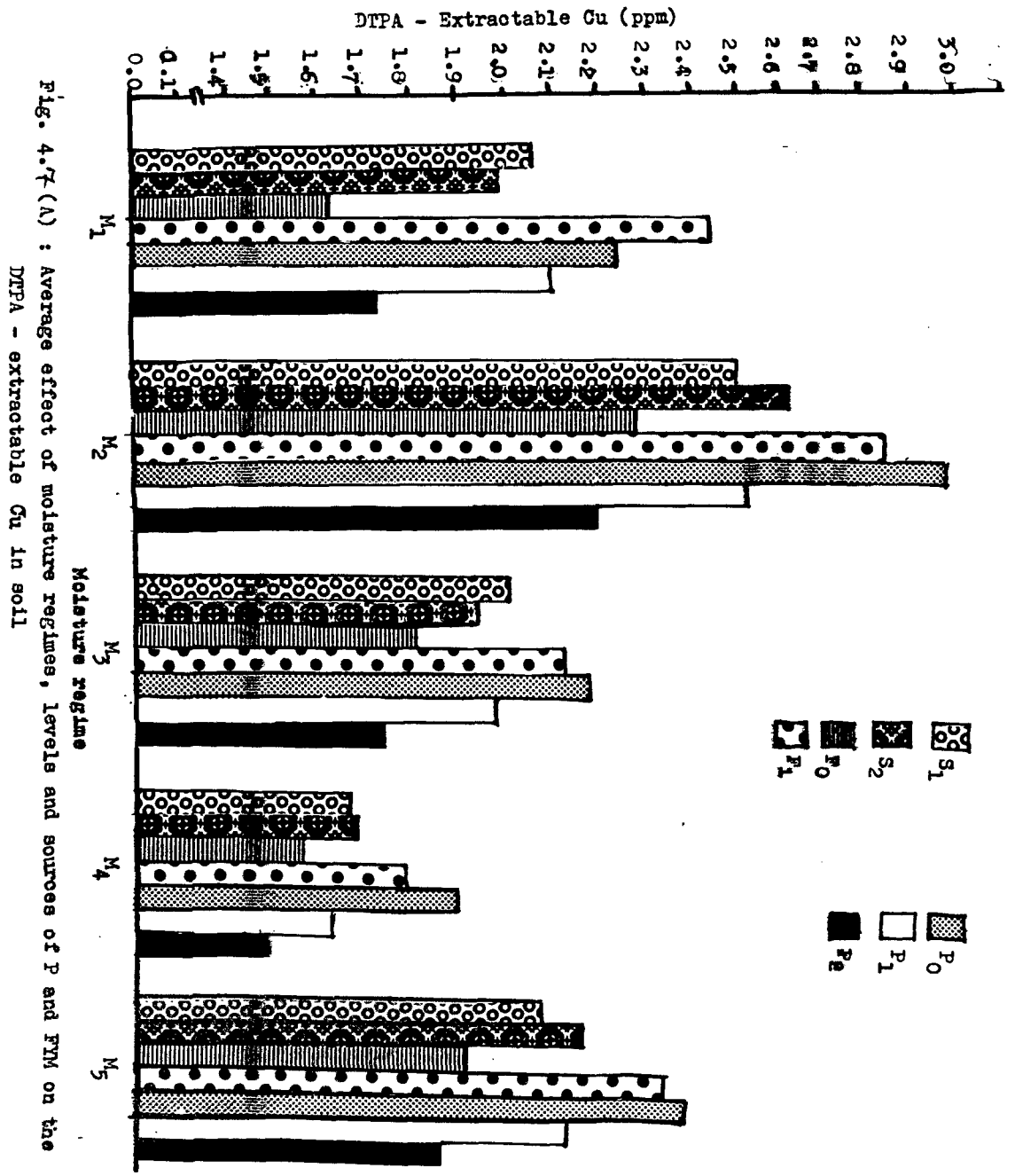


Fig. 4.7 (A) : Average effect of moisture regimes, levels and sources of P and FYM on the DTPA - extractable Cu in soil

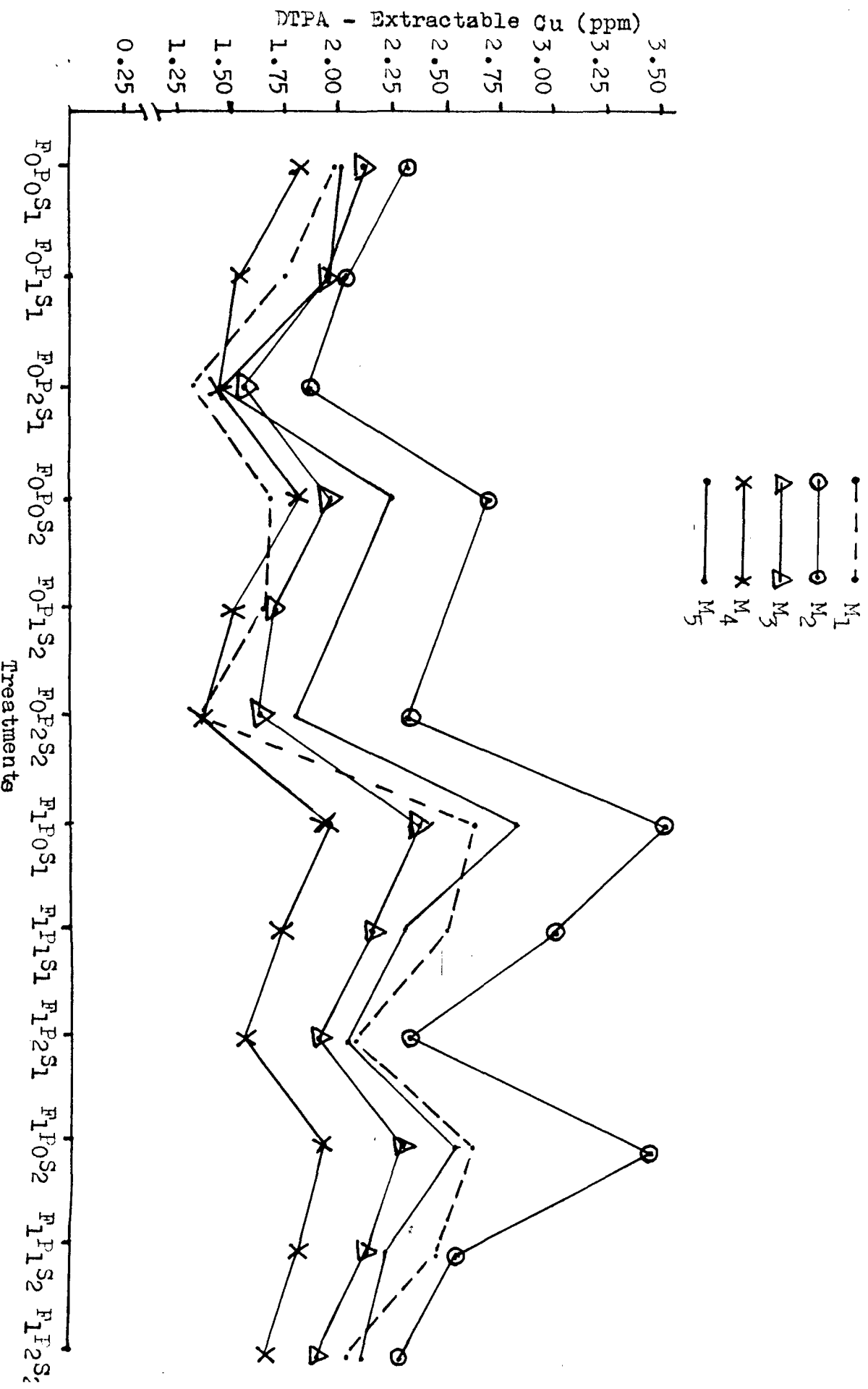


Fig. 4.7 (B) : ~~DTPA~~ - extractable Cu in soil as influenced by the interaction effect of moisture regimes, levels and sources of P and FYM

2.30 ppm ( $F_1$ ) i.e., by 25.0 per cent over  $F_0$ . The role of F x M in increasing the availability of Cu can also be seen from the Fig. 4.7(B). The effect was more pronounced at 30 per cent moisture level.

The interaction of FYM with moisture levels on DTPA-extractable Cu in soil was also found to be significant (Table 4.7). In general, higher values of available Cu at each moisture level were observed with FYM application (13.5 t/ha) as compared to treatments under no FYM. The maximum value of available Cu was observed with  $M_2F_1$  (2.85 ppm), and minimum with  $M_4F_0$  (1.57 ppm). This showed the beneficial effect of FYM in increasing the availability of Cu at higher moisture regimes upto 30 per cent.

The interaction between F x S on DTPA-extractable Cu in soil was found to be significant. The maximum DTPA-extractable Cu content in soil was observed with  $S_1F_1$  (2.32 ppm) and minimum with  $S_1F_0$  (1.80 ppm). It clearly indicated the beneficial effect of FYM in presence of dicalcium phosphate instead of diammonium phosphate in increasing the availability of Cu in soil.

The results also revealed that the interaction of F x P on DTPA-extractable Cu in soil was found to be non significant. The maximum availability of Cu was noted with  $F_1P_0$  (2.59 ppm) and minimum with  $F_0P_2$  (1.59 ppm).

Interaction effect of FYM with other treatments on the availability of Cu is also graphically depicted in Fig. 4.7(B). In general, application of FYM helped in reducing the adverse effect of phosphorus on the availability of Cu in soil and thereby maintained it at higher level.

The increase in the DTPA-extractable Cu in the soil with the application of FYM may be due to the mobilization of insoluble Cu compounds by organic acids produced during the decomposition of FYM. Reduction in pH value (Table 4.1) due to FYM application might have helped in increasing the availability of Cu in the soil. A significant positive correlation between organic matter content and extractable Cu has been reported by several workers (Brar et al., 1982; Khetawat and Vashishtha, 1977; Misra and Fande, 1975, 1976 and Misra et al., 1976).

**SUMMARY  
&  
CONCLUSION**

## V. SUMMARY AND CONCLUSION

With a view to evaluating the effect of different moisture regimes (40, 30, 20, 10 and 40 (rewetting) per cent) simulated due to depletion in moisture from flooded soil and again rewetting in presence (13.5 t/ha)/absence of FYM and different levels of P (4.87 and 9.74 ppm P) applied through DAP and DCP on the availability pattern of P, K, Fe, Mn, Zn, Cu and also the changes in pH in a clay loam soil of wheat-growing area (Bhal), the present investigation was undertaken by conducting a laboratory incubation study during the year 1987. The important findings of the present study are summarised below :

### 4.1 Effect of moisture regimes and FYM on soil pH :

The study revealed that pH value increased when moisture was depleted from 40 ( $M_1$ ) to 10 ( $M_4$ ) per cent. The overall increase in soil pH value due to various moisture regimes was from 7.54 to 7.57, 7.61 and 7.66 under  $M_2$ ,  $M_3$  and  $M_4$ , respectively. Application of FYM markedly decreased the soil pH from 7.73 to 7.40. No much difference in soil pH was observed between  $M_1$  (40 %) and  $M_5$  (40 % - rewetting). Similarly application of phosphorus did not show any marked effect on soil pH.

### 4.2 Effect of moisture regimes, levels and sources of P and FYM on the availability of P in the soil :

The availability of P in the soil was significantly decreased when the moisture was depleted from 40 to 10

per cent. It resulted in as high as 72.9 per cent decrease in the P availability in soil. Similarly the decrease in value in P at  $M_2$  (20 %) and  $M_3$  (30 %) was 26.2 and 51.3 per cent, respectively. The effect of  $M_1$  (9.68 ppm P) and  $M_5$  (9.63 ppm P) on the availability of P content in the soil was at par. Interaction effect of M x P showed that, with the increase in levels of P application, the available P content was significantly enhanced over  $P_0$  at each moisture regimes. However, with the depletion in moisture under each level of P application, the availability of P was decreased.

There was increase of available P content in the soil with the increase in level of P application over control. The maximum P availability (10.0 ppm) was observed with  $P_2$  treatment followed by  $P_1$  (8.01 ppm) and  $P_0$  (5.38 ppm). The increase was as high as 48.9 and 85.9 per cent under  $P_1$  and  $P_2$  treatments over  $P_0$ , respectively. When phosphorus application was made through DAP, the available P content of soil was found significantly higher than that of DCP. The increase in the available P content with DAP (8.58 ppm) was 22.2 per cent higher as compared to DCP (7.02 ppm). Interaction effect of P x S showed the maximum available P content with  $S_2P_2$  treatment combination (11.11 ppm) which was significantly higher (more than double) over rest of the treatments. It is interesting to note that

the availability of P increased to the tune of 79.8 ( $P_1$ ) and 70.0 ( $P_2$ ) per cent when P was applied through DCP alongwith FYM, whereas in case of DAP, the values for the same increased further to the extent of 109.3 ( $P_1$ ) and 93.8 ( $P_2$ ) per cent. In general, the per cent availability of P was higher at higher moisture regimes, and it decreased with the depletion in moisture from 40 to 10 per cent. Data also revealed that at higher moisture regimes in presence of FYM resulted in more than 100 per cent P availability. This means FYM helped in preventing the P fixation and even releasing the native P in the soil.

Application of FYM @ 13.5 t/ha significantly increased the available P content (10.81 ppm) in the soil over no FYM (4.79 ppm). The interaction effect of F x P showed the significantly higher P availability at all the levels of P application alongwith FYM than that of P without FYM. The increase was more than double with  $P_1F_1$  (11.22 ppm P) and about three times more with  $P_2F_1$  (14.59 ppm P) treatments over that of  $P_1F_0$  (4.80 ppm P) and  $P_2F_0$  (5.40 ppm P), respectively. Further, the availability of P was significantly increased (58.9 %) with only FYM application (6.61 ppm P) over no FYM (4.16 ppm P).

#### 4.3 Effect of moisture regimes, levels and sources of P and FYM on the availability of K in the soil :

The availability of K in the soil decreased significantly by 5.1, 20.3 and 34.9 per cent with the depletion

in moisture from 40 (340.1 kg/ha) to 30 (323.6 kg/ha), 20 (282.7 kg/ha) and 10 (252.1 kg/ha) per cent, respectively. However, the availability of K under  $M_1$  and  $M_5$  was at par. The interaction effect of  $M \times S$  showed the maximum availability of K (341.2 kg/ha) under  $M_1S_1$  which was significantly higher over  $M_4S_1$  treatment (250.5 kg/ha). Similarly in case of  $M \times F$  interaction, application of FYM significantly increased the available K content in the soil at all the moisture levels. However, the availability of K under  $M_1F_1$  and  $M_5F_1$  treatments was significantly higher over rest of the treatments.

Application of P significantly increased the availability of K in the soil. However, the increase was very meagre, being 2.2 and 4.1 per cent with  $P_1$  (4.87 ppm) and  $P_2$  (9.74 ppm) <sup>levels</sup> respectively.

Application of FYM @ 13.5 t/ha (323.6 kg/ha) significantly increased (11.3 %) the availability of K in the soil than that of no FYM (290.7 kg/ha). The availability of K in the soil was also significantly increased with FYM application at all the levels of P over no FYM treatments. The maximum K availability with  $P_2F_1$  was 330.7 kg/ha and minimum under  $P_0F_0$  (286.5 kg/ha). The interaction effect of  $F \times S$  showed the maximum available K under  $F_1S_1$  (325.4 kg/ha) which was significantly higher over  $F_0S_2$  (289.3 kg/ha).

4.4 Effect of moisture regimes, levels and sources of P and FYM on the availability of Fe in the soil :

Moisture regime  $M_1$  (40 %) produced on an average 17.11 ppm of DTPA-extractable Fe content in the soil which was significantly higher than rest of the moisture regimes i.e.  $M_2$  (13.43 ppm),  $M_3$  (11.93 ppm),  $M_4$  (10.05 ppm) and  $M_5$  (16.08 ppm). Thus, it indicated that with the depletion in soil moisture from 40 to 30, 20 and 10 per cent, the decrease in available Fe was 27.4, 43.4 and 70.2 per cent, respectively.

With the increase in levels of P application, a significant decrease in the DTPA-extractable Fe was observed. The decrease was 9.1 and 18.8 per cent with  $P_1$  (4.87 ppm) and  $P_2$  (9.74 ppm) levels, respectively over  $P_0$ . Application of P made through DAP produced significantly higher available Fe (13.88 ppm) than that of DCP (13.56 ppm).

Application of FYM (13.5 t/ha) produced significantly higher (43.9 %) DTPA-extractable Fe (16.19 ppm) over no FYM (11.25 ppm). The interactions of P x F and M x F had significant effect on DTPA-extractable Fe content in soil, while the interaction of F x S was found to be non significant. The maximum available Fe content (17.61 ppm) was produced under  $P_0F_1$  whereas the minimum (10.27 ppm) under  $P_2F_0$ . Similarly the maximum availability of Fe in the soil was observed under  $M_1F_1$

treatment (21.35 ppm) which was significantly higher over  $M_4F_0$  (9.63 ppm).

#### 4.5 Effect of moisture regimes, levels and sources of P and FYM on the availability of Mn in the soil :

A significant decrease in the DTPA-extractable Mn was observed with the decrease in moisture regimes from 40 to 10 per cent. The moisture regime  $M_1$  (40 %) produced the maximum available Mn content (88.44 ppm) followed by  $M_2$  (58.14 ppm),  $M_3$  (47.85 ppm) and  $M_4$  (31.24 ppm) treatments. Thus, depletion in moisture regimes from 40 to 30, 20 and 10 per cent resulted in reduction of available Mn in soil by 52.1, 85.9 and 183.1 per cent, respectively. Interaction between M and F as well as M x S was found to be significant, in respect of DTPA-extractable Mn content in the soil. The treatment combination  $M_5P_2$  gave the maximum available Mn content (109.83 ppm) in the soil, whereas the lowest value was observed under  $M_4P_0$  (28.34 ppm). Similarly treatment combination  $M_5S_2$  exhibited maximum (99.1 ppm) available Mn in the soil which was significantly higher over the minimum value (31.2 ppm) observed with  $M_4S_1$  treatment. This indicated the superiority of DAF over DCP on availability of Mn in the soil irrespective of moisture levels. In case of M x F interaction, the significantly highest (109.9 ppm) available Mn in the soil was observed at  $M_1F_1$ , while it was the lowest (15.8 ppm) at  $M_4F_0$ .

There was a significant increase in the available Mn content with increase in the level of P application. In general, the treatment which received 9.74 ppm P ( $P_2$ ) produced on an average 72.37 ppm of available Mn followed by  $P_1$  (63.86 ppm) and  $P_0$  (53.36 ppm), this means 19.7 and 35.6 per cent increased over control. The available Mn was significantly increased when the P application was made through DAP ( $S_2$ ) than that of DCP ( $S_1$ ). In general  $S_2$  treatment raised (3.5 %) the available Mn content from 59.18 to 67.12 ppm. Interaction of  $P_2 \times S_2$  produced maximum available Mn in the soil (76.30 ppm) which was significantly higher over the minimum value (49.99 ppm) under  $P_0S_1$ .

Application of FYM (13.5 t/ha) significantly increased the available Mn content in the soil from 59.18 to 67.21 ppm i.e. 13.6 per cent higher over no FYM. The treatments with higher level of P application in presence of FYM had a significant effect in increasing the availability of Mn in the soil as compared to the lower level of P application. The maximum value (88.17 ppm) of available Mn was observed under  $P_2F_1$  which was significantly higher (more than double) over the minimum value (39.92 ppm) with  $P_0F_0$  treatment. Interaction of F x S showed the maximum available Mn in the soil (84.8 ppm) when P was applied through DAP ( $S_2$ ) in presence of FYM, which was significantly higher over  $S_1F_0$ .

#### 4.6 Effect of moisture regimes, levels and sources of P and FYM on the availability of Zn in the soil :

As the soil moisture depleted from 40 to 10 per cent, the DTPA-extractable Zn content was increased significantly. With the depletion in moisture from 40 to 30, 20 and 10 per cent, the availability of Zn was increased to the tune of 42.9, 51.0 and 55.1 per cent at  $M_2$ ,  $M_3$  and  $M_4$  moisture regimes, respectively. The interaction of  $M \times F$  showed maximum Zn availability (0.89 ppm) which was significantly higher over the minimum value (0.63 ppm) under  $M_1F_1$  treatment. Interaction of  $M \times P$  also had a significant effect in decreasing the Zn availability with increasing the P levels.

The DTPA-extractable Zn was significantly lower with the increase in levels of P application. The decrease was more pronounced with  $P_1$  (0.63 ppm) over control (0.69 ppm) than that of  $P_2$  (0.61 ppm) over  $P_1$  (0.63 ppm) treatment. The availability of Zn (0.68 ppm) was significantly higher (11.5 %) with DAP than that of DCP (0.61 ppm). Interaction effect of  $P \times S$  showed the maximum available Zn content (0.72 ppm) with  $P_0S_2$  which was significantly higher over the minimum value (0.57 ppm) under  $P_2S_1$  treatment.

Application of FYM (13.5 t/ha) produced significantly higher (51.0 %) DTPA-extractable Zn (0.77 ppm) in soil than that of no FYM (0.51 ppm). Interaction effect of

F x P showed the maximum Zn availability in soil (0.82 ppm) with  $P_0F_1$  which was significantly higher (70.8 %) than the minimum value (0.48 ppm) under  $P_2F_0$  treatment. Interaction of F x S showed the significantly higher values of available Zn in soil when P was applied through DAP in presence or absence of FYM over that of DCP.

#### 4.7 Effect of moisture regimes, levels and sources of P and FYM on the availability of Cu in the soil :

Depletion of soil moisture upto 30 per cent, significantly increased the DTPA-extractable Cu content in soil over rest of the moisture regimes. However, the values were at par for  $M_1$  and  $M_5$  (rewetting). The reduction in moisture content i.e. from 30 to 20 and 10 per cent decreased the available Cu content by 30.6 and 53.3 per cent, respectively. The interaction of M x P showed the maximum available Cu content with  $M_2P_0$  (2.97 ppm) treatment, which was significantly higher (about double) than the minimum with  $M_4P_2$  (1.49 ppm) treatment. Similarly the maximum available Cu in the soil was noted with  $M_2S_2$  treatment (2.62 ppm) which was significantly higher than the minimum with  $M_4S_1$  (1.67 ppm) treatment.

Application of phosphorus at  $P_1$  and  $P_2$  levels significantly decreased the DTPA-extractable Cu content in the soil by 12.3 and 29.2 per cent over  $P_0$ , respectively. Interaction effect of P x S showed that the availability of Cu

was significantly decreased at  $P_2$  level (1.75 ppm) when applied through DCP than that made through DAP (1.85 ppm).

Application of FYM (13.5 t/ha) significantly increased the DTPA-extractable Cu in soil from 1.84 ppm ( $F_0$ ) to 2.30 ppm ( $F_1$ ) i.e. by 25 per cent over  $F_0$ . Interaction effects of F x M and F x S were found to be significant. The maximum value of available Cu was observed with  $M_2F_1$  (2.85 ppm) and minimum with  $M_4F_0$  (1.57 ppm). Similarly in case of F x S interaction, the maximum available Cu content in soil was observed with  $F_1S_1$  (2.32 ppm) and minimum with  $F_0S_1$  (1.80 ppm).

The results of the present investigation clearly indicated that at higher moisture level, application of P through DAP alongwith FYM, tremendously influenced the availability behaviour of different nutrients, favourably in P and Zn deficient calcareous soil. The pattern of nutrient availability also remained more or less same on rewetting the treated soil. The findings could help us in the proper nutrition (*Kharrif*) of wheat crop which is generally grown (*Rabi*) under conserved moisture in (*Bhal*) area of Gujarat.

# BIBLIOGRAPHY

## REFERENCES

- \*Adhikari, M.S. and Ganguli, T.K. (1971). Agrokem Talajit. 20, 549. Read from Bull. Indian Soc. Soil Sci. 12, 1979.
- Ahmad, N. and Davis, C.E. (1970). Forms of potassium fertilizers and soil moisture content on potassium status of a Trinidad soil. Soil Sci., 109 : 121-126.
- Akbari, K.N.; Kanzaria, M.V. and Patel, M.S. (1981). Effect of phosphorus and lime application on phosphorus availability at varying periods and soil moisture conditions. J. Indian Soc. Soil Sci., 29 : 193-198.
- Anand Swarup (1979). Availability of manganese under moist and submerged conditions in sodic soil. J. Indian Soc. Soil Sci., 27 : 484-485.
- Anonymous (1977-78). Effect of manuring practices on soil productivity. All India Co-ordinated Research Project on Tobacco, FP. 138-140.
- Babaria, C.J. and Patel, C.L. (1980). Effect of application of iron, farm yard manure and sulphur on the availability of iron in medium black calcareous soil at different moisture regimes. J. Indian Soc. Soil Sci., 28 : 302-306.
- \*Babayan, G.B. and Gasparyan, D.B. (1962). IZV Akad. Nankarmyan SSR Biol. Nauki, 15 (12) : 75. Read from Bull. Indian Soc. Soil Sci., 12 , 1979.

- Badamur, V.P. and Venkata Rao, B.V. (1973). Influence of phosphorus build up on availability of micro-nutrients in red soils of Bangalore. *Soil Sci.*, 116 : 292-294.
- Bagchi, S.N.; Chakravarti, S.N. and Mukherjee, S.K. (1974). Chemical nature of native phosphorus and rate of applied phosphorus in some West Bengal soils. *Indian Agric.*, 18 : 67-74.
- Bandyopadhyay, A.K.; Sahoo, R.; Bhadrachalam, A. and Patnaik, S. (1969). Effect of continuous application of compost, ammonium sulphate and lime on some physical and chemical properties of rice soils. *J. Indian Soc. Soil Sci.*, 17 : 369-374.
- Bandyopadhyay, B.K. and Bandyopadhyay, A.K. (1984). Transformation of iron and manganese in a coastal saline soil. *J. Indian Soc. Soil Sci.*, 32 : 57-61.
- Banerjee, S. and Mandal, L.N. (1965). Inorganic transformation of water soluble phosphate added in fish ponds as influenced by the nature of pond soils. *J. Indian Soc. Soil Sci.*, 13 : 167-173.
- Bapat, M.V. and Bedekar, V.G. (1965). Fertilizer phosphorus in fractions of soil phosphorus. *J. Indian Soc. Soil Sci.*, 13 : 237-239.
- Basu, S.M. and Mukherjee, S.K. (1969). Phosphorus availability from different forms of iron, aluminium and calcium phosphates. *J. Indian Soc. Soil Sci.*, 17 : 391-397.
- Bingham, Frank T. and Gurber, M.J. (1960). Solubility and availability of micronutrients in relation to phosphorus fertilization. *Proc. Soil Sci. Soc. Am.*, 24:209-213.
- Biswas, T.D.; Bharande, K.S. and Naskar, G.C. (1967). Building up of soil structure by phosphate fertilization of a legume in a crop rotation. *J. Indian Soc. Soil Sci.*, 15 : 289-300.

- Bora, P.K. and Goswami, N.N. (1980). Influence of continuous submergence on the kinetics of pH, Eh and EC in some acid soil of Assam. IRRI News Letter, 5 : 20.
- Bradley, D.B. and Sieling, D.H. (1953). Effect of organic anions and sugars on phosphate precipitation by iron and aluminium as influenced by pH. Soil Sci., 46 : 175-179.
- Bradley, J.; Vimpany, I. and Nichollas, P.J. (1984). Effect of waterlogging and subsequent drainage of a pasture soil on phosphate sorption, extractable phosphate and oxalate extractable iron. Aust. J. Soil Res., 22 : 455-461.
- Brams, Eugene (1973). Soil organic matter and phosphorus relationships under tropical forests. Plant and Soil, 39 : 465-468.
- Brar, M.S. and Sekhon, G.S. (1976). Effect of iron and zinc on the availability of micronutrients under flooded conditions. J. Indian Soc. Soil Sci., 24 : 446-451.
- Brar, M.S. and Sekhon, G.S. (1987). Vertical distribution of potassium in five Benchmark soil series in northern India. J. Indian Soc. Soil Sci., 35:732-735.
- Chakravarti Shibnarayan and Ghoshal, Tapas Kumar (1969). Solubility of applied iron and aluminium phosphates in soils. J. Indian Soc. Soil Sci., 17 : 347-350.
- Chakravarti, S.N. and Kar, A.K. (1970). Effect of waterlogging on redox potential, available phosphorus and pH in some Indian acid soils. J. Indian Soc. Soil Sci., 18 : 249-257.

- Chapman, H.D. (1965). Cation exchange capacity. In Black C.A. Ed. "Methods of Soil Analysis" Part - II.
- Chatterjee, A.K.; Mandal, L.N. and Haldar, M. (1983). Effect of P and Zn application on the extractable Zn, Cu, Fe and P in waterlogged rice soils. J. Indian Soc. Soil Sci., 31 : 135-137.
- \*Chaudhary, J. and Deb, D.L. (1979). Quoted from "Nutrient transformation in soils micronutrients" by J.C. Katyal and D.L. Deb in Review of Soil Research in India, Part-I. 12th International Congress of Soil Sci., New Delhi, India, 8-16 Feb., 1982.
- Chauhan, S.S.; Chatnagar, R.K. and Seth, S.P. (1972). Effect on phosphatic fertilizers in soils of chambal command area, Rajasthan. J. Indian Soc. Soil Sci., 20 : 111-116.
- \*Chiang, C. (1963). J. Sci. Soil Manure, Tokyo, 34 : 18. Read from J. Indian Soc. Soil Sci., 25 : 118-121. (1977).
- Das, D.K. and Datta, N.P. (1967). Reaction products from phosphate fertilizers in acid and calcareous soils of India. Indian J. Agric. Sci., 37 : 526-535.
- Das, D.K. and Datta, N.P. (1968). Reaction products from phosphate fertilizers in red and laterite soils of India. Indian J. Agric. Sci., 38 : 382-390.
- Das, D.K. and Datta, N.P. (1969). Products of interaction of fertilizer phosphorus in acid soil of Tripura and alluvial calcareous soil of Bihar. J. Indian Soc. Soil Sci., 17 : 119-124.
- Datta, N.P. and Goswami, N.N. (1962). Effect of organic matter and moisture levels on the uptake and utilization of soil and fertilizer phosphorus by wheat. J. Indian Soc. Soil Sci., 10 : 263-276.

- Datta, N.P. and Kalbande, A.R. (1963). Release of potassium in different Indian soils at different moisture and temperature levels. Proc. Seminar on Potash, Deptt. of Agril., M.S.P., PP. 34-42.
- Deb, D.L. and Zeliang, C.R. (1976). Zinc phosphorus relationship in alluvial soil as measured by crop response and soil and plant analysis. J. Indian Soc. Soil Sci., 46 : 74-78.
- De Datta, S.K.; Moomaw, J.C.; Racho, V.V. and Simsiman, G.V. (1966). Phosphorus supplying capacity of lowland rice soils. Soil Sci. Soc. Amer. Proc., 30 : 613-617.
- Dev, G. and Mann, M.S. (1972). Effect of nitrogen and phosphorus at two moisture levels on the status of the available Zn, Cu, Mn and Fe in the soil. Journal of Res.<sup>(Punjab)</sup>, IX : 277-281.
- Dravid, M.S. and Apte, B.G. (1975). Effect of various phosphatic fertilizers on the availability of phosphorus in black and alluvial soils of Madhya Pradesh. J. Indian Soc. Soil Sci., 23 : 56-60.
- Fathi Amer, M.S.; Shams, K.M. Awad, and Khalli, M.A. (1980). Immobilization of diammonium phosphate and mono-calcium phosphate in calcareous soils. Soil Sci. Soc. Amer. Proc., 44 : 1176-1178.
- \*Gaur, A.C. (1969). Agrochimica, 14 : 62, Read from Bull. Indian Soc. of Soil Sci., 12 : 1979.

- Ghosh, A.B. and Kanzaria, M.V. (1962). Soil fertility investigations under continuous manuring and cropping in the Pusa Permanent Manurial experiments. Read at the Symposium on Fertility of Indian Soils, held on August 3-4, 1962.
- Ghosh, A.B. and Kanzaria, M.V. (1964). Long-term fertilizer experiments. In review of soil research in India. 12th International Congress of Soil Sci., New Delhi, India, 453-364.
- Ghosh, S.N.; Kar, A.K. and Dhua, S.P. (1976). Effect of sampling variation on Eh, pH and available P, Fe and Mn in submerged rice soils. J. Indian Soc. Soil Sci., 24 : 86-87.
- Gill, M.P.S. and Sinha, M.K. (1981). Effect of gypsum and submergence on chemical fractions of manganese in sodic soils. J. Indian Soc. Soil Sci., 29 : 199-203.
- Gotoh, H. and Patrick, W.H. Jr. (1974). Transformation of iron in a waterlogged soil as influenced by redox potential and pH. Soil Sci. Soc. Amer. Proc., 38 : 66-70.
- \*Grechin, I.P. (1961). Akad K.A. Timiryazeva, 63 : 93. Read from Bull. Indian Soc. Soil Sci., 12 : 1979.
- Grewal, J.S. and Kanwar, J.S. (1967). Potassium fixation in some soils of Punjab, Haryana and Himachal Pradesh. J. Indian Soc. Soil Sci., 15 : 237-244.

Gupta, R.K.; Singh, R.S.; Gupta, N. and Yadav, R.S. (1982).

Effect of phosphorus application on the transformation of iron in soil and iron nutrition of rice under two moisture regimes. J. Indian Soc. Soil Sci., 30 : 58-62.

Haldar, M. and Mandal, L.N. (1979). Influence of soil moisture regimes and organic matter application on the extractable zinc and copper content in rice soils.

Plant and Soil, 53 : 203-213.

*and*

Hansraj (1986). Effect of FYM, crop residues / calcium carbonate on the availability of zinc. Thesis Abstr.,

12 : 347. (Miss)

Havanagi, G.V. and Mann, H.S. (1970). Effect of rotations and continuous application of manures and fertilizers on soil properties under dry farming conditions. J. Indian Soc. Soil Sci., 19 : 45-50.

Hulagur, B.F.; Dangarwala, R.T. and Mehta, B.V. (1975 a). Effect of zinc, copper and phosphorus on the yield and composition of hybrid maize grown in loamy sand. J. Indian Soc. Soil Sci., 23 : 83-90.

Hulagur, B.F.; Dangarwala, R.T. and Mehta, B.V. (1975 b). Inter-relationship among available zinc, copper and phosphorus in soil. J. Indian Soc. Soil Sci., 23: 231-235.

Jackson, M.L. (1967). "Soil Chemical Analysis", Prentice Hall of India Pvt. Ltd., New Delhi.

Jaggi, I.K. and Russel, M.B. (1973). Effect of moisture regimes and green manuring of ferrous iron concentration in soil and growth and yield of paddy. J. Indian Soc. Soil Sci., 21 : 71-76.

- Kadrekar, S.B. and Kibe, M.M. (1973). Release of soil potassium on wetting and drying. J. Indian Soc. Soil Sci., 21 : 161-166.
- Kalyanasundaram, N.K. and Mehta, B.V. (1970). Availability of zinc, phosphorus and calcium in soils treated with varying levels of zinc and phosphate. Plant and Soil, 33 : 699-706.
- Kanagaraj, T. and Ramanathan, G. (1980). Effect of different moisture regimes and added Fe on the availability of zinc, and copper in black soils. Madras Agric. J., 67 : 379-381.
- Kanwar, B.B.; Tripathi, B.R. and Kanwar, B.S. (1984). Relationship between available micronutrients and properties of wheat growing valleys of Himachal Pradesh. Himachal Agril. Res., 10 : 1-6.
- Kanwar, J.S. (1954). Influence of organic matter on copper fixation in soil. J. Indian Soc. Soil Sci., 2:73-80.
- (Ed.)
- Kanwar, J.S. (1976). Soil fertility - theory and practice. I.C.A.R., New Delhi.
- Kanwar, J.S. and Prihar, S.S. (1962). Effect of continuous application of FYM and inorganic fertilizers on crop yield and properties of soil. I. Chemical Properties. J. Indian Soc. Soil Sci., 10 : 109-20.
- \*Kar, A.K. (1973). Technology sindri, 10 : 253. Read from Bull. Indian Soc. Soil Sci., 12 : 1979.
- \*Katyal, J.C. (1977). Quoted from "Vertisols and Rice Soils of the Tropics". 12th International Congress of Soil Sci., New Delhi, India 8-16 Feb., 1982.

- Khalid, R.A.; Patrick, W.H. Jr. and Delaune, R.D. (1977). Phosphorus sorption characteristics of flooded soils. *Soil Sci. Soc. Amer. J.*, 41 : 305-310.
- Khan, A.A. and Zende, G.K. (1976). Zinc-phosphorus relationship in soils. *M.A.U. Res. J.*, 1 : 51-55.
- Khanna, P.K. and Datta, N.P. (1968). Amount of easily exchangeable soil K as affected by varying moisture and temperature condition. *Potash Rev. Sub. 5*, 31st Suite PP. 1-6.
- Khetawat, G.K. and Vashishtha, K.S. (1977). Distribution of micronutrients and their relationship with some soil properties in the vineyards of Rajasthan. *J. Indian Soc. Soil Sci.*, 25 : 81-83.
- \*Kononova, M.M. (1966). Soil organic matter pergamon press. Read from *Bull. Indian Soc. Soil Sci.*, 12 : 1979.
- Krishnamurthy, C.H.; Nair, P.K. and Jayaram, N.S. (1963). Dose required to correct phosphorus deficiency in soil for rice. *J. Indian Soc. Soil Sci.*, 11 : 159.
- Kumar, S.; Omanwar, P.K.; Sachan, R.S. and Sharma, R.B. (1981). Changes in some physico-chemical properties and activities of iron and zinc on submergence of some rice soils. *J. Indian Soc. Soil Sci.*, 29 : 204-207.
- Lindsay, W.L. and Norvell, W.A. (1969). Development of DTPA micronutrient soil test. *Proc. Soil Sci. Soc. Amer.* 35 : 600-602.

- Mahapatra, I.C. (1968). Effect of flooding on soil reactions and mobilization of various nutrients. J. Indian Soc. Soil Sci., 16 : 149-153.
- Mahapatra, I.C. (1969). Effect of liming on native and added inorganic phosphate fractions and their transformation and availability on flooding. J. Indian Soc. Soil Sci., 17 : 109-113.
- Mahapatra, I.C. and Patrick, W.H. (1969). Inorganic phosphate transformation in waterlogged soils. Soil Sci., 107 : 281-288.
- Mali, C.V.; More, S.D. and Varade, S.B. (1979). Effect of source, time and level on availability of fertilizer phosphorus in vertisols. "Phosphorus in soils, crops and fertilizers". Bull., 12 : 581-583.
- Mandal, L.N. (1961). Transformation of iron and manganese in waterlogged rice soils. Soil Sci., 91 : 121-126.
- Mandal, L.N. (1964). Effect of time, starch and lime on the transformation of inorganic phosphorus in a waterlogged rice soil. Soil Sci., 97 : 127-132.
- Mandal, L.N. and Chatterjee, G.M. (1972). Transformation of applied water soluble phosphate in Latosolic lowland rice soils. J. Indian Soc. Soil Sci., 20 : 343-353.
- Mandal, L.N. and Halder, M. (1980). Influence of phosphorus and zinc applications on the availability of zinc, copper, iron, manganese and phosphorus in a waterlogged rice soil. Soil Sci., 130 : 251-257.

- Mandal, L.N. and Khan, S.K. (1975). Influence of soil moisture regimes on transformation of inorganic phosphorus in rice soils. *J. Indian Soc. Soil Sci.*, 23 : 31-37.
- Mandal, L.N. and Khan, S.K. (1976). Influence of different moisture regimes on the transformation of applied phosphate in rice soils and its availability to rice plants. *J. Indian Soc. Soil Sci.*, 24 : 374-381.
- Mandal, L.N. and Khan, S.K. (1977). Influence of moisture regimes on the transformation of recently applied phosphate in soil and its availability to rice crop. *J. Indian Soc. Soil Sci.*, 25 : 379-383.
- Mandal, L.N. and Mandal, S.C. (1973). Influence of organic matter and time on the transformation of applied phosphate in acidic low land rice soils. *J. Indian Soc. Soil Sci.*, 21 : 57-62.
- Mandal, L.N. and Mitra, R.R. (1982). Transformation of iron and manganese in rice soils under different moisture regimes and organic matter applications. *Plant and Soil*, 69 : 45-46.
- Mann, M.S.; Takkar, P.N.; Bansal, R.L. and Randhawa N.S. (1978). Micronutrient status of soil and yield of maize and wheat as influenced by micronutrient and FYM application. *J. Indian Soc. Soil Sci.*, 26 : 208-214.
- Mathuvel, P. and Krishnamoorthy, K.K. (1981). Influence of soil moisture regimes and nitrogen levels on the availability of potassium in soils. *Madras Agric. J.*, 68 : 355-359.

- Maurya, P.R. and Ghosh, A.B. (1972). Effect of long term manuring and rotation cropping on fertility status of alluvial calcareous soils. J. Indian Soc. Soil Sci., 20 : 31-43.
- Misra, S.G. and Misra, P.C. (1968). Effect of Anions on the retention of manganese applied to soils. J. Indian Soc. Soil Sci., 16 : 173-178.
- Misra, S.G. and Pande, P.(1975). Distribution of different forms of iron in soils of U.P. J. Indian Soc. Soil Sci., 23 : 242-246.
- Misra, S.G. and Pande, P. (1976). Behaviour of native iron in waterlogged soils of Eastern Uttar Pradesh. J. Indian Soc. Soil Sci., 24 : 297-302.
- Misra, S.G.; Pande, R.S.; Misra, P.C. and Pande, P. (1976). Distribution of available zinc in soil of Uttar Pradesh. J. Indian Soc. Soil Sci., 24 : 93-94.
- Misra, S.G. and Pandey, Girish (1976). Zinc in saline and alkali soils of Uttar Pradesh. J. Indian Soc. Soil Sci., 24 : 336-338.
- Mitra, G.N.; Sharma, A.K. and Moorthy, R. (1958). Comparative studies on the potassium fixing capacities of Indian soils. J. Indian Soc. Soil Sci., 6 : 1-6.
- Modi, D.B. (1986). Goradu soil properties and bidi tobacco yields as influenced by twenty five years of manurial combinations. M.Sc. Thesis submitted to Gujarat Agricultural University.
- Morris, H.D. (1948). The soluble manganese content of acid soils and its relation to the growth and manganese content of sweet clover and lespedeza. Soil Sci. Soc. Amer. Proc., 13 : 362-371.

- Mortland, M.M. (1961). The dynamic character of potassium release and fixation. *Soil Sci.*, 91 : 11-13.
- Motiramani, D.P.; <sup>Giri,</sup>Patel, J.C.;/J.D.; Raman, S. and Agrawal, J.H. (1987). Evaluation of phosphorimeter for estimation of phosphorus availability of Bhal and coastal soils in Gujarat State. *G.A.U. Res. J.* (in press ).
- Motiramani, D.P.; Vyas, K.K. and Sharma, N.K. (1964). Availability of phosphatic fertilizers in some soils of Madhya Pradesh. *J. Indian Soc. Soil Sci.*, 12 : 157-163.
- Mukherjee, S.K. and Basu, S.N. (1971). Study of pH and Eh changes of waterlogged soil and in pure systems. *J. Indian Soc. Soil Sci.*, 19 : 197-202.
- Mukhopadhyay, A.K. and Mandal, S.K. (1969). Influence of moisture regimes and applications of fertilizer P and FYM prior to flooding on the availability of P in soils. Quoted from "Phosphorus in soils, crops and fertilizers" *Bull.* 12 : 300-304.
- Murty, A.N. Ganesha (1987). Transformation of phosphorus in soil and its relation to P requirement of maize-wheat sequence under rainfed conditions. Thesis Abst. <sup>(Hissar)</sup>, XIII : 65-66.
- Murthy, A.S.P. and Ponnampereuma, F.N. (1986). Association of zinc with iron and aluminium oxides in some wetland rice soils of the Philippines. *J. Indian Soc. Soil Sci.*, 34 : 886-888.

- Mathuvel, P.; Kandaswami, P. and Krishnamoorthy, K.K. (1977). Availability of NPK (ppm) in soil after 65 years of fertilization. Madras Agric. J., 64 : 358-362.
- Nad, B.K. and Goswami, N.N. (1981). Potassium availability as affected by its application to rice at two moisture regimes on laterite soils. J. Indian Soc. Soil Sci., 29 : 481-485.
- Naphade, J.D. and Dhua, S.P. (1972). Effect of temperature regimes and time intervals on the availability of phosphorus from different sources. Technology Sindri, 2 : 44-46.
- Naphade, J.D. and Dhua, S.P. (1973). Influence of water regimes and time interval on the availability of phosphate from different sources. Technology Sindri, 10 : 82-84.
- Nayyar, V.K.; Singh, S.P.; Singh, S.; Brar, J.S.; Deol, P.S. and Fukker, P.N. (1982). Available micronutrient status of the soil of Gurdaspur district. J. Res.<sup>(Punjab)</sup>, 19 : 294-299.
- Nedeco (1968). Reports on Bhal reclamation scheme in state of Gujarat, India. Vol. I to IV; Grontmij N. V. de Bilt, the Hague, Netherlands.
- Olomu, M.O.; Racz, G.J. and Cho, C.M. (1973). Effect of flooding on the Eh, pH and concentrations of iron and manganese in several manitoba soils. Soil Sci. Soc. Amer. Proc., 37 : 220 -224.

- Olsen, S.R.; Cole, C.V.; Watanabe, F.S. and Dean, L.A. (1954). Estimation of available phosphorus in soils by extraction with sodium bicarbonate. U.S.D.A. Cir No. 939.
- Parfitt, Roger, L.; Atkinson, Roger, J. and Smart Roger, S.T.C. (1975). The mechanism of phosphate fixation by iron oxides. Proc. Soil Sci. Soc. Am., 39 : 837-841.
- Patel, B.D. (1984). "Studies in salt-affected soils of Bhal-Nal area (Dholka Taluka)". M. Sc. (Agri.) Thesis submitted to Gujarat Agricultural University.
- Patel, G.J. and Patel, A.S. (1979). Manuring in Bidi Tobacco. Tob. Res., 5 : 42-49.
- Patel, M.S. (1975). Phosphorus availability in lowland rice fields. J. Indian Soc. Soil Sci., 23 : 91-93.
- Patel, S.P.; Ghosh, A.B. and Sen, S. (1963). Effect of phosphate manuring of Barseem on the fertility status of the Delhi soil. J. Indian Soc. Soil Sci., 11 : 225-238.
- Patel, Z.N. and Patel, J.C. (1984). Micronutrient status of salt affected soils of Bhal-Nal area (Gujarat) (personal communication).
- Pathak, A.N.; Shri Krishna and Tiwari, K.N. (1972). Correlations between P, Fe, and Mn availability in waterlogged soils at different fertility levels. J. Indian Soc. Soil Sci., 20 : 385-389.
- Patil, J.D. and Patil, N.D. (1981). Effect of moisture regimes on the availability of iron and manganese. J. Indian Soc. Soil Sci., 29 : 549-551.

- Patra, D.; Haldar, M. and Mandal, L.N. (1981). Effect of P, Cu and Zn application on the availability of Zn, Cu, Fe, Mn and P and their uptake by rice in waterlogged soil. I. Availability in Soil. J. Indian Soc. Soil Sci., 29 : 337-342.
- \*Patrick, W.H. Jr. and Reddy, K.R. (1977). Quoted from "Principles and practices of rice production" by S.K. De Datta, I.R.R.I., 1981, PP. 89-145.
- \*Paul, H. and Delong, W.A. (1949). Sci. Agric., 29 : 137. Read from Bull. Indian Soc. Soil Sci., 12 : 1979.
- Piper, C.S. (1966). Soil and Plant Analysis. Hans Publishers, Bombay (India).
- Ponnamperuma, F.N. (1965). Dynamic aspects of flooded soils. PP. 295-328 in IRRI. The mineral nutrition of rice plant. Proceeding of a symposium at IRRI, Feb., 1964.
- Ponnamperuma, F.N. (1967). A theoretical study of aqueous carbonate equilibria. Soil Sci., 103 : 90-100.
- Ponnamperuma, F.N. (1972). The chemistry of submerged soils. Adv. Agron., 24 : 29-96.
- Ponnamperuma, F.N. (1976). Specific soil characteristics for rice production in Asia. IRRI Res. Pap. Ser., 2 : PP. 18.
- Ponnamperuma, F.N. (1977). Physico-chemical properties of submerged soil in relation to fertility. IRRI Res. Pap. Ser., 5 PP. 3-29.
- Ponnamperuma, F.N.; Martinez, E. and Loy, T.A. (1966). Influence of redox potential and partial pressure of carbon dioxide on the pH value and the suspension effect of flooded soils. Soil Sci., 101 : 421-431.

- Prabhakar, A.S.; Patil, S.V. and Krishnamurthy, K. (1972).  
Influence of organic manures, ammonical and  
nitrate nitrogen on the availability of applied  
and soil phosphorus. J. Indian Soc. Soil Sci.,  
20 : 413-415.
- Prabhakar, A.S.; Patil, S.V. and Krishnamurthy, K. (1974).  
Influence of moisture on the availability of applied  
phosphorus in different soils. Mysore J. Agric. Sci.,  
8 : 361-365.
- Prasad, B.; Singh, R.P.; Roy, H.K. and Sinha, H. (1983).  
Effect of fertilizer, lime and manure on some  
physical and chemical properties of a red loam  
soil under multiple cropping. J. Indian Soc. Soil  
Sci., 31 : 601-603.
- \*Premi, P.R. (1971). Effect of addition of compounds of  
copper, manganese, zinc, chromium and calcium on  
extractable iron from soil incubated under aerobic  
and anaerobic conditions. Soil and Ferti. Abstr.,  
34 : 3620.
- Rulford, K.L. IU, I.D. and Duncan, H.J. (1981). Influence of  
waterlogging and time or organic matter additions  
on the distribution of trace metals in acid soil  
(Manganese and Iron). Plant and Soil, 59 : 317-326.
- Rahate, G.Z.; Furanik, R.B.; Bapat, M.V.; Kohadkar, W.S. and  
Joshi, R.P. (1979). Quoted from "Phosphorus in  
Indian Soc. Soil Sci.  
soils, crops and fertilizers". Bull. 12 : PP.  
216-223
- Rahmatullah, F.M.; Chaudhary and Rashid, A. (1976). Effect  
of flooding on electro-chemical properties of soil.  
Plant and Soil, 45 : 411-420.

- Rajagopal, C.K.; Moosa Sheriff; Selvakumar, G.; Madappan, K. and Devarajan, R. (1974). Relation between organic carbon and available micronutrients in the soils of the Nilgiris. *J. Indian Soc. Soil Sci.*, 22 : 347-351.
- Rajagopal, V. and Mehta, B.V. (1971). Effect of zinc and phosphorus application on the response and chemical composition of hybrid maize grown on Torana soil. *Indian J. Agric. Sci.*, 41 : 156-166.
- Rajukannu, K. and Ravikumar, V. (1978). Transformation of phosphorus in rice soils under field capacity and flooded conditions. *Madras Agric. J.*, 65 : 296-302.
- Ramanathan, K.M.; Subbiah, S.; Francis, H.J. and Krishnamoorthy, K.K. (1977). A study on the fixation of NPK by Noyyal alluvium. *Madras Agric. J.*, 64 : 149-153.
- Randhawa, N.S. and Katyal, J.C. (1982). Micronutrients management for submerged rice soils. Quoted from "Vertisols and Rice Soils of the Tropics", pp.192-211. 12th International Congress of Soil Science, New Delhi, India, 8-16 Feb., 1982.
- Rao Lakshminarasimha, C.R.; Krishnamoorthy, K.K. and Venkatanarayan, C.R. (1978). Effect of moisture regimes on the availability of iron and manganese. *Madras Agric. J.*, 65 : 253-255.

- Rao, M.B. and Venkateswarlu, J. (1974). The physico-chemical changes of the newly flooded soils. J. Indian Soc. Soil Sci., 22 : 13-18.
- Rao, N.N.; Biddappa, C.C. and Sarkunam, V. (1984). Transformation of added sulphate in relation to Eh, pH, iron and manganese in flooded soils. J. Indian Soc. Soil Sci., 32 : 62-66.
- Rawat, P.S. and Mathpal, K.N. (1981). Micronutrient status of some soil of U.P. hills. J. Indian Soc. Soil Sci., 29 : 208-214.
- Reddy, Damodar G.; Venkatasubbiah, V. and Venkateswarlu, J. (1973). Zinc phosphate interaction in maize. J. Indian Soc. Soil Sci., 21 : 433-445.
- \*Redman, F.H. and Patrick, W.H. Jr. (1965). Quoted from "Principles and practices for rice production" by S.K. De Datta, IRRI, 1982, pp. 89-145.
- Reddy, M.R. and Perkins, H.F. (1974). Fixation of zinc by clay minerals. Soil Sci. Soc. Amer. Proc., 38 : 229-232.
- Richards, G.E. and McLean, E.O. (1963). Potassium fixation and release by clay minerals and soil clays on wetting and drying. Soil Sci., 95 : 308-314.
- Richards, L.A. (1954). Diagnosis and improvement of saline alkali soils. Hand book No. 60. Oxford and IBH Pub. Co., 1954.
- Sacheti, A.K. and Saxena, S. (1972). Availability of some soil phosphate reaction products. J. Indian Soc. Soil Sci., 20 : 219-224.

- Sadana, U.S. and Takkar, P.N. (1985). Zinc equalibria in submerged sodic soils as influenced by application of amendmets. Ferti. Res., 6 : 91-96.
- Sahi, B.P. ; Singh, H.M. and Singh, S.N. (1979). Effect of phosphorus application on some of the forms of phosphorus in soil at varying periods and moisture regimes. Quoted from "Phosphorus in soils, crops and fertilizers". Bull. No. 12, PP. 265-269.
- Sahu, B.N. and Nayak, B.C. (1971). Soil fertility investigation under continuous application of ammonium sulphate alone and in combination with the organic manure in the Bhubaneswar long-term fertility trial. Proc. Int. Symp. on Soil Fertility Evaluation, New Delhi, 873-880.
- Sakal, R.; Singh, B.P.; Singh, A.P.; Singh, R.B.; Singh, S.P. and Jha, S.N. (1986). Availability of zinc, iron, copper and manganese in sub-Himalayan hill and forest soils as influenced by certain soil properties. J. Indian Soc. Soil Sci., 34 : 191-193.
- Sakal, R.; Singh, B.P.; Singh, R.B.; Sinha, S.N.; Jha, S.N. and Singh, S.P. (1985). Distribution of available micronutrient cations in calcareous soils as related to certain soil properties. J. Indian Soc. Soil Sci., 33 : 672-675.

\*Sanyal, S.K. and Deb, D.L. (1975). J. Nuclear Agric. Biol.,  
5 : 54. Read from Bull. Indian Soc. Soil Sci.,  
12 : 1979.

Satyanarayana, T.; Shivamurthy, S.C. and Hadimani, A.S.  
(1970). Influence of texture and soil moisture  
regimes on phosphate mobility. Mysore J. Agric.  
Sci., 4 : 247-252.

Savant, N.K. and Ellis, R. Jr. (1964). Changes in  
redox potential and phosphorus availability  
in sub-merged soil. Soil Sci., 98 : 388-394.

Savant, N.K.; Kene, D.R. and Kibe, M. M. (1970). Influ-  
ence of alternate submergence and drying of  
rice soils prior to resubmergence on availa-  
ble phosphorus. Plant and Soil, 32 : 521-525.

Savant, R.D.; Kadrekar, S.B. and Dongale, J.H. (1981).  
Phosphorus and potassium availability as  
affected by organic matter and different  
moisture regimes. M.A.U. Res. J., 6 :  
179-182.

Sen, A. and Deb, D.L. (1975). Mobility of zinc in soils  
J. Indian Soc. Soil Sci., 23 : 365-370.

Seshagiri Rao, T.; Nisar Ahmed and Gopinath Rao, H.K.  
(1972). Fractionation of the residual phos-  
phorus compounds in black and red soils treated  
with phosphatic fertilizers. J. Indian Soc. Soil  
Sci., 20 : 323-326.

- Shanthamallalah, N.R.; Thimmegowda, S.; Satyanarayana, T.S. and Krishnamurthy, K. (1976). Influence of submergence in presence or absence of added organic matter on changes in pH and release of phosphorus. *J. Indian Soc. Soil Sci.*, 24 : 325-327.
- Sharma, B.M.; Gangwar, M.S. and Ghidyal, B.P. (1977). Effect of soil moisture on chemical kinetic of available nutrients in paddy soils. *Mysore J. Agric. Sci.*, 11 : 175-181.
- Sharma, K.N. and Meelu, O.P. (1975). Effect of long term application of P, K and farm yard manure on the zinc content of soil. *J. Indian Soc. Soil Sci.*, 23 : 76-82.
- Sharma, S.K. and Banerjee, S.K. (1983). Ferrous iron formation in presence of nitrogenous salts as influenced by moisture regimes of soils. *J. Indian Soc. Soil Sci.*, 31 : 598-600.
- Shinde, D.A. and Ghosh, A.B. (1971). Effect of continuous cropping and manuring on crop yield and characteristic of a medium black soil. *Proc. Int. Symp. on Soil Fertility evaluation, New Delhi*, 905-16.
- Shuman, L.M. (1980). Effect of soil temperature, moisture and air drying on the extractable manganese, iron, copper and zinc. *Soil Sci.*, 130 : 336-343.
- Shuman, L.M. and Anderson, A.E. (1978). Relationship of extractable soil manganese to soil properties. *Soil Sci. Soc. Amer. Proc.*, 42 : 666-668.

- Siewkee, N.G. and Bloomfield, C. (1962). The effect of flooding and aeration on the mobility of certain trace elements in soils. *Plant and Soil*, 16 : 108-113.
- Sims, J.L. and Patrick, W. H. Jr. (1978). The distribution of micronutrient cations in soil under conditions of varying redox potential and pH. *Soil Sci. Soc. Amer. J.*, 42 : 258-262.
- Singh, A. and Lal, B. (1976). Organic matter in soil and its maintenance. "Soil Fertility Theory and Practice" Ed. by J.S. Kanwar, I.C.A.R., New Delhi, PP. 128.
- Singh, Bijay; Sharma, K. N.; Rana, D. S.; Sodhi, J. S. and Kapur, M. L. (1983). Application of P and K and soil organic matter contents as influenced by long term application of fertilizers and FYM. *J. Indian Soc. Soil Sci.*, 31 : 491-494.
- Singh, R.; Bahaman and Chand, P. (1976). Transformation of phosphorus in acid soil under waterlogged and upland conditions. *J. Indian Soc. Soil Sci.*, 24 : 171-174.
- Singh, R. P. and Prasad, R. N. (1982). Effect of organic amendments and moisture regimes on zinc availability in a calcareous soil. *J. Indian Soc. Soil Sci.*, 30 : 545-546.

- Singh, R.S. and Hariram (1977). Effect of organic matter on the transformation of inorganic phosphorus in soils. J. Indian Soc. Soil Sci., 25 : 118-121.
- Singh, S. and Patiram (1977). Changes in solubility of phosphorus and its availability to rice plant in the waterlogged soils. J. Indian Soc. Soil Sci., 25:129-133.
- Singh, S. and Ram, P. (1979). Transformation of iron and manganese in submerged rice soil. J. Indian Soc. Soil Sci., 27 : 79-82.
- Sinha, M.K. (1972). Organo-metallic phosphates IV. The solvent action of fulvic acids on insoluble phosphates. Plant and Soil, 27 : 457-467.
- \*Smith, A.N. (1969). Agric. Digest., 17 : 10. Read from Bull. Indian Soc. Soil Sci., 12 : 1979.
- Spencer, W.F. (1960). Effects of heavy applications of phosphate and lime on nutrient uptake, growth, freeze injury and root distribution of grape fruit trees. Soil Sci., 89 : 311-318.
- Srivastava, O.P.; Mann, G.S. and Bhatia, I.S. (1969). Effect on organic manures on the availability of native and applied phosphate. Journal of Res. (Punjab), 6: 620-625.
- \*Srivastava, O.P. and Sethi, B.C. (1981). Contribution of FYM on the build up of available Zn in arid soil. Zinc in Agril., 12 : 355-361.
- Steckel, Joe; Bertramson, B.R. and Olurogge, A.J. (1948). Manganese nutrition of plants as related to applied super phosphate. Proc. Soil Sci. Soc. Am., 13 : 108-111.

- Subrahmanyam, A.V. and Mehta, B.V. (1975). Effect of Zn, Fe and moisture on the availability of Zn, Fe and Mn in soil. *J. Indian Soc. Soil Sci.*, 23 : 236-241.
- Takkar, P.N.; Mann, M.S.; Bansal, R.L.; Randhawa, N.S. and Singh Hardev (1976). Yield and uptake response of corn to zinc as influenced by phosphorus fertilization. *Agron. J.* 68 : 942-946.
- Takkar, P.N. and Sidhu, B.S. (1979). Kinetics of zinc transformation in submerged alkaline soils in the rice growing tracts of Punjab. *J. Agric. Sci. Camb.*, 93 : 441-447.
- Tiwari, K.N. and Pathak, A.N. (1978). Zinc phosphate relationship in submerged rice in an alluvial soil. *J. Indian Soc. Soil Sci.*, 26 : 385-389.
- Tiwari, K.N.; Pathak, A.N. and Upadhyay, R.L. (1976). Studies on iron and zinc nutrition of rice at varying moisture regimes in black clay soil of Uttar Pradesh. *J. Indian Soc. Soil Sci.*, 24:303-307.
- Trehan, S.P. and Grewal, J.S. (1983). Available micro-nutrients status of alluvial and hill soils as influenced by intensive cropping and manuring. *J. Indian Soc. Soil Sci.*, 31 : 343-346.
- Vekaria, F.R. (1985). Effect of moisture regimes and zinc application on the availability pattern of different nutrients in a clayey paddy soil. M.Sc.(Agri.) Thesis submitted to Gujarat Agricultural University.
- Venkata Reddy, N.; Saxena, M.C. and Shrinivasulu, R. (1983). Inorganic 'P' fractions of foot-hill soils after long continued 'P' fertilization. *J. Indian Soc. Soil Sci.*, 31 : 124-125.

- Vittal, K.F.R. and Gangwar, M.S. (1974). Zinc in soil profiles of Nainital Tarai. J. Indian Soc. Soil Sci., 22 : 151 - 155.
- Volk, N.J. (1934). The fixation of potassium in difficultly available forms in soil. Soil Sci., 37 : 267-287.
- Vyas, K.K. (1964). Availability and uptake of phosphorus by wheat under different moisture organic matter levels. Current Sci., 23 : 756.
- Vyas, M.K. and Motiramani, S.P. (1971). Effect of organic matter, silicates and moisture levels on the availability of phosphate. J. Indian Soc. Soil Sci., 19 : 39-43.
- \*Walsh, T.; Golden, J.D. and Fleming, G.A. (1950). Trans. 4th Int. Congr. Soil Sci., 3 : 115. Read from Bull. Indian Soc. Soil Sci., 12 : 1979.
- \*Yadav, V.B. and Mishra, K.B. (1977). Proc. Int. Symp. Improving Crop Animal Productivities by Nuclear and Allied Techniques, Feb. 1-4, New Delhi. Read from Bull. Indian Soc. Soil Sci., 12 : 1979.
- Yu, T. and J. Liu, S. H. (1965). Oxidation reduction processes in paddy soils and their relation to rice growth. Soil and Fertil. <sup>Abst.</sup> 28 : 2170.

\*Zachariah, P. K. (1962). J. Inst. Chem. India, 34 : 230.  
Read from Bull. Indian Soc. Soil Sci., 12 :  
1979.

\*Zachariah, P. K. (1964). J. Inst. Chem. India, 36 :  
211. Read from Bull. Indian Soc. Soil Sci.,  
12 : 1979.

-----  
\* : Original not seen.

# APPENDICES

Appendix - I : Per cent P available and fixed of the applied phosphorus as influenced by moisture regimes and farm yard manure

Levels of moisture	Levels of P *	No farm yard manure						Farm yard manure					
		Dicalcium phosphate			Diammonium phosphate			Dicalcium phosphate			Diammonium phosphate		
		Increase over P <sub>0</sub> (ppm)	Available	Fixed	Increase over P <sub>0</sub> (ppm)	Available	Fixed	Increase over P <sub>0</sub> (ppm)	Available	Fixed	Increase over P <sub>0</sub> (ppm)	Available	Fixed
M <sub>1</sub>	P <sub>1</sub>	0.63	12.94	87.06	0.76	15.61	84.39	5.94	121.97	-21.97	7.42	152.36	-52.36
	P <sub>2</sub>	1.10	11.29	88.71	1.94	19.92	80.08	10.00	102.67	-2.67	9.81	100.72	-0.72
	Mean	0.86	12.12	87.88	1.35	17.76	82.24	7.97	112.32	-12.32	8.62	126.54	-26.54
M <sub>2</sub>	P <sub>1</sub>	0.55	11.29	88.71	0.60	12.32	87.68	4.24	87.06	12.94	4.98	102.26	-2.26
	P <sub>2</sub>	0.64	6.57	93.43	0.86	8.83	91.17	5.27	54.11	45.89	10.71	109.96	-9.96
	Mean	0.60	8.93	91.07	0.73	10.58	89.42	4.76	70.58	29.42	7.84	106.11	-6.11
M <sub>3</sub>	P <sub>1</sub>	0.19	3.90	96.10	0.00	0.00	100.00	3.20	65.71	34.29	5.34	109.65	-9.65
	P <sub>2</sub>	0.39	4.00	96.00	0.71	7.29	92.71	4.61	47.33	52.67	8.32	85.42	14.58
	Mean	0.29	3.95	96.05	0.36	3.64	96.36	3.90	56.52	43.48	6.83	97.54	2.46
M <sub>4</sub>	P <sub>1</sub>	0.72	14.78	85.22	0.61	12.53	87.47	2.39	49.08	50.92	4.53	93.02	6.98
	P <sub>2</sub>	1.01	10.37	89.63	1.04	10.68	89.32	3.53	36.24	63.76	6.17	63.35	36.65
	Mean	0.86	12.58	87.42	0.82	11.60	88.40	2.96	42.66	57.34	5.35	78.18	21.82
M <sub>5</sub>	P <sub>1</sub>	0.98	20.12	79.88	1.41	28.95	71.05	3.66	75.15	24.85	4.34	89.12	10.88
	P <sub>2</sub>	1.98	20.33	79.67	2.50	25.67	74.33	10.70	109.86	-9.86	10.65	109.34	-9.34
	Mean	1.48	20.22	79.78	1.96	27.31	72.69	7.18	92.50	7.50	7.50	99.23	0.77
Overall mean	P <sub>1</sub>	0.49	12.61	87.39	0.68	13.88	86.12	3.89	79.79	20.21	5.32	109.28	9.28
	P <sub>2</sub>	1.02	10.51	89.49	1.41	14.48	85.52	6.82	70.04	29.96	9.13	93.76	6.24

\* : P<sub>1</sub> = 4.87 ppm; P<sub>2</sub> = 9.74 ppm.

Appendix - II : Chemical analysis of farm yard manure  
(Oven dry basis).

Constituent		ppm (Total)
Phosphorus	(P)	1013
Potassium	(K)	5279
Iron	(Fe)	2938
Manganese	(Mn)	259
Zinc	(Zn)	100
Copper	(Cu)	45