

**STUDY ON UREA TRANSPORT IN SOILS IN RELATION TO
THEIR PHYSICAL PROPERTIES**

**THESIS SUBMITTED IN PART FULFILMENT OF THE REQUIREMENTS FOR
THE DEGREE OF DOCTOR OF PHILOSOPHY (AGRICULTURE)
IN SOIL SCIENCE AND AGRICULTURAL CHEMISTRY TO THE
TAMIL NADU AGRICULTURAL UNIVERSITY COIMBATORE**

LIBRARY

TNAU, Coimbatore - 3



000135749

BY

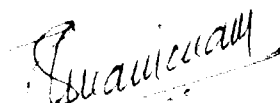
N. ARUNACHALAM, M.Sc

**DEPARTMENT OF SOIL SCIENCE AND AGRICULTURAL CHEMISTRY
AGRICULTURAL COLLEGE AND RESEARCH INSTITUTE
TAMIL NADU AGRICULTURAL UNIVERSITY
COIMBATORE - 641 003
1991**

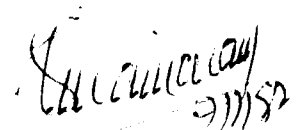
CERTIFICATE

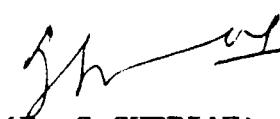
This is to certify that the thesis entitled "STUDY ON UREA TRANSPORT IN SOILS IN RELATION TO THEIR PHYSICAL PROPERTIES" submitted in part fulfilment of the requirements for the award of the degree of DOCTOR OF PHILOSOPHY (Agriculture) in soil science and Agricultural chemistry to the Tamil Nadu Agricultural University, Coimbatore is a record of bona fide research work carried out by Thiru N.ARUNACHALAM under my supervision and guidance and that no part of this thesis has been submitted for the award of any other degree, diploma, fellowship or other similar titles or prizes and that the work has not been published in part or full in any scientific or popular journal or magazine.

Place : Coimbatore
Date : 2.12.91


(Dr. T. S. MANICKAM)
Chairman

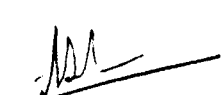
Approved

Chairman : 
(Dr. T. S. MANICKAM)

Members : 
(Dr. S. SUBBIAH)


(Dr. S. PURUSHOTHAMAN)

External Examiner : 
Date :


(Dr. A. SUNDARAM)

To my Parents, Late Tmt. Adaikkammai Narayanan and

Thiru. S.M. AR. AR. Narayanan

and

to my family, Meenal, Kamal Narayanan, Adaikkamai and

Ramanathan

Acknowledgements

ACKNOWLEDGEMENT

I wish to place on record my deep sense of gratitude and indebtedness to my chairman, Dr.T.S. Manickam, formerly Dean, Agricultural College and Research Institute, Madurai and presently the Professor and Head, Soil Salinity Research Centre (NARP), Trichy for his expertise and guidance with critical appraisal and continuous encouragement during the course of this investigation. Right from the day of registration, he has been a source of inspiration to me. I deem it a great privilege to have worked under his inspired guidance.

I am highly indebted and grateful to the advisory committee members Dr. S. Subbiah, Professor of Soil Science and Agricultural Chemistry, Tamil Nadu Government Agricultural College, Kumulur, Dr.S. Purusothaman, Professor and Head, Department of Agronomy, Tamil Nadu Agricultural University, Coimbatore and the former advisory committee members, Dr. G. Ramanathan, Professor of Soil Science and Agricultural Chemistry, and Dr.SP. Palaniappan, Director, Soil and crop management studies, Tamil Nadu Agricultural University, Coimbatore, for their valuable guidance and encouragement.

No words can adequately express the sense of gratitude and indebtedness, I owe to Dr. A. Sundaram, Associate Professor of Mathematics, Department of Physical Sciences, Agricultural College and Research Institute,

Madurai and one of the advisory committee members, for the emanation of his timely and valuable guidance , especially in mathematical aspect of the thesis and computer work.

I owe my heart felt thanks to the Tamil Nadu Agricultural University, for having permitted me to pursue my Doctoral Programme under internal deputation.

I profusely thank my classmates, Thiru. M. Dhakshinamoorthy, Dr. A. Rajarajan, Dr. C. Clarson, Thiru. A.R.Mohamed Haroon, Dr. H. Hameed Khan and Dr.P.Muthu Krishnan for their keen interest and encouragement for this piece of work.

I extend my words of appreciation for the spontaneous and affectionate assistance by Dr. A. Saravanan, Asst. Professor of Soil Science and Agricultural Chemistry, Horticultural Research Station, Kodaikanal and gratefulness to Dr. V. Murugappan, Associate Professor of Soil Science and Agricultural chemistry, Forest College, Mettupalayam for his counselling throughout the period of investigation.

I am pleased to record my thanks to Dr. S. Subramaniyan, Associate Professor of Soil Science and Agricultural Chemistry, Agricultural College and Research Institute, Madurai and Dr. S. Natarajan, Associate Professor of Soil Science and Agricultural Chemistry, Tamil Nadu Agricultural University, Coimbatore and Tmt. P.Malarvizhi, Asst. Professor of Soil Science and Agricultural Chemistry,

Agricultural College and Research Institute, Madurai for their help rendered during the period of investigation.

I will be failing in my duty, if I do not thank Dr. R. Radhakrishnan Professor of crop Physiology, Dr. K. Ramasamy, Professor of Agricultural Microbiology and Thiru .M. K. Ayyasamy, Professor of Agricultural Statistics, Tamil Nadu Agricultural University, Coimbatore for their encouragement throughout the period of investigation.

I gratefully acknowledge the help of Thiru. K. Sundareswaran, Data Entry Operator, Computer Centre, Department of Physical Sciences, Agricultural College and Research Institute Madurai, for his contribution in the graphics .

My thanks are due to in no small measure to M/s. ARASU COMPUTERS, Tallakulam, Madurai for the fine work of preparing the thesis in a short period.

Finally, my thanks are due to my wife Mrs. Meena Arunachalam for her unceasing encouragement and my children Kamal Narayanan, Adaikkannai and Ramanathan for their patience and tolerance besides their help throughout the study.


(N. ARUNACHALAM)
21/2/91.

Abstract

A B S T R A C T

**STUDY ON UREA TRANSPORT IN SOILS IN RELATION
TO THEIR PHYSICAL PROPERTIES**

BY

N. ARUNACHALAM

Degree: **DOCTOR OF PHILOSOPHY (AGRICULTURE) IN SOIL SCIENCE
AND SCIENCE AND AGRICULTURAL CHEMISTRY**

Chairman: **Dr. T.S. MANICKAM**

Professor and Head,
Soil salinity Research Centre
(NARP),
Tamil Nadu G.D. Naidu
Agricultural University
Trichy 629 009.

1991

A laboratory investigation was carried out with single level of urea (100 kg ha^{-1}) application in sandy clay loam, loamy sand and sandy clay soils subjected to saturated, normal rainfall, excess of rainfall and flooded conditions with the objectives of studying the spatial and temporal movement of urea in the soils in relation to their physical properties and to construct a simple mathematical model for the prediction of the temporal variations in the concentration of urea at different depths of the soils.

The study revealed that the saturated and normal rainfall conditions were found to be favourable for urea transport in sandy clay loam and sandy clay soils, whereas the excess of rainfall and flooded conditions were found to be favourable for the loamy sand soil. The depth mean average of the urea concentration was found to be higher in loamy sand soil than the sandy clay loam soil and it was found to be comparatively lesser in the sandy clay soil.

The present study also revealed that the increase in the proportion of the textural fractions in the soils viz., of fine sand and total sand and the decrease in the proportion of clay and coarse sand help the process of urea transport in soils. In addition, the following physical properties namely bulk density, hydraulic conductivity and percentage of waterstable aggregates were found to influence the transport property of urea in soils. The study ranked the loamy sand soil as first among the three soils based on the fact that the combination of its higher sand and fine sand components and lower clay content and water stable aggregates with its greater values of hydraulic conductivity or lesser value of bulk density.

The direct and indirect effects of the various physical properties of the soils studied in relation to the Urea transport in soils were worked out in the present study.

The movement of urea was found to be in existence for four, five and seven days in loamy sand, sandy clay loam and sandy clay soils respectively. The maximum concentration of urea was recorded in the first day of urea transport for all the soils and then the concentration was found to decrease with days. A simple mathematical model was constructed for the prediction of the temporal variations in the log concentration of urea at different depths of the soils. The model was found to be in good fit with the observed values.

CONTENTS

Chapter No	Title	Page No
I	INTRODUCTION	1
II	REVIEW OF LITERATURE	4
III	MATERIALS AND METHODS	35
IV	RESULTS	44
V	DISCUSSION	135
VI	SUMMARY AND CONCLUSION	158
	REFERENCES	169

LIST OF TABLES

Table No	Title	Page No
1.	Properties of surface soils	52
2.	Physical properties of soils (Sandy clay loam)	53
3.	Physical properties of soils (Sandy clay)	54
4.	Physical properties of soils (Loamy Sand)	55
5.	Range in physical properties of soils	56
6.	Concentration of urea (ppm) at different depths, days and treatments in sandy clay loam soil.	66
7.	Concentration of urea (ppm) at different depths for different treatments in sandy clay loam soil	66
8.	Concentration of urea (ppm) at different depths for different days in sandy clay loam soil	68
9.	Concentration of urea (ppm) at different days with different treatments (Sandy clay loam soil)	68
10.	Concentration of urea (ppm) at different depths for different treatments and days in Sandy clay loam soil	70
11.	Concentration of ure (ppm) at different depths, days and treatments in loamy sand soil	72
12.	Concentration of urea (ppm) at different depths for different treatments in loamy sand soil	74
13.	Concentration of urea (ppm) at different depths for different days in loamy sand soil	76

LIST OF TABLES (Contd..)

14.	Concentration of urea (ppm) for different days under treatments in loamy sand soil	76
15.	Concentration of urea (ppm) at different depths for different treatments and days in loamy sand soil	78
16.	Concentration of urea (ppm) at different depths, days and treatments in sandy clay soil	81
17.	Concentration of urea (ppm) at different depths for different treatments in sandy clay soil	82
18.	Concentration of urea (ppm) at different depths for different days in sandy clay soil	84
19.	Concentration of urea (ppm) at different days under different treatments in sandy clay soil	84
20.	Concentration of urea (ppm) at different depths for different treatments and days in sandy clay soil	86
21.	Concentration of urea (ppm) in soils with depths (pooled analysis)	89
22.	Concentration of urea (ppm) in soils at different depths and treatments (pooled analysis)	89
23.	Concentration of urea (ppm) in different soils and treatments (pooled analysis)	91
24.	Concentration of urea (ppm) at different depth under different treatments (pooled analysis)	91
25.	Concentration of urea (ppm) at different depths, soils and treatments (pooled analysis)	94
26.	Regression lines of $\log(a-x)$ Vs time, $\frac{1}{B^2}$, reaction co-efficient and $t^{1/2}$ for different soils.	96

LIST OF TABLES (Contd..)

27.	Predicted equations for temporal variations of urea concentraion at various depths of soils (sandy clay loam soil)	98
28.	Predicted - equations for temporal variations of urea concentraion at various depths of the soils (loamy sand soil)	99
29.	Predicted equations for temporal variations of urea concentraion at various depths of the soils (sandy clay soil)	100
30.	Predicated equations for temporal variation for pooled value of urea concentraion in 50 cm depth of soil columns under different water treatments	101
31	Correlation Co-efficients of various physical properties of soil and urea concentraion	121
32.	Correlation matrix: Independednt variables (physical properties of soils) and dependent variable (concentraion of urea in soil)	124
33.	Path Co-efficient analysis; Direct and indirect effects of physical properties of soils on transport of urea in soils	127
34.	Path Co-efficient analysis: Direct and indierect effects of textural properties of soils on urea concentration in soil	132

LIST OF FIGURES

Figure No	Title	Page No
1.	Percentage of soil textural fractions	51
2.	Mean urea concentraion in soils in different days	57
3.	Mean urea concentration in soils of different depths	58
4.	Mean urea concentration in soils for different treatments	59
5.	Urea concentration at different depths and days in sandy clay loam soil	61
6.	Urea concentration at different depths and days in loamy sand soil	62
7.	Urea concentration at different depths and days in sandy clay soil	63
8.	Concentration of urea different depths and days sandy clay loam soil : Saturated condition	102
9.	Concentration of urea different depths and days sandy clay loam soil : Normal rainfall condition	103
10.	Concentration of urea different depths and days sandy clay loam soil : Excess of rainfall condition	104
11.	Concentration of urea different depths and days sandy clay loam soil : Flooded condition	105
12.	Concentration of urea different depths and days Loamy sand soil:Saturated condition	106

LIST OF FIGURES (Cont...)

13.	Concentration of urea different depths and days Loamy sand soil: Normal rainfall condition	107
14.	Concentration of urea different depths and days loamy sand soil: Excess of rainfall condition	108
15.	Concentration of urea different depths and days loamy sand soil: Flooded condition	109
16.	Concentration of urea different depths and days sandy clay soil : Saturated condition	110
17.	Concentration of urea different depths and days sandy clay soil: Normal rainfall condition	111
18.	Concentration of urea different depths and days sandy clay soil: Excess of rainfall condition	112
19.	Concentration of urea different depths and days sandy clay soil: Flooded condition	113
20.	Mean urea concentration of different depths of soil columns	114
20 (a)	Sandy clay loam soil	115
20 (b)	Loamy sand soil	116
20 (c)	Sandy clay soil	117
20 (d)	Urea concentration of different soils	118

A B B R E V I A T I O N S U S E D

1. Kilograms per hectare	Kg ha ⁻¹
2. Millimetre per hectare	mm ha ⁻¹
3. Milli litre	ml
4. Milli metre	mm
5. Millimhos per centimetre	m mhos cm ⁻¹
6. Gram per cubic centimetre	gm cm ⁻³
7. Centimetre per hour	cm hr ⁻¹
8. Parts per million	ppm
9. Gram	g
10. Bulk density	B.D
11. Hydraulic conductivity	H.C
12. Coarse sand	C.S
13. Fine sand	F.S
14. Organic carbon	O.C
15. Concentration	Conc.
16. Nitrate nitrogen	NO ₃ ^{-N}
17. Ammonical nitrogen	NH ₄ ^{-N}
18. Treatment 1 (saturated condition)	T ₁
19. Treatment 2 (Normal rainfall condition)	T ₂
20. Treatment 3 (Excess of rainfall condition)	T ₃
21. Treatment 4 (Flooded condition)	T ₄
22. Standard error of difference	SE _D
23. Critical difference	C.D
24. Non-significant	NS

Introduction

CHAPTER 1

INTRODUCTION

To meet the food requirements of ever increasing world population in future ,maximisation of the agricultural production should be aimed at the level of exploiting the full genetical potentiality of the plant species concerned. The key to the success in this endeavour, is to build up a high soil fertility status that nourishes the entire plant community of the world. The pathways for the success may be routed through the physical fertility of the soil as the "Physical fertility" and "Chemical fertility" are the two sides of the coin "Soil fertility".

It is important to apply fertilizer to a soil, if it is found to be deficient in plant nutrients, but it is more important that it should be effectively distributed in the soil medium for successful crop utilisation. The process involved in the supply and the distribution of the vital plant requirements such as soil-air, water, nutrients, and temperature, is being well operated only by the soil physical environment constituted by the texture, structure, and the material properties of the soil matrix. The study of these parameters will be of much use in achieving the goal of maximising crop production particularly to design suitable management practices which are more efficient, sustainable and less hazardous to environment.

Building up of the fertility of the soil necessitates the use of larger dose of fertilizers particularly nitrogenous fertilizers for boosting the crop production.

Among the solid N fertilizers, urea is a popular and major source in the world fertilizer market. The world consumption of N in the form of urea is about 32 per cent. It is expected that consumption of urea will still increase in coming years, because of many advantages which urea has over the other nitrogeneous fertilizers. The paramount importance of urea as fertilizer is that every farmer invariably uses it in one or other occasion in his attempt to cultivate crops.

The farmers generally follow the practice of applying urea in soil either when the soil is at saturated condition or immediately after the receipt of a single rain. Some times it happens that the application of urea is followed by a normal or excess of rain or even a heavy rain causing flooded condition in the soil. The answer to the question "What will be the fate of urea applied in the soil?" is our subject of interest. The documents on the transformations of urea are in abundance. Because of the fact that the rate of hydrolysis and transformation of urea are quick, most of the studies on urea are centred at the transformation of urea and the availability of the different fractions of urea-N. It is felt that a study on the transport of urea in its original form applied in the soil,

as practised by the farmers, will be useful for advocating the fertilizer management practices under specific situations. Hence an attempt was made to study the urea transport property of different textured soils.

With a view to obtain information on the above said problems, the present investigation was undertaken with the following objectives;

(1) To study the concentration of urea at the various depths of the different textured soils namely, sandy clay loam, loamy sand and sandy clay soils in relation to the simulated rainfall conditions.

(2) To construct a simple mathematical model to describe the temporal variation of the concentration of urea at different depths of the soil columns.

(3) To understand the relationship between the various physical properties of soils and the urea transport.

Review of Literature

CHAPTER II

REVIEW OF LITERATURE

The use of nitrogen fertilizers has steadily and significantly increased during the past 30 years and the maximum share has been in the use of urea. Also urea utilisation is expected to continuously increase, particularly in the developing countries. For rice crop use of fertilizer urea as N source has constituted more than 80 per cent (Craswell et al., 1981). In India among the different nitrogenous fertilizers, urea is a major source and fulfills 78 per cent of fertilizer nitrogen demand.

Most of the rice soils, especially in South India, are low in available N warranting judicious application of N fertilizers for sustained rice yields (Manickam, 1988). In these soils urea is being used as the main fertilizer N source both for basal and top dressings in all rice growing situations. At the same time, very low use efficiency of added urea-N has been reported under all rice growing situations. This poor N use efficiency by rice crop is due to the intensity of various loss mechanisms, viz., NH_3 volatilisation, denitrification, immobilisation, leaching and run off which are constantly operating in the wet land system under which the rice is mainly grown (Reddy and Patrick, 1986. and Watanabe et al., 1988). Urea, which is the principal N fertilizer and will remain so in most of the rice growing countries, also in India, is more susceptible to losses warranting a clear understanding of the fate of urea

in soils in relation to the chemical and physical fertility status of the soils. Literature on the urea transformation processes is exhaustive, but on the transport of urea is limited.

It has been reported that the upland crops generally used 40 to 60 per cent of the applied fertilizer N (Mitsui, 1955) Whereas the flooded rice crop used only 20 to 40 per cent (Prasad et al., 1971; Krishnappa and Shinde, 1980; Rao and Shinde, 1985; and Manickam and Natarajan, 1990), and it rarely exceeded 40 per cent under Asian rice farmers management practices (De Datta, 1981). The percentage recovery of applied N varied to a greater extent with soil properties, fertilizer sources, application methods, rate and time of application (De Datta, 1986 and Watanabe et al., 1988).

2.1. Urea application

In case of the soluble nitrogenous fertilizer, the method and rate of application greatly determine the efficiency of the fertilizer under consideration. It is not definitely known whether fertilizers like urea should be applied in dry soil or wet soil, it should be mixed in surface layer or placed deeper, should be applied before or after the irrigation or should be applied in different ways to different soils (Singh et al., 1984). The performance of urea under specific soil-crop-water climatic situation is still to be studied in depth and characterised.

The general practice of rice farmers is to apply ordinary urea in wet soil. The rate of application ranges from 50 ppm to 800 ppm Broadbent et al., (1958) depending upon the soil and crop requirement. The author had reported that at 45°F, a quantity 400 ppm of urea completely hydrolysed within 7 days. At 75°F, no urea remained after 2 days when the initial application was 400 ppm or less. At 800 ppm, considerable urea remained after 7 days but nil after 14 days. Ibrahim et al. (1984) found that urea hydrolysis rate increased with increasing concentration upto 8000 ppm N and decreased at 20000 ppm N. They also found that complete hydrolysis of 250, 500, and 1000 ppm urea N took 1, 2 and 3 weeks respectively whereas even 6 weeks time was not sufficient for complete hydrolysis of 20000 ppm N.

The rate of urea hydralysis increased as first order reaction with respect to amount of urea applied Overrein and Moe (1967). Dalel (1975), Douglas and Bremner (1971) have shown that rate of urea hydrolysis in soil increased with urea concentration until the amount of urea added is sufficient to saturate the enzyme. Several workers have demonstrated that the rate of urea hydrolysis in soil is less at lower N levels than observed with higher amounts of urea (Wagenet, 1984 ; and Tewatia, 1986).

Inorder to increase the urea nitrogen use efficiency in rice, several indigenous as well as synthetic materials like shellac (Rana et al., 1984; Velu and

Ramanathan, 1985 and Saravan et al., 1988). Coal tar (Sahu and Pal, 1987 and Saravanan et al., 1988) and sulphur (Craswell and Vlek, 1979; Craswell et al., 1981; Rana et al., 1984 and Sankaran and Balasubramanian, 1985) as coating materials to reduce the dissolution rate of prilled urea, neem oil and neem cake (Subbiah et al., 1980 and Velu et al., 1988) and N serve (Subbiah et al., 1980 and Singh et al., 1984) as nitrification inhibitors and PPD (Vlek et al., 1980; Byrnes et al., 1983, Manickam and Ramaswamy, 1987 and Manickam and Natarajan, 1990) as urease and nitrification inhibitors have been extensively used world wide and found promising.

The effect of gypsum coated urea on rice yield and nitrogen use efficiency has been reported by Kandaswamy and Arulmozhiselvan (1985). Slow and steady release of N from gypsum coated urea was also reported by many workers (Kandaswamy et al., 1985; Sankaran et al., 1985, and Jayaramamoorthy et al. 1985) and the effect was confirmed by the results of multilocal trials under AICRIP (1989).

The combined application of urea with zinc sulphate had been studied by several investigations (Ramanathan and Saravanan, 1985 and Islam et al., 1985). Increased nitrogen use efficiency was reported by Sujatha and Subbiah (1990), Jawahar et al. (1990) and Soundarapandiyan and Subbiah (1990).

The placement of urea in a band in a region of

high pH and high salt concentration within soil resulted in inhibitions in nitrification (Wetselaar et al., 1972). Banded urea is in contact with less volume of soil than broadcasted or incorporated urea and thus N immobilization is reduced. Incorporation of urea in large pellets as granules is an alternative means of retarding nitrogen transformation rate Nommik(1973).

Deep placement of urea supergranules has shown promise for the fertilization of flooded rice, Craswell et al (1981). However, in permeable soils with high leaching rates, the deep placement of large urea granules resulted in higher leaching losses of nitrogen than was observed with other methods of application. (Vlek et al., 1980).

2.2 Nature of urea

Among the various solid N fertilizers, urea is the major source because of many advantages, viz., easy nature of manufacture; cheaper than other N sources, can be mixed easily with insecticides and pesticides for foliar spray, leaves less acidic residue in comparison to other nitrogenous fertilizers, can be handled safely and has no explosion hazards when applied to moist soil, and it is easily converted into ammonium carbonate with the help of urease enzyme, and then nitrified, so that the nitrate formed may be taken up by plants, immobilized, leached or denitrified depending upon soil moisture conditions. But a substantial amount of NH_3 may also be lost during urea

hydrolysis through NH_3 volatilization both in upland and water logged conditions, besides other losses. Therefore, N applied through urea may undergo simultaneously various transformation process before it is actually utilized by plants. The extent of various loss mechanisms operating in the soil determines the efficiency of urea in field crops, which generally ranges from 40 to 60% in both upland and waterlogged conditions.

Urea as such, as NH_4^+ , and NO_3^- ions produced after transformation of urea are subjected to leaching losses depending upon soil texture and soil moisture regime. The efficiency of urea is thus related to the pattern of movement in the soil.

2.3. Fate of applied urea in the soil

2.3.1. Loss by leaching

As urea is a non ionic compound, it is easily susceptible to leaching in soil, but at a slower rate than nitrate ion. It can be absorbed by soil and is simultaneously hydrolysed to ammonium bicarbonate by soil urease (Broadbent et al. 1958). Urea is retained within soil due to salt formation between urea and the carboxyl groups of soil organic matter. Urea can also complex with clay minerals, Farmer and Ahrlichs, (1969).

Leaching losses of urea may occur by two processes

- (1) Urea is leached from the soil,

(2) Urea migrates below the rooting zone, is hydrolysed, nitrified and then leached as nitrate. Bauder and Montgomery, (1980). Split applications of urea have shown to result in large losses of nitrate by leaching. Bauder and Schneider, (1979).

The leaching losses of urea in dry and wet soils as affected by irrigation water was studied by Mahendra Singh et al (1984) in 90 cm long and 5 cm diameter plaziglass columns. The study revealed that more urea was recovered in sandy soil than in sandy loam soil following infiltration and redistribution for 24 hours. Urea behaved as a non-reacting ion like Cl with respect to its movement with soil-water before it was hydrolyzed. In higher water application, urea was not only displaced to the deeper layers but a wider upper zone was almost free of urea. If water or rain of 10 cm or more happen to follow urea application, almost entire urea will reach beyond rooting-zone in sandy loam soils. Musa (1968) reported that urea washed down from surface layer got distributed in the lower depth. Vlek et al (1980) reported that the permeability of the clay soil was too low for any leaching of urea to take place. The results indicated that moderate to high percolation through silt loam soil will lead to significant fertilizer N loss and drastically decrease the fertilizer uptake by plants.

Effects of water application rates on transport and leaching of urea, NH_4^+ N and NO_3^- N in

laboratory and field conditions were studied by several workers (Haque and Ibrahim, 1965; Protasov and Karasteleve, 1972; Wagenet et al., 1981; Boudier and Schneider, 1979; EI-Wali et al., 1980; Fenn and Miyamoto, 1981; Maustafa and Khadar, 1983; Singh et al. 1984; Singh and Bajwa, 1986; Tewatia, 1986).

Singh and Ghosh (1982) studied the leaching of N through urea in the presence of cotton (*Gossipum arboreum*) crop in lysimeters. Percolation of urea started only after total rainfall reached 23.46 cm. The leaching losses in the form of urea, NH_4^+ NO_3^- were 17.0, 1.24 and 4.88% respectively after 83.4 cm of rain received during the entire growing season of the crop. In another study, leaching of ^{15}N urea N (100 kg N ha^{-1}) was measured in lysimeters with barley crop. The leaching fraction amounted to 6 and 14% after application of 100 mm plus 186 mm water through rainfall and irrigation respectively (Mohamed et al., 1984).

Leaching losses of urea were found reduced by application of nitrification inhibitors like N-serve or coating of urea with neem cake (EI-Wali et al., 1980; and Rao et al., 1980). Pre-incubation of urea with moist soil for 24 hours and use of other nitrification inhibitors reduced leaching losses of urea in upland and water logged field conditions. Rao and Schinde (1985) found that application of neem cake coated urea was better in reducing NH_4^+ and NO_3^- N leaching losses from urea in paddy crop than split application of urea alone. Most of urea N (69%) was leached

in 0-20 cm soil depth. . The studies of Baker (1987) suggested that transport of urea N greatly reduced or impeded by the presence of divalent and trivalent metals and hydrous oxides of Fe and Al.

2.3.2. Urease activity in soils

Different views have been reported by workers on urease activity in different soils depending upon the method adopted for assay. Savant et al. (1985) found urease activity lesser in wet land soils than in wetland oxidised soils. Similar effects of water logging on urease activity of north Indian soils were observed by Tewatia (1986) who found that urease activity was higher at field capacity than at flooded condition. Most of the workers found significant correlations between urease activity and organic matter content of soil Gould et al., 1973; Beri et al., 1978; and Reynolds et al., (1985); Dalal (1975), Zantua et al. (1975); and Reynolds et al. (1985) found that urease activity of surface soils was significantly correlated with total N, CEC and clay content. Urease activity was found to be negatively correlated with sand (Zantua et al., 1975). In most cases, urease activity was not found to have any significant relationship with pH. Kumar and Wagenet (1984). Again Kumar and Wagenet (1984) found no significant correlation of urease activity with Ca CO₃ silt, sand and clay of 18 Utah soils.

2.3.3. Urea hydrolysis in soils

The hydrolysis of urea is catalized by urease enzyme present in cells of urolistic micro organisms and in adsorbed phase on soil colloids (Paulson and Kurtz, 1969; 1970; Gould et al., 1973). Urea when applied to moist soils converted first into ammonium carbonate and later on into NH_3 , CO_2 and water. The ammonia so produced may be adsorbed by soil colloids or taken up by plants and microbes or nitrified or lost as gaseous form.

Urea transformation and factors affecting it have been reviewed by Kiss et al (1975); Bremner and Mulavamey (1978); Ladd (1978) and Gould et al (1986). The urea transformation was found to be depending on the physical, chemical and environmental conditions in the field.

2.3.4. Rate of urea hydrolysis

Singh and Yadav (1981) observed that complete hydrolysis of urea occurred atleast after one week in sandy loam soil and in two weeks in sandy soil. Mohamed et al. (1984) applied $100 \text{ kg of urea N ha}^{-1}$ to the soil surface and found about 86 per cent of the urea hydrolysed after one week found that all the urea hydrolysed within 14 days. Sannigrahi and Mandal (1982) found that within 4 days of incubation, 83.3 per cent from prilled urea, 82.6 per cent from lac-coated urea were released as ammonical-N. The prilled urea was completely hydrolysed within 4 days and

supergranules within 8 days whereas sulphur coated urea hydrolysed more gradually. Moisture regime was found to influence the hydrolysis of urea. Farooqui et al. (1983) observed complete hydrolysis of urea within 11 days and found that mineralization potential of soil under aerobic condition was more than anaerobic. Kumar and Wagenet (1984) indicated that the rate of urea hydrolysis increased with water content.

Balwinder Singh and Bajwa (1986) observed that urea hydrolysis was considerably more with increase in soil pH and the time required for complete hydrolysis to occur ranged from 3-14 days. The average time for one half ($t^{1/2}$) of the hydrolysis to occur ranged from 0.51 to 4.55 days. Simpson and Melstead (1963) noted that compared to 1°C, hydrolysis rates were 2-6 times greater at 25°C.

An increase in bulk density from 0.8-1.4 g cm⁻³ markedly increased the hydrolysis of surface applied urea in soil that contained water more than 6 per cent and upto near field capacity, (Savant et al. 1987).

Hydrolysis of urea is slightly fast in upland conditions than water logged condition, Savent et al., (1985) Tewatia, (1986).

The duration of urea hydrolysis generally varies from 1 to 7 days depending upon urea application rates, temperature, soil pH, moisture conditions and organic

matter content of soil (Carpena et al., 1965; Knop and Mastalir 1970; Shankhayan and Shukla, 1976; Skiba and Wainwright, 1984). However, some workers reported that urea hydrolysis period may extend from 1 to 7 weeks depending upon soil pH, salinity, substrate concentration and method of urea application. (NG and Tay, 1977).

The hydrolysis of urea in soil generally follows the Michaelis-Menten Kinetics, i.e. hydrolysis rate increases with increasing substrate concentration until the enzyme is saturated (Tabatabai, 1973).

2.3.5. Adsorption of urea in soils

The significance of urea adsorption in soils is not considered as much as that of NH_4^+ absorption. Broadbent et al (1958) found that urea is adsorbed by weak forces in soils.

Said (1972) studied the adsorption of urea in seven Sudan soils and found that adsorption of N in urea form ranged from 2.17 to 9.42 per cent of total N applied in Tang sandy loam and Suleini clay soils respectively. Chin and Kroontje (1963) found that urea adsorption followed Freundlich type of isotherm and was not related with CEC, pH and clay content. Singh and Nye (1984) found no adsorption of urea on Begbroke sandy loam soil (pH 4.9).

2.3.6. Mineralization

The ammonia produced after enzymatic hydrolysis of urea is subjected to nitrification by a group of autotrophic bacteria of family nitrobacteraceae. When urea is applied in moist soil, it is converted into NH_3 and CO_2 with urease enzyme and NH_3 so produced is nitrified first to NO_2^- and then NO_3^- by nitrosomonas and nitrobacters species of bacteria respectively.

Factors affecting nitrification are 1) soil type, 2) temperature, 3) pH, 4) Salinity, 5) Soil moisture 6) O_2 supply and 7) other factors such as biurete content of urea, depth of placement, salts and other fertilizers, heavy metals, herbicides and pesticides application.

The best range of temperature for nitrification of urea in soils has been found between 20 to 33°C. (Mahendrappa et al., 1977 and Knop and Mastalir 1970;

The optimum soil pH range for nitrification is between 6 to 8. Many workers have shown that nitrification of urea increased with increasing soil pH towards neutrality. Simpson and Melsted, 1963; Sandanam et al 1978, Kumar et al. 1980).

In saline soils, the process of nitrification is affected adversely thus leading to the accumulation of heavy amount of nitrates (Mann, 1969, Shankhayan and Shukla, 1976).

Gandhi and Paliwal (1976) found that nitrification of urea in three Indian soils was negatively correlated with increasing salinity.

Soil moisture is the most important factor governing the rate of nitrification (Alexander, 1965; Sarigumba et al., 1978, Ivano., 1981). There is no nitrification increase as water content increased from air dry to field capacity. However, further increase in water content in soil from field capacity to saturation or flooding state decreases the rate of nitrification.

2.3.7. Immobilization on urea N in soils

The microbial immobilization is commonly referred as incorporation of mineral N into organic pools. Availability of fertilizer N to plants is reduced temporarily by microbial immobilisation. The rate of microbial immobilization depends on microflora population of soil, soil pH, temperature and organic matter.

Recent studies of Mohammed et al. (1984) in field and lysimeter indicated that most of the immobilization of ^{15}N urea applied at 100 kg ha^{-1} was completed in 3 to 4 days and by 35 days about half of the N was present in organic form which was uniformly distributed throughout the top 200 mm soil. Foster et al (1985) found that after 3 months 25 per cent of total 200 kg ha^{-1} applied through ^{15}N urea was immobilized in forest flora. They also found that

microbial immobilization might be exceeded by reaction between NH_3 and soil organic matter.

2.3.8. Other losses of urea

The loss of nitrogen as volatile ammonia and the ammonia toxicity are the major problems encountered with fertilizer urea. The alkaline hydrolysis products of urea ammonium bicarbonate and ammonium hydroxide can increase the pH of soil microenvironments, resulting in the loss of soil ammonium by volatilization (Terman, 1979).

The loss of nitrogen from urea by ammonia volatilization is favoured by a high initial soil pH (Overrein and Moe, 1967) low soil buffer capacity (Ferguson et al., 1984) and high temperatures (Lippold et al., 1975; Wetselaar, et al., 1972). Ammonia losses from agricultural soils vary from 0.4 to 80 per cent of the applied urea nitrogen (Fernendo and Roberts, 1975; Gasser, 1964, Torello et al., 1983) and from 3.5 to 24.9 per cent in forest soils (Nommik., 1973, Overrein, 1968). Bouwneester et al (1985) reported a loss of 40% of the urea nitrogen when a simulated rainfall of 1 cm was applied 7 days subsequent to fertilization. Research reports by several workers (Bouldin and Alimagno, 1976; Vlek and Craswell, 1979) revealed that NH_3 loss was to the extent of 30 to 60 per cent of applied N in low land rice soils.

Apart from the various losses mentioned earlier, the mobility of urea beyond the root zone may also

be considered as a loss by transport. The important factors affecting the transport of urea in soils are, soil texture, urea application rate, initial soil moisture, and the rate and method of applications of water.

2.4. Quantification of urea movement in soils

The important factors affecting the transport of urea in soils are, soil texture, urea application rate, initial moisture content and the application of water. Eventhough studies have been conducted on the factors cited, the literature on the systematic study of urea transport in relation to soil texture is limited. reported that urea behaves as a non-reacting ion like Cl with respect to its movement with soil-water before it's hydrolysis. Ghuman and Prihar (1980) emphatically stressed that "the comparative effect of soil texture on solute profiles during miscible displacement of non interacting electrolytes are not available in literature".

2.4.1. Urea transport in soils

The important factors affecting the transport of urea in soils are 1) soil texture, 2) urea application rates, 3) initial moisture content of soil, 4) rate of water application, 5) time of urea application and 6) other factors such as nitrification inhibitors etc.

2.4.2. Soil Texture

Mobility of urea is quite high in sandy and sandy loam soils than in soils with higher clay content (Broadbent et al., 1958; Haque and Ibrahim, 1965; Kumar and Wagenet, 1985; Singh and Bajwa, 1986). The authors reported that mechanical composition of soil is very important factor governing the movement of urea in soils. Singh et al. (1984) studied the transport of urea in flexiglass columns in a sandy (Typic torripasments) and sandy loam (Typic comborthids) soils. The peak depth of urea leaching in initially dry soils after 24 hours with 15 cm water application was at 48 and 77 cm in sandy loam and sandy soil, respectively. Leaching may not be an important mechanism for loss of urea in loam, silty loam and sodic soils. However, in light textured sandy loam soils leaching beyond the rooting zone may create a serious problem in fertilizer management (Singh and Bajwa, 1986). Looking into high mobility of urea in sandy and sandy loam soils, leaching of urea beyond rooting zone may be expected especially when field application of urea is immediately followed by heavy irrigations or heavy rains. Under such conditions, split application of urea followed by light irrigation should be done in order to avoid any appreciable loss of urea through leaching.

2.4.3. Urea application rates

Leaching losses of urea increase with the amount of urea applied in soil (Sarigumbe et al., 1978; Beri et al., 1978 and Tewatia, 1986).

2.4.4. Initial moisture content in soil

When urea applications in initially dry and wet soils are followed by water applications, the mobility of urea is higher in initially wet soils than in dry soils. (Fenn and Matocha, 1981). Singh et al (1984) studied the effects of different rates of irrigation water application (5, 7.5, 10 and 15 cm) in initially dry and wet (10% moisture) sandy and sandy loam soils. The depth of urea penetration immediately and 24 hours after application of water was increased with increasing water application rates. Effects of different initial moisture contents in sandy loam soils were studied by Tewatia (1986). Wet sandy loam soils were packed in 30 cm long columns to which 200 ppm urea N was applied in top one cm layer. It was observed that 70% of the $\text{NH}_4^+ - \text{NO}_2^- \text{N}$ derived from urea hydrolysis was retained in 0 to 2 cm layer at all moisture contents (25, 50, 75 and 100% of FC) and rest 30% was present in the bottom layers. The depth of movement of NH_4^+ and NO_3^- increased with increasing moisture content.

2.4.5. Rate of water application

Effects of water application rates on transport and leaching of urea, NH_4^+ and $\text{NO}_3^- \text{N}$ in laboratory and field conditions were studied by several workers (Haque and Ibrahim, 1965; Protasov and Karasteleva, 1972; Wagenet et al., 1977; Bauder and Schmeider, 1970; Tanji et al., 1967;

El-wali et al., 1980 Fenn and Matocha, 1981; Shinde et al., 1982; Maustafa and Khadar, 1983; Singh et al. 1984; Singh and Bajwa, 1986; Tewatia, 1986).

Praveen kumar., et al (1990) studied the effect of method of application of urea, time and depth of water application on movement of urea in an arid sandy soil. In soil columns, movement of urea applied on soil surface and mixed in 0-5cm, 5-10 or 10-15 cm depth layer of soil and its subsequent redistribution as NH_4^+N was studied in initially dry and moist soil. The quantity of water representing different rainfall situations was applied (i) immediately and (ii) 48 hours after the addition of urea. The results revealed that in the initially dry soil, when water was applied immediately after the addition of urea, the urea moved along with the water front but it lagged behind the front in initially moist soil. The depth of urea movement increased with increase in the amount of water applied and was more in initially moist soil.

Ghuman and Prihar (1980) studied the displacement of a surface applied chloride slag as a function of initial soil wetness, amount and rate of water application and redistribution time in soils of three different textured soils, viz., loamy sand, sandy loam and silt loam. For air-dry soil, maximum solute concentration occurred at the wetting fronts in sandy loam and silt loam soils but lagged behind the front in loamy sand soil. After redistribution, the salt peak was located several centimeters behind the wetting front

in air-dry loamy sand soil, but coincided with the wetting front in air-dry sandy loam and silt loam soils. In initially moist soils the salt peak lagged behind the wetting front in all soils. They also had reported that the comparative effects of soil texture on solute profiles during miscible displacement of non-interacting electrolytes are not available in literature. Similarly the disagreement on the effect of initial wetness of soil on salt displacement by water still persists. (Nielson and Biggar 1961; Warrick et al. 1971)

2.4.6. Time of urea application

It is generally agreed that leaching losses of N from urea can be reduced considerably in field crops by splitting the urea doses. Bauder and Schmeider (1979) reported that leaching loss of $\text{NO}_3^- \text{N}$ reduced considerably by splitting the urea with optimum irrigation (18.3 cm). Gupta et al (1982) found that splitting of 150 kg N ha^{-1} of urea applied in one to four split doses at different growth stages of wheat in a sandy soil reduced the leaching losses as NO_3^- with light (5.5cm), medium (7.5cm) and heavy (9.5cm) irrigations. They found light irrigation with three split applications of urea was better for wheat crop in sandy soils. However, with excessive irrigation splitting of urea was not beneficial.

2.4.7 Other factors

Leaching loss of urea was reduced by application of nitrification inhibitors, like N-serve or coating of urea with neem cake. El-wali et al., (1980); Rao and Shinde (1985) found that application of neem cake coated urea was better in reducing leaching losses from urea in paddy crop than split application alone. Application of coated urea fertilizers in rice soils reduced the leaching losses of N substantially (Pande and Mohanty, 1986; Velu et al 1988 and Velu, 1989).

2.4.8. Modelling of urea movement in soils

The steady state of flux of water can be described by Darcey's equation Richard (1931). The steady state transport of non-reactive solute by water is assumed to be composed of the two interacting processes of diffusion and mass transport.

Miscible displacement studies based on primarily laboratory soil columns have generally been analysed through the use of convective-dispersion equation (CDE) with parameters assumed to be deterministic. Analytical solutions for such equations are numerous. The traditionally used solute-transport parameters, the convective velocity and the hydro-dynamic dispersion co-efficients can be estimated from the break through curve (BTC) Statistical parameter estimation techniques such as methods of least squares and maximum-likely hood procedures

are common at present (Kool et al., 1987). Apparent dispersion co-efficients are usually obtained by matching the calculated with experimental data.

2.4.9. Different approaches

The first quantitative model of solute transport in soil was presented by Gardner (1956) and in a series of papers by Nielsen and Biggar (Nielsen and Biggar, 1961, 1962, 1963). Biggar and Nielsen, 1962) who considered the principal mechanisms of transport of dissolved species to be convection within flowing soil water, dispersion of the solutes by virtue of the variations in local soil water velocity and diffusion of the dissolved solutes within the soil solution. Their model has undergone many tests in the laboratory and seems to be valid beyond question when the porous medium is isotropic and homogeneous. A thorough discussion of many of these studies is given in several reviews of solute transport (Gardner, 1965; Biggar and Nielsen, 1967; Boast, 1973; William, 1978).

The model presented by Nielsen and Biggar was solved by these authors only for a specialized set of surface conditions and for study of water flow without plant water uptake. More complex mathematical models were presented by Bresler (1967), who used a mixing cell model and for infiltration and redistribution, and by Henks et al., (1969) who solved the general one-dimensional water and salt flow equations on a computer. These latter approaches

require substantial data input on soil water properties to characterize the water regime. However, Wierenga and co-workers (Wierenga, 1977; Beese and Wierenga, 1980) have shown that only a small error in the prediction of solute movement results from using a steady state water flux approximation even when the water regime has wetting and drying cycles, provided that the output is plotted against cumulative drainage. This approximation greatly simplifies the calculation of solute transport.

Studies on solute transport through aggregated soils with preferential flow pathways and blocked channels showed that the simple convection dispersion model was inadequate to accurately predict the break through curves (BTC) resulting from a change in solute concentration at the inlet end. The theory has been modified in different ways to account for this phenomenon, by dividing the water volume where water is stagnant and salt is excluded (El prince and Day, 1977) or by treating the stagnant region of the porous medium as a region accessible to salts by diffusion from the mobile water region (Van Genuchten and Wierenga, 1976, 1977). The difficulty with such approaches is that they introduce new parameters into the model which can not be independently measured. El prince and Day (1977) and Bear (1979) presented a method to estimate diffusion coefficient (D_0) from the slope of the BTC at a time corresponding to the displacement of one pore volume. This method is exact, but difficult to practice because it depends on only, a few points of the BTC.

Several authors have presented models for simultaneous estimation of two or more parameters from BTC data. Parker and Van Genuchten, 1984 proposed three methods (Least sum of squares, maximum likelihood and method of moments) and Yamaguchi et al (1989) proposed two methods (Slope method and first-term method) to simultaneously estimate θ and "Do" from BTC data. Sadeghi et al., (1989) proposed a method for the estimation of molecular diffusion coefficients of urea in unsaturated soil. The correct value for the molecular diffusion coefficient of urea in soil "Do" is required to accurately predict urea movement in soil by molecular diffusion.

Sadeghi et al (1988) used an empirical equation of Papendick and Chabell to estimate diffusion coefficient (D_s) in a simulation model of urea diffusion. The equation describes " D_s " for a dissolved species in a soil to be a product of tortuosity factor squared, the species diffusion coefficient in water (D_w), and the volumetric water content. Comparisons of measured and computed urea concentration was not adequately general over a wide range of soils. The same authors (Sadeghi et al 1989) modified their approach by computing the urea concentration using numerical techniques with an initial estimate for " D_s ", instead of computing it using Papendick and Chabell's equation. A good agreement was obtained between measured and computed urea concentration with depth.

Hydrodynamic dispersion in soils presents a number of conceptual problems even though it has been studied closely for several decades. Particular difficulties relate to the nature of dispersion coefficient, to the effect of chemical reaction, and to the effect of pore water velocity gradients close to the particle surface and in inaccessible pores. A major problem in these studies appears to relate the possible velocity dependence of the dispersion coefficient.

Smiles and Philip (1978) proposed an approach to dispersion during horizontal absorption of water by an unsaturated soil material from a constant water potential source. The author extended the analysis to constant-flux absorption by an unsaturated sand. These experiments revealed that at low pecklet numbers the dispersion coefficient appears to be velocity dependent. Smiles and Philip (1978) suggested that, for unsaturated flow in a majority of field soils, the pecklet number would be small and the dispersion coefficient velocity independent.

The use of deterministic convective-dispersion equations to analyse field studies of leaching has yielded highly skewed relative frequency distributions of pore water velocity, and the apparent diffusion coefficient (Amoozegar-Fard, et al., 1982).

To describe steady state transport of urea, Wagenet et al (1977) and Kumar and Wagenet (1985) used

following input parameters viz. pore water velocity, apparent diffusion coefficient, distribution coefficients of urea, bulk density, concentration of urea, time, volumetric water content and the rate constant describing urea hydrolysis, oxidation of ammonia and nitrate reduction properties.

Wagenet (1981) gave a model describing simultaneous transformations of urea in profile at different times, water content in profile at different times, and N uptake by crop. The investigation had modelled the effects of irrigation water application, urea application rates and methods of losses of NO_3^- below rooting zone of wheat crop in a sandy soil. However, they did not consider processes like ammonia volatilization, denitrification, mineralization and immobilization of urea-N in the profile.

Tanji et al (1981) proposed a field model which calculates soil water as N fluxes in soil profile in presence of irrigated corn. They considered water movement in soil in vertical direction, NH_4^+ adsorption, NH_3 volatilization, N leaching, crop N uptake and microbial processes like mineralization, immobilization and denitrification.

Vinod kumar and Richter, (1989) recently revealed the transformation and transport of urea in soils, and discussed urea transport model which includes the various aspects such as water flow, solute flow, mineralization and immobilization, ammonia volatilization and plant uptake.

They have concluded that intensive studies should be conducted taking into consideration the effect of factors influencing the hydrolysis, nitrification and gaseous loss of nitrogen, and spatial variations in hydraulic properties of soils.

Field studies of the solute movement have been less successful than laboratory studies because of the large variations in soil water flow properties in both the horizontal and vertical directions. However, basic principles developed in the laboratory have been successfully generalized to the field situations (Jaynes, 1991., Van Wessenbeeck, 1991).

The extent of the field variability of solute transport was illustrated in a paper by Biggar and Nielsen (1976) who showed that water velocities and solute dispersion coefficients were log-normally distributed over a 150 ha field where solutes were leached by ponding. In a separate field experiment, Vander Pol et al (1977) found log-normal variation in salt concentration of a given depth even when water input flux was controlled by drip irrigation across the field. These results and other findings (Luxmoore and Sharma 1980) have led to the suggestion that solute transport be modeled stochastically, either as random Monte carlo problem (Warrick and Amoozeger-Fard, 1979) or, in terms of frequency response function (Dagan and Bresler, 1979). To date, these approaches have not been tested in the field condition.

2.4.10. Movement under specific situations

Mobility of urea in most of the laboratory experiments in transient state conditions has been studied under the following experimental situations.

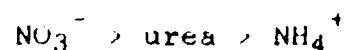
- i. When urea was applied to air-dry or initially moist soil and no water was applied.
- ii. When urea applied to air-dry or initially moist soil with different water application rates.

The mobility of urea in initially wet soil without adding water generally does not exceed 5 cm through diffusion. There was no effect of initial moisture content on mobility of urea in any soil (Campbell et al. 1984). However, results of Tewatia (1986) indicated that initial moisture content has considerable influence on movement of urea. Warnick et al (1971) reported that the disagreement on the effect of initial wetness of soil on salt displacement by water still persists.

When urea application is followed by application of different quantities of water, urea moved along with water front in air dry soil, whereas urea peak lagged behind in initially wet (50% WHC) soil (Beri et al., 1978). Similar results were obtained by Singh et al. (1984). They found, after 24 hours, urea peaks at 18, 23, 31 and 48cm, in sandy loam soil and at 22.5, 38.0, 43.0 and 77.0cm

depths in sandy soil after application of 5, 7.5, 10 and 15cm water pulse respectively. The depth of penetration of urea increased in initially wet soil. Singh and Bajwa (1986) found that urea peak concentration in sandy sodic soil of North India at 12, 22 and 27.5cm depth after application of 5, 7.5 and 10 cm water and with application of 20 and 30 cm of water, urea penetrated to 50 and 70cm depths respectively.

Wagenet et al. (1977) studied the movement of urea, NH_4^+ and NO_3^- in steady state conditions. The mobility of urea, NH_4^+ and NO_3^- was found to be in the following order;



The transport of urea in field depends on soil texture, amount of irrigation water applied and initial water content in soil profile. Most of the studies on transport of urea in transient field conditions included simultaneous transport of NH_4^+ produced after hydrolysis of urea (Gupta et al., 1982; Wagenet, 1981; and Tewatia, 1986).

Moustafa and Khadar (1983) have shown that most of the applied ^{15}N labelled urea to a clay soil remained in surface soil and only 10 per cent of the fertilizer urea was leached to 75 to 125 cm soil depth. Gupta et al. (1982) found that 50 per cent of applied N leached below 60 cm depth with 5.5 cm irrigation and 81.2 per cent with 9.5 cm irrigation water applied after first irrigation in a sandy soil. The leaching below 180 cm soil depth ranged from 28.7

to 12.6 per cent, 42.9 to 25 per cent and 52.4 to 14.3 per cent with 5, 7.5 and 9.5 cm irrigations respectively.

Much of the research being conducted today in soil physics is directed towards developing tools for dealing with the complex problems discussed above. One of the major tools under development is the solute transport model. In its simplest form, a solute transport model may be nothing more than a guide for interpreting measurements, which in the most complex form, it may seek to describe the space and time dependence of all phases of every chemical species in the soil-water system.

Eventhough many models are available in literature, they are found to be complex in their nature. For the present no single model can be fit in for different textured soils under different water treatments. In the present study, the use of the deterministic parameters, which are not actually measured, is avoided and the functional relationship between the urea concentration and time as given by a solution of CDE is utilised for the prediction of the temporal variation in the urea concentration at different depths of sandy clay loam, loamy sand, and sandy clay soils under various rainfall conditions. Hence a simple model which predicts the temporal variation of urea concentration at different depths of the soils will be handy.

While the literature on the influence of soil texture on the urea movement are limited, those on the

influence of associate physical properties over urea transport are practically nil. In addition to the textural fractions viz., total sand, fine sand, silt and clay, the physical properties of soil such as bulk density, hydraulic conductivity, percentage of water stable aggregates are generally varying with depth. It necessitates the study on the influence of the various physical properties of soil, on the quantification of urea movement in soil.

Materials and Methods

CHAPTER III

MATERIALS AND METHODS

It is a well established fact that the application of fertilizers in soil plays a vital role in building up the fertility status of the soil. The fertilizer or solute movement in soil not only depends upon the textural and structural properties of the soil but also the rate and amount of the water application. Hence an attempt was made to study the temporal movement of one of the important nitrogenous fertilizers, namely, urea in three varied textured soils under different rainfall conditions. The study was aimed at in Constructing a simple mathematical model to describe the temporal variation in the concentration of urea at different depths of the soil columns and to understand the relationship between the various physical properties of soils and the urea transport. Undisturbed soil samples were collected at different depths from the different textural soils namely Sandy clay loam, Loamy sand and Sandy clay soils and were subjected to saturated, normal rainfall, excess of rain fall and flooded conditions. The urea was applied at the rate of 100kg ha^{-1} (50ppm) and the concentration of urea in its original form at different depths of the soil columns were periodically estimated for different days. The chemical and physical properties of the soils at different depths were estimated. Using the data observed, a simple mathematical model was constructed to

describe the temporal variations of the concentration of urea in each depth of the soil columns.

3.1. Collection of Soil samples

The soils used in this study were collected from Field No.B.46 and Field No.A 65 of Agricultural college and Research Institute Farm, TamilNadu Agricultural University Madurai and Field No.38 of Water Management Training Institute Farm, Vinayagapuram. The undisturbed core soil samples were collected for 0-10, 0-20, 0-30, 0-40 and 0-50cm depths. The core samples of 10cm thickness were also collected from 0-10, 10-20, 20-30, 30-40 and 40-50cm depths. As described in section 4 of this chapter, the undisturbed soil columns were constructed in G.I. Pipes for 0-10, 0-20, 0-30, 0-40 and 0-50cm depths of the three soils collected. The soil samples from 0-10, 10-20, 20-30, 30-40 and 40-50cm depths were separately collected for the soils. They were analysed for their physico-chemical properties following the standard procedures.

3.2. Physical properties of soils

3.2.1. Infiltration rate

The double ring infiltrometer method of Gupta and Dakshinamurthy (1981) was followed. Rings of 30 and 50cm diameter and 20cm height were driven in to the ground with the help of hammer until 10cm of each ring entered into the soil. The constant head supply of water was opened so that a constant head of 5cm was maintained on the soil

surface of inner ring. The amount of water going into the soil was recorded at 1,3,5,10,20,30,45,60 and 90 minutes in the piezometer until the value become constant. The infiltration rate was then calculated as per the method described by Gupta and Dhakshinamurthy (1981) .

3.2.2. Textural Analysis

The textural fractions of the soil samples were estimated as per the method outlined by Piper (1966).

3.2.3. Bulk Density

The core samples collected were oven dried at 105°C for 8 hours and weighed. The bulk density was calculated as mass per volume (Gupta and Dhakshinamiurthy, 1981)

3.2.4. Hydraulic Conductivity

Hydraulic conductivity of the soil samples was carried out using the constant head method (Gupta and Dhakshinamurthy, 1981) and Darcey's equation was employed to calculate K value.

3.2.5. Water Stable Aggregates

The estimation was based on a technique first developed by Tiulin (1928) and Yoder (1936) and with modifications suggested by Bayer (1956). Fifty gram of sample prepared for sturcture analysis was kept on the top sieve of a set of seives having openings of 5.2,1,0.5, 0.25,

0.1mm. Water was sprayed with a hand atomizer to saturate the sample and the soil was allowed to attain equilibrium with water. The sample was then wet sieved observing the usual details. The particles retained on each sieve were transferred, dried for 6 hours at 105°C and weighed. They were then dispersed with sodium hexametaphosphate and sand fraction was estimated. From the results the percentage of water stable aggregate was calculated (Yoder, 1936; and Baver, 1956).

3.2.6. Total Porosity, Capillary and Non-capillary Porosity

A suction of 50cm height of water column was created in the Buchner funnel and the sectional cylinder containing the known weight of saturated soil was transferred to the Buchner funnel fitted with Whatman No.40 filter paper. The soil was allowed to attain equilibrium with the applied tension for 8 hours and then removed and weighed. It was oven-dried at 105°C to constant weight. The data collected were used to calculate the total porosity, capillary and non-capillary porosity (Gupta and Dhakshinamurthy, 1981).

3.2.7. Soil moisture content

10g of moist sample was taken and dried in an oven at 105°C for 8 hours to calculate the moisture content.

3.2.8. Soil Moisture Tension Relationship

soil Moisture Tension Relationship was

determined using pressure plate apparatus (Gupta and Dhakshinamurthy 1981) .

3.3. Physico-chemical Properties

3.3.1. Soil Reaction

The pH of the soils was estimated using a pH meter in 1:2 soil water suspension Piper (1966).

3.3.2. Electrical Conductivity

The electrical conductivity of the supernatant liquid from the above suspension was determined with the help of conductivity bridge Piper (1966).

3.4. Chemical Properties

3.4.1. Organic Carbon

The organic carbon content of the soil was estimated by the method of wet chromic acid digestion of Walkley and Black (1935).

3.4.2. Cation Exchange Capacity (CEC)

Normal neutral ammonium acetate extract was used and the cation exchange capacity of the soils were determined Piper (1966).

3.4.3. Available Nitrogen

Available nitrogen content of the soils was determined by the Alkaline Permanganate method (Subbiah and Asija, 1956).

3.4.4. Available Phosphorus

Available phosphorus content of the soils was estimated by Olsen's method (Olsen et al., 1954).

3.4.5. Available Potassium

Neutral normal ammonium acetate extract was used and the content was estimated through EEL flame photometer (Standford and English, 1949).

3.4.6. Urea-N

Soil samples were removed from the bottom of all the soil columns after a regular interval of 24 hours of urea movement. Urea-N was determined in the 2MKCl-PHA extract (Douglas L.A and J.M. Bremner, 1970).

3.5. Column study

A column study was carried out to estimate the concentration of Urea-N at different depths namely 10, 20, 30, 40 and 50cm of the sandy clay loam, loamy sand and sandy clay soils.

Cylinders with 20, 30, 40, 50 and 60cm height and 8 cm diameter were fabricated with non-corrosive GI pipes. The bottom of the cylinder was sharpened for the purpose of easy driving into the soil. Out-let provisions were made in the tubes to maintain 5cm of water column on the surface of the soil column. Specially designed iron stands

were constructed for keeping the columns in a perfectly vertical position and for easy handling in the collection of soil samples. The cylinders were directly driven in to the soil as done for the collection of core samples. The soil core are was carefully collected for 10, 20, 30, 40 and 50cm columns. After removing from the soil, the bottom of each column was sealed with a muslin cloth supported by a wire gauze and the column was mounted on the iron stands.

The treatment consists of three texturally different and four simulated rain fall conditions with a common dose of Urea 100Kg ha^{-1} . The amount of water pertaining to single rain and excess of rain were calculated as described by Arnon et al.(1972).

All the soil columns were saturated with rain water. Then urea as solution was sprayed on the surface of all the soil columns. The calculated amount of water for the normal rain fall condition (83 ml), and excess of rain fall (101ml) were added to the second and third set of columns with the help of burette and a porous steel plate. Flooded condition was maintained in the fourth set of soil columns by maintained in 5cm of water column above the surface of the soil. Rain water was used throughout the study. Soil samples were collected from the bottom of the soil columns at a time interval of 24 hours. The soil samples were seperately analysed for their moisture and urea-N contents.

3.6. Urea Hydrolysis.

An incubation study on Urea hydrolysis was conducted with the surface soil of sandy clay loam, loamy sand and sandy clay soils. Ten grams of soil was mixed with the urea solution (50ppm) and incubation was carried out at $33\pm^{\circ}\text{C}$ for 4 days, 5 days and 7 days for loamy sand, sandy clay loam and sandy clay soils respectively. Urea-N was determined in 2M KCl-PMA extract. (Douglas et al. 1970).

3.7. Statistical Analysis.

The data gathered from the experiments were tested by using Factorial Randomised Block Design to deduce precise information on

- i) the concentration of Urea-N at different depths with days and treatments,
- ii) interaction of depths with Urea-N concentration,
- iii) interaction of days with Urea-N concentration,
- iv) interaction among the depths, days and treatments,
- v) interaction among the soils.

Correlation coefficients were worked out to find out the strength of relationship among the parameters studied in the present investigation (Panse and Sukathme, 1967).

Path coefficient analysis was carried out to determine the direct and indirect effects of the various physical properties of soils on the urea transport in soils (Dewey and Lu, 1959).

A curvefit invoking least square principle was performed for the prediction of the temporal variations in the concentration of Urea-N at different depths of the soil columns.

Experimental Results

CHAPTER IV

R E S U L T S

The results of the various experiments carried out on urea transport in different soils are presented in this chapter under the following headings

1. Profile description of the soils
2. Soil properties
3. Temporal and spatial variations of urea concentration in soil columns
 - i. Sandy clay loam soil
 - ii. Loamy sand soil
 - iii. Sandy clay soil
 - iv. Pooled analysis on the urea concentration in different soil columns.
4. Urea hydrolysis
5. Prediction of temporal and spatial variations of urea concentration in soils
6. Relationship between urea transport in soils and their physical properties

4.1. Soil profile description

Soil samples were collected from the fields No.B46 and A65 of Agricultural College and Research Institute Farm, Madurai and in the field No.38 of State seed

farm, Agricultural Department, Vinayagapuram. The profile description for the sandy clay loam, loamy sand and sandy clay soils are presented below.

Soil type

4.1.1. Madukkar sandy loam

Location : B46, Agricultural College and Research Institute, Madurai

Land scape : Mid upland

Elevation : 147 m above MSL

Slope : B (very gently sloping)

Drainage : Moderately well drained

Parent material : Weathered granite

Soil moisture
regime : Ustic

Soil temperature
regime: Isohyperthermic

Higher category
classification : Alfisol

Typifying pedon : Madukkur sandy clay loam

Horizon	Depth (cm)	Description
Ap	0-25	Dark brown (10 YR 4/3); sandy loam; weak, fine, subangular; slightly firm, slightly hard, slightly hard, slightly sticky and slightly plastic; moderately slow permeability; many coarse roots; clear smooth boundary; pH 7.2

Horizon	Depth (cm)	Description
B _{1t}	25-60	Very dark greyish brown (10 YR 3/2); sandy clay loam; weak to moderate medium subangular blocky; very hard, firm, sticky and plastic; slow permeability; many moderately thick clay skins on ped faces; clear wavy boundary; pH 7.8
B _{2t}	60-85	Very dark brown (10 YR 2/3); gravelly sandy clay loam; moderate medium subangular blocky; slightly hard; firm, slightly sticky and plastic; moderately slow permeability; many thick clay skins on ped faces; clear wavy boundary; pH 7.8 weathered granite mixed with feruginous gravels.

4.1.2. Anaiyur soil series

Location : A65, Agricultural College and Research Institute,
Madurai

Land scape : Mid upland
Elevation : 147 m above MSL
Slope : A (nearly flat)
Drainage : Moderately drained
Parent material : Weathered granite
Soil moisture
regime : Ustic

Soil temperature
regime: Isohyperthermic

Higher category
classification : Alfisol

Typifying pedon : Anaiyur sandy clay

Horizon	Depth (cm)	Description
Ap	0-12	Dark grayish brown (10 YR 3/3); sandy clay; weak, medium sub angular blocky; slightly hard, slightly firm, slightly sticky and slightly plastic; common coarse pores; abundant medium roots; slight effervescence; moderate permeability; clear smooth boundary; pH 7.8
B _{2t}	12-54	Very Dark greyish brown (10 YR 3/2); sandy clay; moderate, medium, sub- angular blocky; slightly hard, slightly firm, sticky and plastic; few medium pores; common, medium roots; thin patchy clay skins on ped faces; few, fine, kankar nodules; moderate effervescence; moderate permeability; deep vertical cracks of 2.5 cm width tapering down; clear, diffuse boundary; pH 8.2
B _{22t}	54-80	Very dark greyish brown (10 YR 3/2); clayey; strong, coarse, angular blocky, hard, firm, sticky and plastic;

common, very fine pores; very few, very fine roots; thick patchy clay skins on ped faces; many, fine to medium kankar nodules; violent effervescence; slow permeability; pH 8.5

4.1.3. Vanjinagaram soil series

Location : Field No. 38, Water management training Institute,
Vinayagapuram

Land scape : Plain land
Elevation : 147 m above MSL
Slope : A (nearly plain)
Drainage : Well drained
Parent material : Alluvium over weathered granite
Soil moisture regime : Ustic
Soil temperature regime: Isohyperthermic
Higher category classification : Entisol
Typifying pedon : Vanjinagaram loamy sand

Horizon	Depth (cm)	Description
Ap	0-25	Dark greyish brown (10 YR 3/4) moist; loamy sand; massive; friable moist; many coarse and few fine pores; common fine and few coarse roots; rapid permeability; clear smooth boundary pH7.2

A ₁₂	25-48	Dark greyish brown (10 YR 3/3) moist; loamy sand; massive; very friable moist; many coarse and few fine pores; common fine and few coarse roots; rapid permeability; clear smooth boundary pH 7.0
A ₁₃	48-60	Dark brown (7.5 YR 3/4) moist; loamy sand; massive; friable moist; many fine and very fine pores; few fine and very fine roots; rapid permeability; clear smooth boundary; pH 6.8
B ₁	60-90	Dark brown (7.5 YR 3/4) moist; sandy loam; friable moist; few fine and common medium pores; few fine and very fine roots; rapid permeability; abrupt smooth boundary; pH 6.8
B ₂	90-120	Dark brown (7.5 YR 3/2) moist; loamy sand; friable moist; few fine and common medium pores, few fine and very fine roots; rapid permeability; clear smooth boundary; pH 6.8
C ₁	120-150	Strong brown (7.5 YR 5/6) moist; loamy sand; friable moist; common medium pores; very rapid permeability; pH 6.7

4.2. Soil properties

Considering the various morphological, physical, physico-chemical and chemical properties, the three soils selected for the present investigation may be considered as representatives of the following three textural grades

1. Loamy sand
2. Sand clay loam
3. Sandy clay

The soils collected for the different experiments were analysed for their physical and chemical properties.

4.2.1. Physical properties

The various textural properties namely

1. Total sand (per cent)
2. Coarse sand (per cent)
3. Fine sand (per cent)
4. Silt (per cent)
5. Clay (per cent)

of the three soils are presented in tables 1 to 5 and Fig.1. The various structural properties and the moisture characters of the soils are also presented in the same tables.

The infiltration rate was higher for the loamy sand soil (3.0 cm hr^{-1}) than the Sandy clay loam (1.8 cm hr^{-1}) and the Sandy clay (0.6 cm hr^{-1}) soils.

Fig. 1 Percentage of Soil Textural Fractions

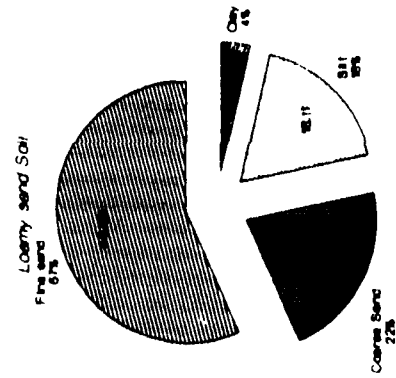
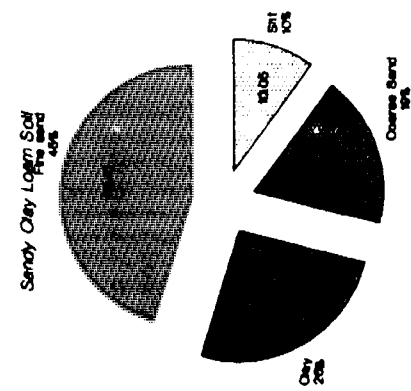
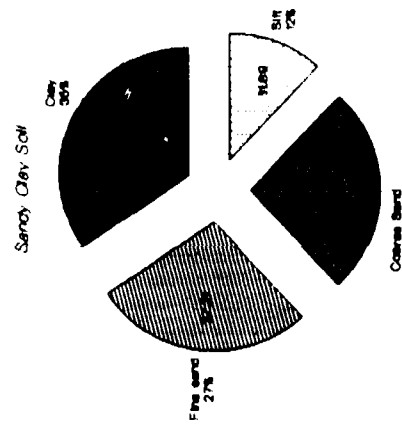


Table 1. Properties of surface soils

Soil property	Madukkur series	Vanjinagaram series	Anaiyur series
Taxonomical classification	Fine loamy, kaolinitic isohyperthermic, ustic haplustalfs	Coarse loamy, mixed isohyperthermic, ustic ustic haplustalfs	Fine, kaolinitic, isohyperthermic, ustic haplustalfs
Textural class	sandyclayloam	Loamysand	sandyclay
Infiltration ₁ rate (cm hr ⁻¹)	1.8	3.0	0.6
pH	7.2	6.7	7.8
E.C (m.mhos cm ⁻¹)	0.2	0.10	0.6
CEC (me 100 gm ⁻¹)	5.30	3.12	8.30
Organic carbon (per cent)	0.66	0.21	0.82
Available N (kg ha ⁻¹)	210	135	260
Available P (kg ha ⁻¹)	13.9	7.3	17.1
Available K (kg ha ⁻¹)	198	108	275

Table 2. Physical properties of soils
Series : Madukkur (sandy clay loam)

Depth (cm)	Total sand (per cent)	Coarse sand (per cent)	Fine sand (per cent)	Silt (per cent)	clay (per cent)	Bulk density (g cm ⁻³)	Hydraulic conductivity (cm hr ⁻¹)
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
0-10	54.69	20.00	44.69	14.15	20.54	1.462	3.117
10-20	60.22	20.40	39.82	18.18	21.44	1.498	3.771
20-30	63.71	17.94	45.78	5.79	30.30	1.594	3.511
30-40	65.44	18.28	47.16	6.01	27.66	1.512	2.768
40-50	65.70	17.48	48.22	5.33	28.90	1.560	2.248
Mean	63.95	18.82	45.13	10.05	25.79	1.518	3.083

Depth (cm)	Capillary porosity (per cent) (9)	Non-capillary porosity (per cent) (10)	Total porosity (per cent) (11)	Moisture (percent) (12)	Moisture at 1/3 bar (per cent) (13)	Moisture at 15 bar (per cent) (14)	Water stable Aggregates (per cent) (15)
0-10	25.02	5.64	30.66	10.92	17.91	9.62	62.99
10-20	37.78	4.27	42.05	13.70	22.19	10.56	70.46
20-30	3.61	3.30	34.90	13.40	10.36	0.51	53.03
30-40	27.86	8.17	36.01	15.60	22.42	12.75	49.08
40-50	16.13	9.40	27.61	15.18	19.25	11.43	47.50
Mean	20.00	6.21	34.29	15.36	20.03	15.36	56.77

Table 3. Physical properties of soil
Series : Anaiyur (Sandy clay)

Depth (cm)	Total sand (per cent)	Coarse sand (per cent)	Fine sand (per cent)	Silt (per cent)	Clay (per cent)	Bulk density (gm cm ⁻³)	Hydraulic conductivity (cm hr ⁻¹)
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
0-10	61.20	28.86	32.34	11.31	38.11	1.744	1.797
10-20	55.05	26.19	28.86	7.54	38.41	1.669	1.409
20-30	49.58	26.86	22.72	13.12	38.29	1.799	1.311
30-40	49.98	25.14	25.14	12.77	38.26	1.907	1.224
40-50	54.17	25.19	26.98	9.46	39.28	2.004	1.043
Mean	52.27	25.12	27.21	10.84	38.67	1.825	1.357

Depth (cm)	Capillary porosity (per cent) (9)	Non-capillary porosity (per cent) (10)	Total porosity (per cent) (11)	Moisture (per cent) (12)	Moisture at 1/3 bar (per cent) (13)	Moisture at 15 bar (per cent) (14)	Water stable Aggregates (per cent) (15)
0-10	32.41	7.53	39.94	19.24	18.56	8.56	76.68
10-20	26.89	8.64	35.54	15.34	23.44	12.65	73.53
20-30	25.53	5.50	31.03	17.84	22.06	12.89	58.49
30-40	23.86	10.73	34.59	17.09	18.44	8.68	59.10
40-50	22.76	15.62	38.22	14.78	30.12	13.50	62.12
Mean	26.29	9.60	35.86	16.86	20.23	11.26	65.98

Table 4. Physical properties of soils
Series : Vanjinagaram (Loamysand)

Depth (cm)	Total sand (per cent)	Coarse sand (per cent)	Fine sand (per cent)	Silt (per cent)	Clay (per cent)	Bulk density (gm cm ⁻³)	Hydraulic conductivity (cm hr ⁻¹)
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
0-10	78.98	21.41	57.57	18.49	1.36	1.438	5.864
10-20	82.81	38.15	52.66	13.85	6.62	1.424	8.937
20-30	78.81	21.26	57.55	18.86	2.98	1.448	5.198
30-40	76.16	19.84	57.12	19.38	3.12	1.513	4.952
40-50	72.16	15.46	56.52	21.65	4.86	1.528	4.176
Mean	77.78	21.46	56.28	18.11	3.63	1.467	5.828

Depth (cm)	Capillary porosity (per cent) (9)	Non-capillary porosity (per cent) (10)	Total porosity (per cent) (11)	Moisture (percent) (12)	Moisture at 1/3 bar (per cent) (13)	Moisture at 15 bar (per cent) (14)	Water stable Aggregates (per cent) (15)
0-10	18.48	4.53	23.03	16.68	21.47	19.45	38.76
10-20	28.76	4.18	33.15	16.98	12.41	7.82	27.27
20-30	36.87	4.53	40.86	16.85	14.72	7.34	26.46
30-40	38.19	16.53	54.61	20.12	18.77	11.43	33.53
40-50	38.11	16.71	54.81	20.13	13.78	8.52	36.21
Mean	31.91	18.24	42.18	18.14	16.23	9.75	38.85

Table 5. Range in physical properties of soils

Physical properties	Madukkur series		Vanjinagarao series		Anaiyur series	
	From	To	From	To	From	To
Total sand (per cent)	60.22	65.70	72.16	82.01	47.56	55.85
Coarse sand (per cent)	40.48	20.40	15.46	30.15	21.84	26.86
Fine sand (per cent)	19.62	40.22	56.66	51.86	25.72	28.94
Silt (per cent)	11.33	10.10	13.05	21.65	1.34	13.12
Clay (per cent)	20.54	30.30	1.36	6.62	30.11	39.28
Bulk density (g cm ⁻³)	1.462	1.599	1.424	1.520	1.667	2.004
Hydraulic conductivity (cm hr ⁻¹)	1.248	3.771	4.176	5.864	1.043	1.797
Capillary porosity (per cent)	18.13	37.78	18.40	38.19	22.76	32.41
Non-capillary porosity (per cent)	3.30	9.48	4.10	16.71	5.50	15.62
Total porosity (per cent)	27.61	42.05	27.73	54.01	31.03	39.94
Moisture (per cent)	13.40	18.92	16.68	20.12	15.30	19.24
Moisture at 1/3 bar (per cent)	11.91	22.42	12.41	21.47	18.14	30.17
Moisture at 15 bar (per cent)	8.51	12.75	7.02	14.45	8.36	11.50
Water stable aggregates (per cent)	47.56	40.46	26.46	36.21	58.49	46.68

Fig.2. Mean urea concentration in soils
in different days.

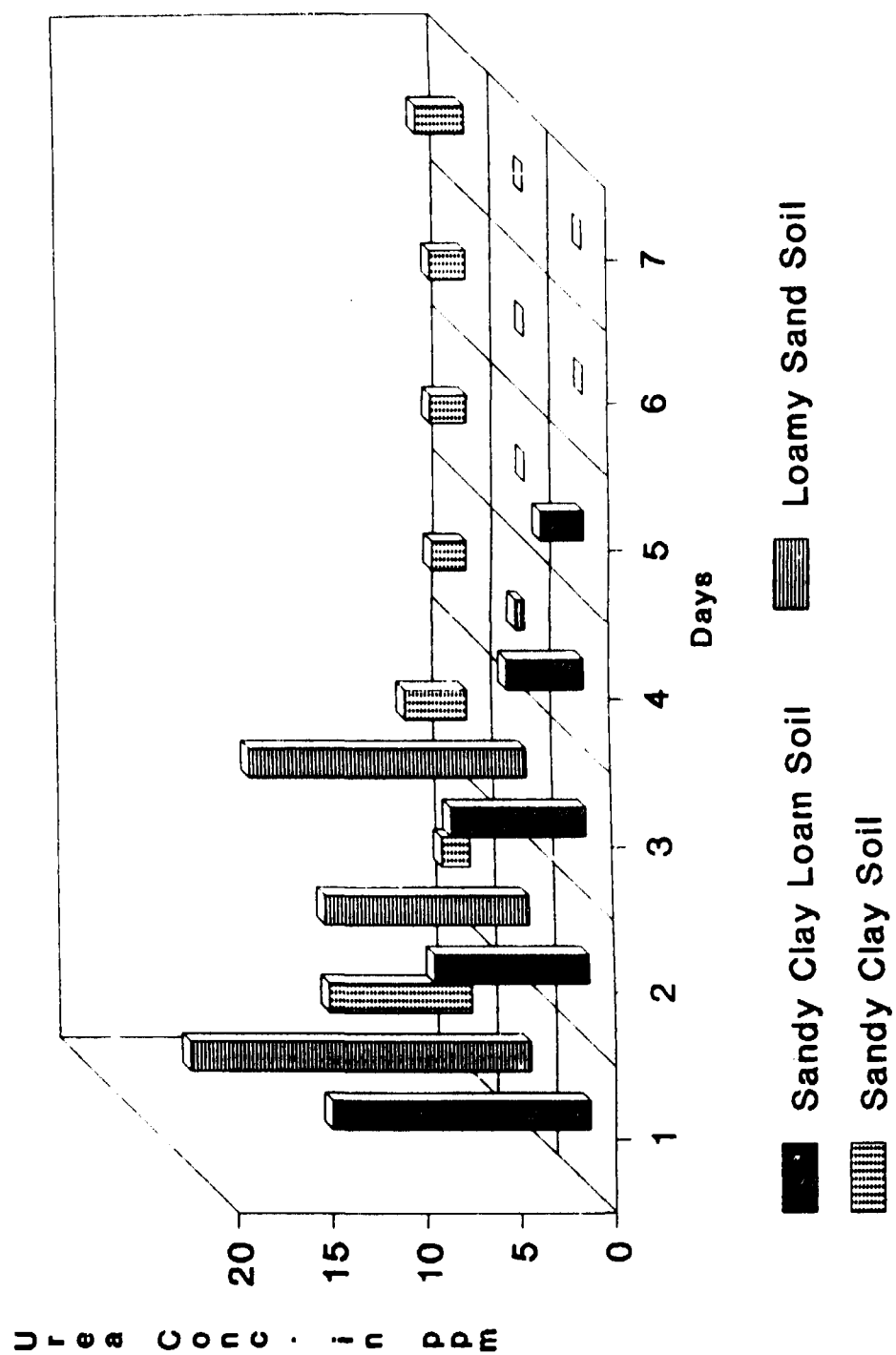


Fig.3 Mean urea concentration in soils
at different depths.

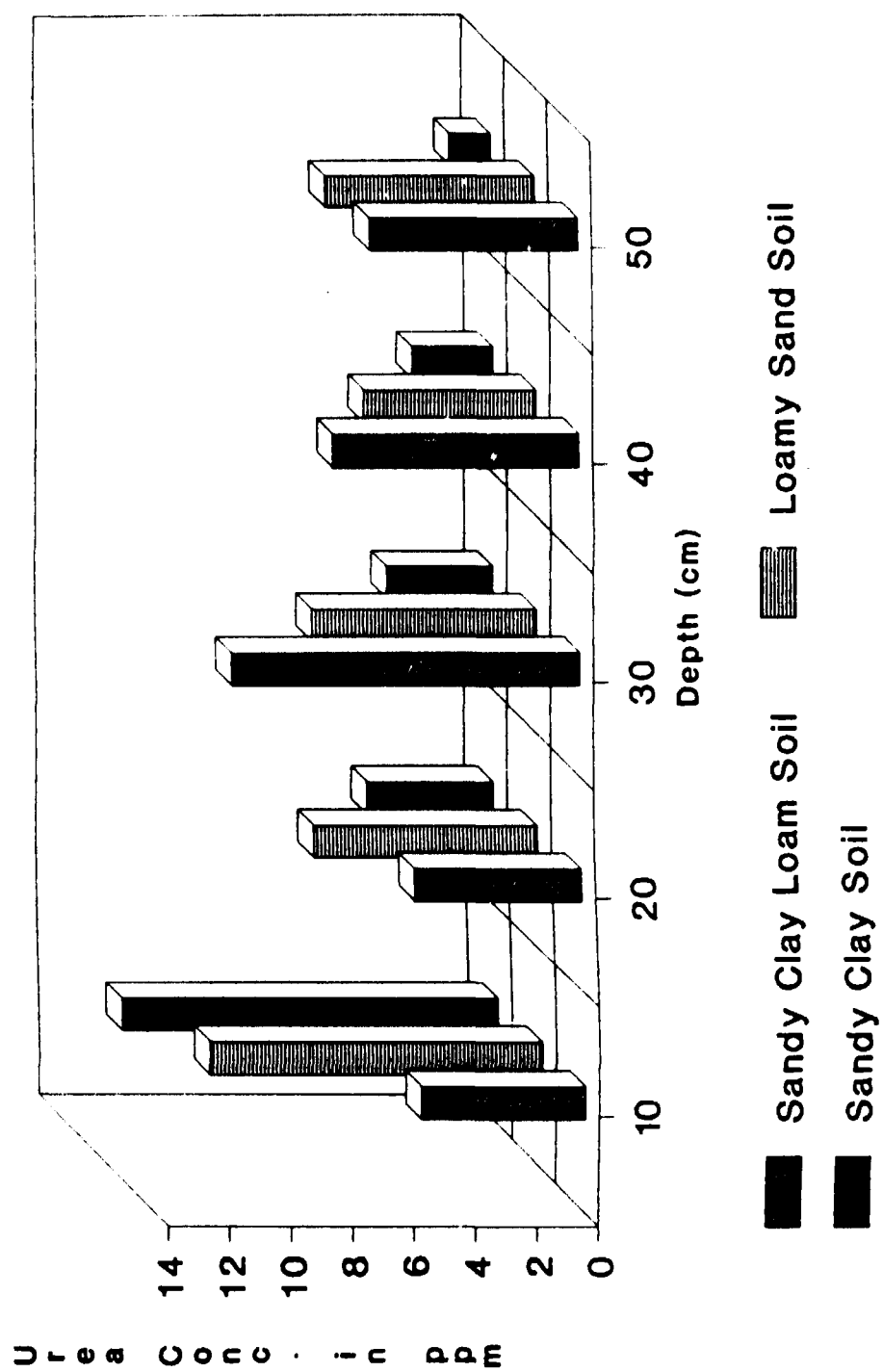
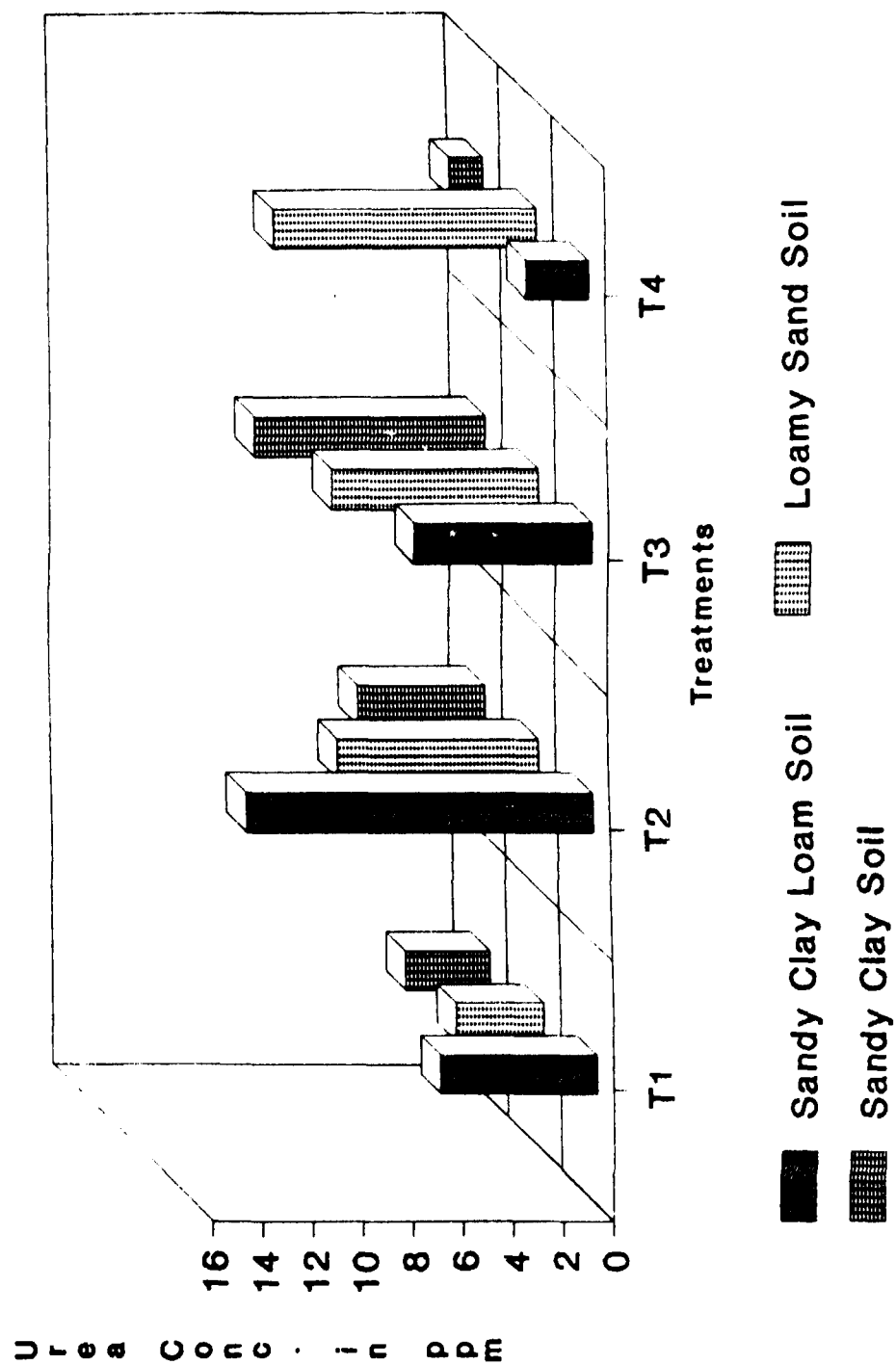


Fig.4 Mean urea concentration in soils
for different treatments.



T1-Saturated T2-Natural Rainfall T3-Excess Rainfall T4-Flooded Conditions

The three soils selected for the present study can be ranked as follows based on the combination of the high values of the fine sand (per cent), the sand (per cent) and the hydraulic conductivity with low values of the clay (per cent), the water stable aggregates (per cent) and the bulk density.

1. Loamy sand soil
2. Sandy clay loam soil and
3. Sandy clay soil

4.2.2. Chemical properties

The soils collected for the present study were analysed and the results are presented in Table 1.

The pH of the surface soil of sandy clay (7.8) was found to be higher than the sandy clay loam (7.2) and Loamy sand (6.7) soils.

The electrical conductivity was also found to be higher for the surface soil of sandy clay ($0.6 \text{ mmhos cm}^{-1}$) than for the sandy clay loam ($0.2 \text{ m. mhos cm}^{-1}$) and loamy sand ($0.10 \text{ m mhos cm}^{-1}$) soils.

The same trend was observed for the organic carbon (per cent) in the surface soils and it was 0.82, 0.66 and 0.21 per cent for the sandy clay, sandy clay loam and Loamy sand soils respectively.

Fig.5 Urea Concentration at different depths and days in Sandy Clay loam Soil.

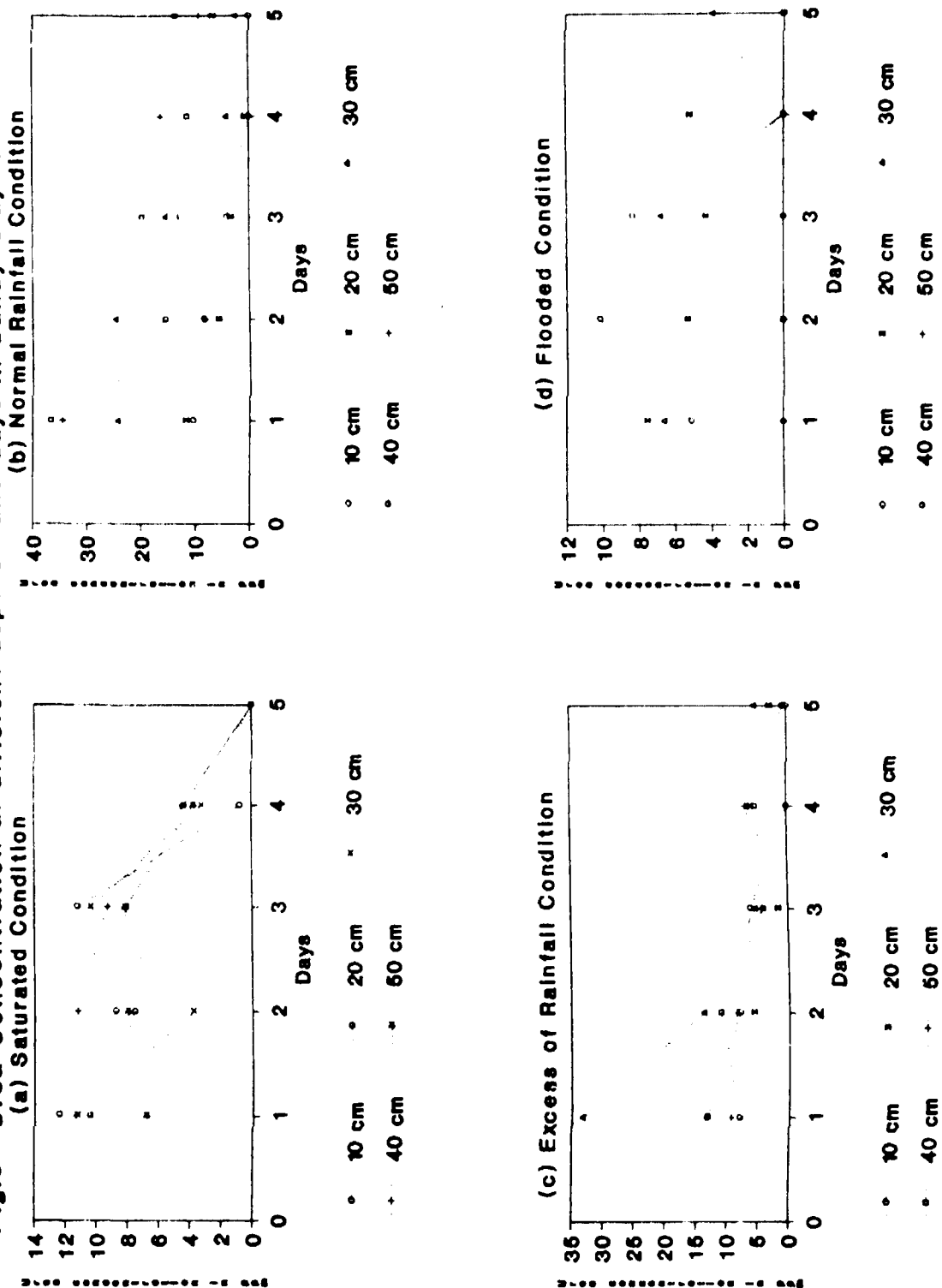


Fig.6 Urea Concentration at different depths and days in Loamy Sand Soil.

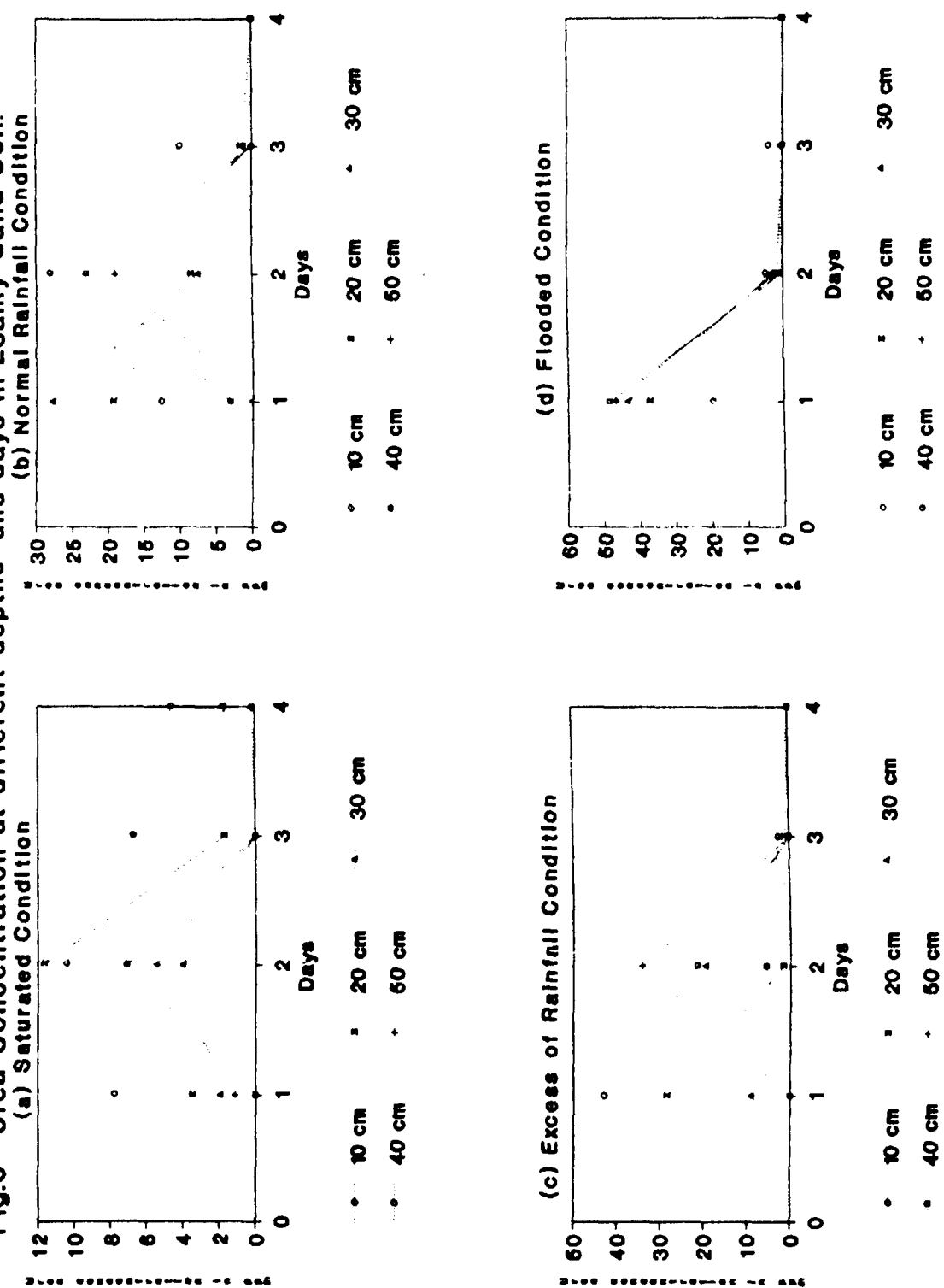
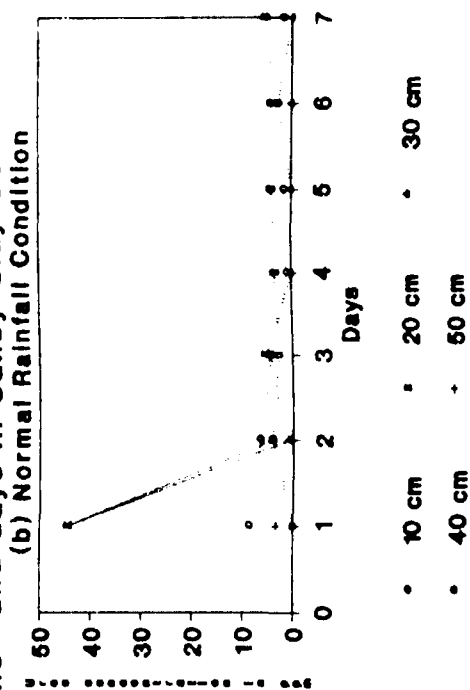
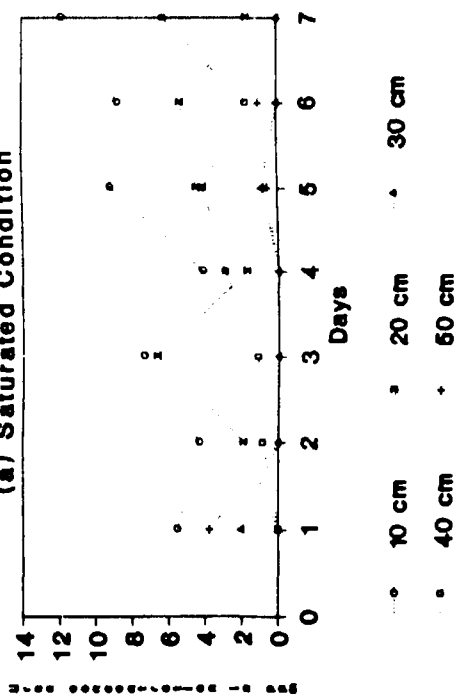
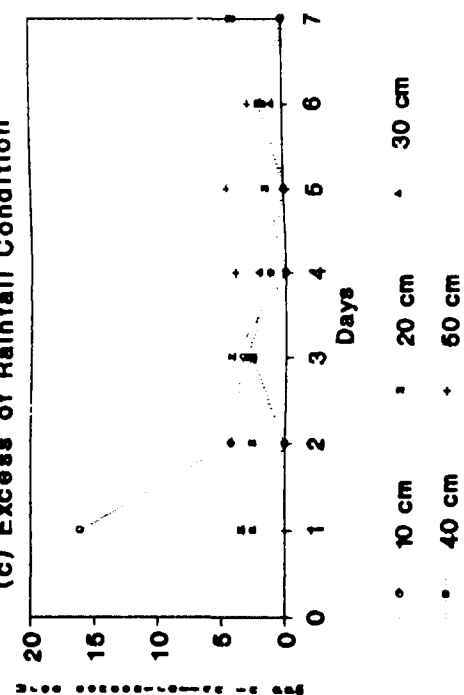


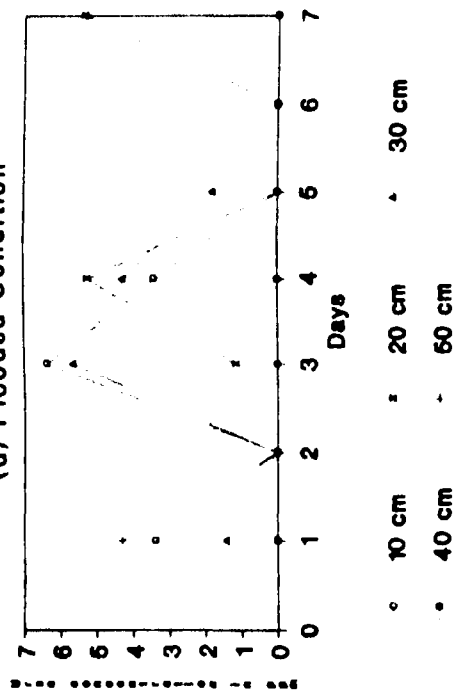
Fig.7 Urea Concentration at different depths and days in Sandy Clay Soil.
(a) Saturated Condition



(c) Excess of Rainfall Condition



(d) Flooded Condition



Similar trend was observed for the CEC of the surface soils and it was 8.30 (me 100 gm⁻¹), 5.30 (me 100 gm⁻¹) and 3.12 (me 100 gm⁻¹) for the sandy clay, sandy clay loam and Loamy sand soils respectively.

The available nitrogen, phosphorus and potassium in the surface soil was found to be low, medium and high fertility status of the soils in the following order namely

Sandy clay > Sandy clay loam > Loamy sand

4.3. Temporal and spatial variations of urea concentration in soil columns

The temporal and spatial variations of urea concentrations in three different textured soils namely sandy clay loam, Loamy sand and sandy clay with reference to the four simulated water treatments are presented in Fig. 2 to 4.

The pattern of urea movement at various depths of the soils for different days under different water treatments was found to be zig - zag in nature. The data on the urea movement in sandy clay loam, Loamy sand and sandy clay soils are presented in Fig. 5 to 7.

The presence of urea in its original form was observed upto five, four and seven days in sandy clay loam, loamy sand and sandy clay soils respectively (Table 6,12,18). The life period for urea in these soils was found to be in the following order.

Sandy clay > Sandy clay loam > Loamy sand

The maximum concentration of urea was recorded after the first day of application for all the soils and the concentration was found to decrease with days. The depth mean average of urea concentration per day in soils were observed as 7.68 ppm (15.36%), 7.06 ppm (14.12%) and 2.57 ppm (5.14%) for the Loamy sand, sandy clay loam and sandy clay soils respectively.

Simulated normal rainfall condition was found to be favourable for the urea movement in sandy clay loam and sandy clay soils whereas the flooded condition was favourable for the loamy sand soil. The statistical analysis on the interactions among, the urea concentration at different depths, for different days and water treatments are presented separately for each soil.

4.3.1. Movement of urea through soil columns of sandy clay loam soil

The transportation of urea was observed at all depths namely 10, 20, 30, 40 and 50 cm within a day. Subsequently there was a significant reduction in urea concentration in soil with days and the transport was found to cease on the sixth day.

The depth mean concentration of urea was found to be significantly higher in the lower depths (Table 6) viz., 30 cm (9.32 ppm), 40 cm (8.13 ppm) and 50 cm (6.88 ppm) than in the upper horizons viz., 10 cm (5.50 ppm) and 20 cm (5.49 ppm).

Table 6. Concentration of urea (ppm) at different depths, days and treatments in sandy clay loam soil

Depth (cm)	Urea (ppm)	Treatment	Urea (ppm)	Days	Urea (ppm)
10	5.50	T ₁	6.36	1	13.63
20	5.49	T ₂	12.00	2	8.16
30	9.32	T ₃	7.36	3	7.18
40	8.13	T ₄	2.52	4	4.07
50	6.88	--	--	5	2.29
Mean	7.06		7.06		7.06

	S.E _D	CD
Depth	0.24	0.47
Treatment	0.21	0.42
Days	0.24	0.47

Table 7. Concentration of urea (ppm) at different depths for different treatments in sandy clay loam soil

Depth (cm)	Treatments				Mean
	T ₁	T ₂	T ₃	T ₄	
10	7.31	4.58	5.40	4.72	5.50
20	6.08	5.60	5.86	4.44	5.50
30	5.73	14.21	13.86	3.46	9.32
40	7.34	19.36	5.80	0.0	8.13
50	5.35	16.27	5.89	0.0	6.88
Mean	6.36	12.00	7.36	2.52	---

	S.E _D	CD
Depth X treatment	0.84	1.40

Among the four simulated water treatments viz., the saturated condition (T_1), the normal range for condition (T_2), the excess of rainfall condition (T_3) and the flooded condition (T_4), the normal rainfall condition (T_2) was found to be significantly influencing the urea movement in sandy clay loam soil and the next significant treatment was found to be the excess of rainfall condition (T_3). The following order for urea movement was observed in the study.

$$T_2 > T_3 > T_1 > T_4$$

4.3.1.1. Interaction of depths with treatments (Table 7)

For the T_1 (7.34 ppm) and T_2 (19.36 ppm) treatments, the concentrations of urea was found to be significantly higher in 40 cm depth of the soil column. For the T_3 and T_4 treatments, it was found to be significantly higher at 30 cm and 10 cm depths respectively. The concentration of urea was found to be minimum at 50 cm depth for the T_1 (5.35 ppm), and at 10 cm for T_2 (4.58 ppm) and T_3 treatment (5.40 ppm). For the T_3 treatment there was no appreciable change in urea concentration with depths except for 30 cm depth of the soil column. For the T_4 treatment, the concentration of urea was found to decrease with depths.

4.3.1.2. Interaction of depths with days (Table 8)

During the first three days after urea application, the concentration of urea was found to be significantly higher at 30 cm (20.50 ppm) depth and during

Table 8. Concentration of urea (ppm) at different depths for different days in sandy clay loam soil

Depth (cm)	Days					Mean
	1	2	3	4	5	
10	10.25	8.79	7.45	1.02	0.0	6.88
20	10.71	6.03	4.29	4.00	2.43	5.49
30	20.50	10.28	9.48	3.42	2.91	9.32
40	13.99	9.51	8.27	5.22	3.63	8.12
50	12.69	6.17	6.39	6.69	2.45	6.88
Mean	13.63	8.16	7.18	4.07	2.28	--

	S.E _D	CD
Depth X treatment	0.84	1.40

Table 9. Concentration of urea (ppm) at different days with different treatments in sandy clay loam soil

Treat- ment	Days					Mean
	1	2	3	4	5	
T ₁	10.46	7.94	9.44	3.97	0.0	6.36
T ₂	23.47	12.46	11.17	6.51	6.40	12.00
T ₃	16.75	9.14	4.21	4.76	1.95	7.36
T ₄	3.84	3.09	3.88	1.03	0.79	2.53
Mean	13.63	8.16	7.18	4.07	2.29	--

	S.E _D	CD
Days X treatment	0.75	1.25

the last two days it was higher at 40 cm and 50 cm depths of soil columns.

4.3.1.3. Interaction of treatments with days (Table 9)

The interaction between the T₂ treatment with all days of urea transport in soil was found to be significant and the interaction between the T₄ treatment with all days after urea application in the soil was found to be meagre. The interaction effect of the T₃ treatment with days was found to be the next best to the T₂ treatment for all the days except for the third day. It was also observed that the interaction of the T₁ treatment was found to be better than the T₄ treatment and not in the other treatments.

4.3.1.4. Interaction among the soil depths, days and treatments (Table 10)

For the first day of urea transport under the T₁ treatment, it was found out that the urea concentration was more or less the same in all the soil depths except for the 50 cm depth of the soil column. For T₂ treatment, the concentration of urea was found to be more in the lower depths than in the upper depths of the soil column. For the T₃ treatment, the concentration of urea was found to be higher in upper depths than in lower depths. For the T₄ treatment, the concentration of urea was found to be more at the upper depths whereas no urea could be detected at the lower depths.

Table 10. Concentration of urea (ppm) at different depths for different treatments and days in sandy clay loam soil

Depth (cm)	Days					Days					Days				
	1					2					3				
	T ₁	T ₂	T ₃	T ₄	Mean	T ₁	T ₂	T ₃	T ₄	Mean	T ₁	T ₂	T ₃	T ₄	Mean
10	11.43	10.42	13.04	5.10	10.25	8.80	8.35	7.80	10.15	8.80	11.24	4.15	6.06	8.35	7.45
20	10.44	11.55	13.25	7.52	10.72	7.55	5.64	5.64	5.27	6.00	8.68	3.30	1.51	4.25	4.29
30	11.26	24.20	39.94	6.58	20.50	3.78	24.66	12.68	0.0	10.28	10.39	15.48	5.25	6.78	9.48
40	11.35	36.59	6.04	0.0	14.00	11.58	15.51	10.97	0.0	9.52	9.31	19.81	3.96	0.0	0.27
50	6.80	34.51	9.46	0.0	12.69	7.99	8.16	8.53	0.0	6.17	8.18	13.11	4.25	0.0	6.39
Mean	10.46	23.47	16.75	3.84	--	7.94	12.46	7.14	3.08	--	9.44	11.17	4.28	3.88	--

Depth (cm)	Days					Days				
	4					5				
	T ₁	T ₂	T ₃	T ₄	Mean	T ₁	T ₂	T ₃	T ₄	Mean
10	4.04	0.0	0.0	0.0	1.02	0.0	0.0	0.0	0.0	0.0
20	4.34	0.76	5.6	5.14	4.00	0.0	6.62	3.12	0.0	2.44
30	0.21	4.15	6.30	0.0	3.42	0.0	2.55	5.13	3.95	2.91
40	4.40	11.33	5.10	0.0	5.21	0.0	13.57	0.97	0.0	3.64
50	3.78	16.35	5.65	0.0	6.78	0.0	9.24	0.57	0.0	2.45
Mean	3.96	6.52	4.76	1.03	--	0.0	6.40	1.96	0.79	--

Depth	0.24	0.47
Treatment	0.21	0.42
Days	0.24	0.47
Depth x Treatment	0.40	0.94
Depth x Days	0.53	1.05
Treatment x Days	0.40	0.94
Depth x Treatment x Days	0.06	2.10

4.3.2. Movement of urea through soil columns of Loamy sand soil

The maximum amount of urea was found transported in loamy sand soil on the first day after application for the two water treatments namely the excess of rainfall and flooded conditions whereas it was on the second day for the saturated and normal rainfall conditions simulated in the soil columns.

The pattern of urea movement at various depths of the soil for different days of urea transport under the four water treatments was found to be zig-zag in nature. The data on the urea movement in loamy sand soil is presented in Fig. 2.

The transportation of urea took place at all the soil depths namely 10, 20, 30, 40 and 50cm within one day after application. Thereafter there was significant reduction in urea concentration of soil with days and the transport was found to cease on the fourth day onwards.

The depth mean concentration of urea was found to be significantly higher at 10 cm depth (10.87 ppm) followed by 50 cm (7.77 ppm), 30 cm (7.74 ppm) and 20 cm (7.34 ppm) which were on par with each and lower at 40 cm (5.69 ppm) depths of the soil column.

Out of the four water treatments given to the soil, the flooded condition was found to be significantly favourable for urea movement in the loamy sand soil followed

by the other treatments in the order of decrease of addition of water and the last in the order was the saturated condition.

The statistical scrutiny revealed that there was significant interaction between the urea movement at various depths and the four simulated water treatments imposed on the soil.

4.3.2.1. Interaction of depth with Treatments (Table 12)

For T₁, T₂ and T₃ treatments the concentration of urea at 10 cm depth was found to be significantly higher with the values 7.36 ppm, 12.70 ppm and 16.14 ppm respectively and for T₄ treatment, it was significantly higher at 40 cm (12.28 ppm) depth of the soil column.

4.3.2.2. Interaction of depth with days (Table 13)

After the first day of urea application, the concentration of urea at 20 cm (22.16 ppm) depth was significantly higher than the other depths. The concentration at 20 cm (22.16 ppm) depth was on par with 30 cm depth (22.06 ppm) which in turn was on par with 10 cm depth (20.77 ppm) of the soil column. The concentration of urea was found to be significantly lower at 40 cm depth (12.90 ppm) and 50 cm depth (11.96 ppm) than at the upper horizons of the soil column.

On the second, third and fourth days after

Table 11. Concentration of urea (ppm) at different depths, days and treatments in loamy sand soil

Depth	Urea (ppm)	Treatments	Urea (ppm)	Days	Urea (ppm)
10	10.87	T ₁	3.82	1	17.97
20	7.34	T ₂	8.08	2	10.83
30	7.74	T ₃	8.31	3	1.47
40	5.69	T ₄	10.51	4	0.46
50	7.17	-	-	-	-
Mean	7.68	-	7.68		7.68

	SED	CD
Depth	0.42	0.70
Treatment	0.38	0.62
Days	0.38	0.62

On the second day of urea transport and under the T₁ treatment it was found out that the concentration of urea was more at 40 cm (11.58 ppm) depth than the other depths. For the T₂ and T₃ treatments, the concentration of urea was found to be higher at 30 cm depth and for the T₄ treatment it was at 10 cm depth of the soil column.

On the third day, the concentration of urea was found to be higher at 10 cm depth under T₁, T₃ and T₄ treatments except for the T₂ treatment for which the maximum concentration was recorded at 30 cm depth of the soil column.

On the fourth day after urea application, it was observed that the concentration of urea was more at the lower depths than at the upper depths for all the moisture treatments except for the T₄ treatment for which the concentration was higher at 20 cm depth.

On the fifth day of urea transport and under the T₁, T₃ and T₄ treatments it was observed that the urea concentrations at different depths were on par with each other and in the T₂ treatment, the concentration of urea was found to be significantly higher at the lower depths than at the upper depths of the soil column.

On the sixth day of urea transport, the concentration of urea at all depths was found to be zero under all the water treatments.

Table 12. Concentration of urea (ppm) at different depths for different treatments in loamy sand soil

Depth (cm)	Treatment				Mean
	T ₁	T ₂	T ₃	T ₄	
10	7.36	12.70	16.14	7.29	10.87
20	4.68	7.33	7.70	9.65	7.34
30	3.19	9.08	7.03	11.68	7.75
40	1.82	6.53	2.13	12.28	5.69
50	2.06	4.77	8.57	11.66	6.77
Mean	3.82	8.08	8.31	10.51	--

	SE _D	CD
Depth x Treatment	0.84	1.40

Table 13. Concentration of urea (ppm) at different depths for different days in loamy sand soil

Depth (cm)	Treatment				Mean
	T ₁	T ₂	T ₃	T ₄	
10	20.77	16.17	5.18	1.37	10.87
20	22.16	5.75	1.02	0.44	7.34
30	22.06	8.45	0.43	0.05	7.75
40	12.90	9.08	0.73	0.05	5.69
50	11.96	14.70	0.0	0.42	6.77
Mean	17.97	10.83	1.47	0.47	--
SE _D CD					
Depth x Days	0.84	1.40			

Table 14. Concentration of urea (ppm) for different days under treatments in loamy sand soil

Treat- ments	Days				Mean
	1	2	3	4	
T ₁	4.22	7.71	1.69	1.68	3.83
T ₂	12.56	17.21	2.55	0.0	8.08
T ₃	16.03	16.46	0.75	0.0	8.31
T ₄	39.05	1.93	0.90	0.18	10.52
Mean	17.97	10.83	14.73	0.47	--
SE _D CD					
Treatment x Days	0.75	1.25			

urea application, the concentration of urea was found to be significantly higher at 10 cm depth with the concentration values of 16.17 ppm, 5.18 ppm and 1.37 ppm respectively.

On the fifth day, the transport of urea in its original form was found to be nil in this soil in all treatments.

4.3.2.3. Interaction of treatment with days (Table 14)

On the first day, the urea concentration in the soil was found to be significantly higher for the T₄ (39.05 ppm) followed by the T₃ (16.03 ppm) T₂ (12.56 ppm) and T₁ (4.22 ppm) treatments.

On the second day after urea application the concentration of urea in the soil column was found to be significantly higher for the T₂ (17.21 ppm) which was on par with the T₃ (16.46 ppm) followed by T₁ (7.71 ppm) and T₄ (1.93 ppm) treatments.

On the third day, the concentration of urea in the soil was found to be significantly higher for the T₂ treatment (2.55 ppm) which was on par with the T₁ treatment (1.69 ppm). The concentration of urea in the soil under the T₃ and T₄ treatments was found to be significantly less.

On the fourth day, the concentration of urea in the soil was found to be significantly higher only for the T₁ treatment (1.68 ppm) and for the other treatments the

Table 15. Concentration of urea (ppm) at different depths for different treatments and days in loamy sand soil

Depth (cm)	Days					Days				
	1					2				
	T ₁	T ₂	T ₃	T ₄	Mean	T ₁	T ₂	T ₃	T ₄	Mean
10	1.73	12.67	43.09	19.85	20.84	10.40	28.05	21.46	4.76	16.17
20	3.66	19.30	28.44	37.23	22.16	11.62	8.44	1.57	1.30	5.75
30	8.60	27.77	6.64	43.21	22.06	3.97	7.41	19.47	2.93	8.45
40	8.8	3.85	0.0	48.54	12.90	7.10	23.08	5.57	0.57	9.08
50	5.52	0.0	0.0	46.00	12.06	5.44	19.08	34.23	0.0	14.78
Mean	4.12	12.56	6.05	34.11	--	7.71	17.21	16.40	1.73	--

Depth (cm)	Days					Days				
	3					4				
	T ₁	T ₂	T ₃	T ₄	Mean	T ₁	T ₂	T ₃	T ₄	Mean
10	0.74	10.00	0.0	3.92	5.16	4.59	0.0	0.0	0.00	1.37
20	1.70	1.75	0.18	0.0	0.91	1.74	0.0	0.0	0.0	0.44
30	0.0	1.13	0.0	0.57	0.43	0.19	0.0	0.0	0.0	0.05
40	0.0	0.0	2.93	0.0	0.73	0.19	0.0	0.0	0.0	0.05
50	0.0	0.0	0.0	0.0	0.0	1.68	0.0	0.0	0.0	0.42
Mean	1.69	2.59	0.62	0.90	--	1.68	0.0	0.0	0.18	--

	SE _D	CD
Depth	0.42	0.70
Treatment	0.38	0.62
Depth x Treatment	0.04	1.39
Depth x Days	0.04	1.39
Treatment x Days	0.75	1.25
Depth x Treatment x Days	1.69	2.79

values were found to be meagre.

4.3.2.4. Interaction among depth, days and treatments (Table 15)

On the first day after urea application under the T_1 treatment, the concentration of urea was found to be significantly higher at 30 cm (8.60 ppm) and 10 cm depth (7.73 ppm) followed by 20 cm (3.66 ppm), 50 cm (1.52 ppm) and 40 cm (0 ppm) depth of the soil column. In T_2 treatment the concentration of urea was found to be significantly higher at 30 cm (27.77 ppm) followed by 20 cm (19.30 ppm), 10 cm (12.67 ppm), 40 cm (0 ppm) and 50 cm (3.05) of depth of the soil column. For the T_3 treatment, the concentrations was found to be significantly higher at 10 cm (43.09 ppm) followed by 20 cm (28.44 ppm) and 30 cm (8.64 ppm) depths. For the T_4 treatment, the concentration of urea was found to be significantly higher at 40 cm (48.54 ppm) followed by 30 cm (43.22 ppm), 20 cm (37.23 ppm) and 10 cm (19.85 ppm) depths.

On the second day of urea application, the concentration of urea was found to be significantly higher at 10 cm depth for T_2 (28.05 ppm) and T_4 (4.76 ppm) treatments and at 20 cm (11.62 ppm) and 50 cm (34.27 ppm) for the T_1 and T_3 treatments respectively. After the third day, the concentration of urea was found to be significantly higher in 10 cm depth for T_1 (6.74 ppm), T_2 (10.06 ppm) and T_4 (3.92 ppm) treatments and at 40 cm depth for the T_1 (2.93

ppm) treatments.

On the fourth day of transport, it was observed that the concentration of urea was found to be significantly higher only at 10 cm (4.59 ppm) depth of the soil, that too only for the first treatment. On the fifth day, it was found out that the concentration of urea in all depths was zero under all the water treatments.

4.3.3. Movement of urea through soil columns of sandy clay soil

The study on the transport of urea in the sandy clay soil under the four simulated water treatments revealed that the concentration of urea was found to be significantly higher on the first day after application and the transport was observed to cease on the eighth day. The concentration of urea on the fourth, fifth and sixth day was found to be on par and the concentration was found to be least in the second day of transport.

The concentration of urea was found to be significantly higher at the upper depths namely 10 cm (3.51 ppm) 20 cm (3.68 ppm), and 30 cm (2.66 ppm) than the lower depths viz., 40 cm (1.73 ppm) and 50 cm (1.25 ppm).

Out of the four simulated water treatments studied, the normal rainfall condition was found to be significantly favourable for the urea movement in sandy clay soil than the other water treatments. The concentration of urea was found to be statistically on par for T_1 and T_3 with

Table 16. Concentration of urea (ppm) at different depths days and treatments in sandy clay soil

Depth	Urea (ppm)	Treatments	Urea (ppm)	Days	Urea (ppm)
10	3.51	T ₁	2.47	1	7.53
20	3.68	T ₂	4.48	2	1.47
30	2.66	T ₃	2.09	3	3.28
40	1.73	T ₄	1.23	4	1.83
50	1.25	-	-	5	1.93
-	-	-	-	6	1.91
-	-	-	-	7	2.59
Mean	2.57		2.57		2.57
	SE _D	CD			
Depth	1.00	0.19			
Treatment	0.09	0.17			
Days	0.12	0.24			

Table 17. Concentration of urea (ppm) at different depths for different treatments in sandy clay soil

Depth (cm)	Treatment				Mean
	T ₁	T ₂	T ₃	T ₄	
10	6.40	3.20	3.21	1.22	3.51
20	2.70	8.68	1.68	1.64	3.68
30	0.36	6.24	1.75	2.31	2.67
40	2.00	2.98	1.52	0.42	1.73
50	0.91	1.27	2.28	0.54	1.25
Mean	2.47	4.74	2.09	1.23	--
		SE _D	CD		
Depth x Treatment		0.20	0.38		

each other and the least was for T₄ treatment. After the third day, the concentration of urea was found to be significantly higher in 10 cm depth for the T₁ (6.74 ppm), T₂ (10.06 ppm) and T₄ (3.92 ppm) treatments and at 40 cm depth for the T₃ (2.93 ppm) treatment (Table 15).

4.3.3.1. Interaction of depth with treatment (Table 17)

For the T₁ and T₃ treatments, the concentration of urea in the soil was found to be significantly higher at 10 cm depth (6.40 ppm) whereas for the T₂ and T₄ treatments the concentration was significantly higher at 20 cm (8.68 ppm) and 30 cm depths (6.24 ppm) respectively. For the T₁, T₂ and T₄ water treatments, the concentration of urea was found to be minimum in the lower depths and for the T₃ treatment, the minimum concentration was found to be at 20 to 40 cm depths of the soil column.

4.3.3.2. Interaction of depth with days (Table 18)

On the first day it was noticed that the applied urea had travelled upto 30 cm depth of the soil column and the concentration of urea was found to be comparatively lesser in other depths. On the second, third and sixth days of application the concentration of urea was found to be significantly higher at 10 cm depth and subsequently it was found to be higher at 20 cm depth of the soil column. On the last day of observation the concentration of urea was found to be significantly higher at

Table 18. Concentration of urea (ppm) at different depths for different days in sand clay soil

Depth (cm)	1	2	3	4	5	6	7	Mean
10	7.58	3.79	5.30	2.10	2.64	3.28	3.38	4.01
20	11.95	2.13	4.36	2.50	2.75	2.60	3.10	4.20
30	13.78	0.21	3.32	1.58	0.66	0.21	1.54	3.04
40	1.48	1.20	1.70	1.94	1.81	1.87	3.85	1.98
50	2.84	0.0	1.75	1.00	1.78	1.58	1.06	1.43
Mean	7.53	1.47	3.29	1.83	1.93	1.91	2.59	--

	SE _D	CD
Depth x Days	0.28	0.54

Table 19. Concentration of urea (ppm) at different days under different treatments in sandy clay soil

Treatment	1	2	3	4	5	6	7	Mean
T ₁	2.25	1.44	3.03	1.76	3.99	3.35	3.99	2.83
T ₂	20.08	3.07	4.28	1.51	1.90	2.53	2.43	5.11
T ₃	5.95	1.36	3.19	1.45	1.19	1.76	1.79	2.38
T ₄	1.82	0.0	2.64	2.60	0.64	0.0	2.14	1.41
Mean	7.53	1.47	3.29	1.83	1.93	1.91	2.59	--

	SE _D	CD
Treatment x Days	0.25	0.48

40 cm depth which was on par with the concentration at 50 cm depth of the soil column.

4.3.3.3. Intereaction of days and treatments (Table 19)

During the first three days after urea application, the concentration of urea in the soil was found to be significantly higher under the normal rainfall condition than under other treatments, whereas during the later three days the saturated condition was found to be favourable. Only on the fourth day, the influence of T₄ treatment was found to be dominant. During the first three days of the urea transport, the effect of the T₄ treatment was found to be the least and for the last three days, the effect of T₃ treatment was found to be the least.

4.3.3.4 Interaction among depths, days and treatments (Table 20)

On the first day of urea application, it was found out that the concentration of urea was significantly higher at 10 cm depth for the T₁ (5.53 ppm) and T₃ (16.20 ppm) treatments, at 20 cm depth for the T₂ (44.41 ppm) treatment and at 50 cm depth of the soil column for the T₄ (4.31 ppm) treatment.

On the second day, it was found out that the concentration of urea was found to be significantly higher at 10cm depth of the soil column irrespective of the treatments.

On the third day, the concentration of urea

Table 20. Concentration of urea (ppm) of different depths for different treatments and days in sandy clay soil

Depth (cm)	Days																			
	1				2				3				4							
	T ₁	T ₂	T ₃	T ₄	Mean	T ₁	T ₂	T ₃	T ₄	Mean	T ₁	T ₂	T ₃	T ₄	Mean	T ₁	T ₂	T ₃	T ₄	Mean
10	5.53	8.58	16.22	0.0	7.58	4.44	5.47	4.25	0.0	3.79	7.27	4.25	3.35	6.32	5.32	4.55	2.85	2.0	3.40	2.33
20	0.0	44.41	3.38	0.0	11.92	1.89	4.05	2.55	0.0	2.12	5.63	5.36	4.25	1.16	4.36	1.70	5.12	2.0	5.33	2.54
30	2.23	44.23	7.63	1.42	13.78	0.0	0.85	0.0	0.0	0.21	0.0	5.07	2.55	5.64	3.32	0.0	0.0	2.09	4.25	1.58
40	0.0	0.0	2.53	3.39	2.48	0.85	3.97	2.0	0.0	1.21	1.13	2.64	3.02	0.0	1.78	2.93	3.59	1.22	0.0	1.94
50	3.66	3.37	0.0	4.31	2.84	2.0	0.0	2.0	0.0	0.0	0.0	4.25	2.74	0.0	1.5	0.0	0.0	3.97	0.0	0.99
Mean	2.25	20.66	5.95	1.62	--	1.44	2.87	1.76	0.0	--	2.03	4.25	3.19	2.64	--	1.95	1.53	1.45	1.62	--

Contd....

Depth (cm)	Days					Days				
	5					6				
	T ₁	T ₂	T ₃	T ₄	Mean	T ₁	T ₂	T ₃	T ₄	Mean
10	9.16	1.42	0.0	0.0	2.65	8.72	2.54	1.84	0.0	3.28
20	4.43	3.77	1.42	1.40	2.76	5.23	3.30	1.84	0.0	2.69
30	0.85	0.0	0.0	1.79	0.06	0.0	0.0	0.85	0.0	0.21
40	2.93	4.32	0.0	0.0	1.81	1.70	4.25	1.51	0.0	1.87
50	2.57	0.0	4.53	0.0	1.78	1.04	2.55	2.74	0.0	1.36
Mean	5.99	1.90	1.19	0.64	--	3.34	2.53	1.76	0.0	--

	SE	SD
Depth	2.12	2.13
Treatment	0.07	0.17
Days	0.12	2.24
Depth x Treatment	0.20	0.38
Depth x Days	2.28	2.54
Treatment x Days	0.25	2.45
Depth x Treatment x Days	0.35	1.86

was found to be significantly higher in 10 cm depth for the T_1 (7.37 ppm) and T_4 (6.38 ppm) treatments, whereas at 20 cm depth for the T_2 (5.38 ppm) and T_3 (4.25 ppm) treatments. On the fourth day of transport, it was observed that the concentration of urea to be significantly higher only at 10 cm (4.65 ppm) depth of the soil that too only for the T_1 treatment. On the fifth day of application, it was found out that the concentration of urea in all depths was zero under all the water treatments.

On the fourth day, the concentration of urea in the soil was found to be significantly higher at 10 cm (4.65 ppm) and 20 cm (5.33 ppm) depths for the T_1 and T_4 treatments respectively whereas they were at 40 cm (3.59 ppm) and 50 cm (3.97 ppm) of the soil column for the T_2 and T_3 treatments respectively.

On the fifth day, the concentration of urea in the soil was found to be significantly higher at 10 cm (9.16 ppm) and 20 cm (4.43 ppm) depths for T_1 treatment and at 40 cm (4.32 ppm) depth for T_2 treatment and at 50 cm (4.53 ppm) depth for T_3 treatment and at 30 cm (1.79 ppm) depth for T_4 treatment.

On the sixth day of transport, it was observed that the concentration of urea was found to be significantly higher at 10 cm (8.72 ppm), 40 cm (4.25 ppm), and 50 cm (2.74 ppm) for T_1 , T_2 and T_3 treatments respectively.

On the last day of observation (Seventh day),

Table 21. Concentration of urea (ppm) in soils with depths (pooled analysis)

Depth (cm)	Sandy clay loam soil	Loamy sand soil	Sandy clay soil	Mean
10	10.25	20.85	9.32	13.47
20	10.71	19.47	10.12	13.43
30	20.46	23.44	13.34	19.08
40	19.99	15.26	5.44	11.56
50	12.69	12.36	2.77	9.27
Mean	13.62	18.28	8.20	--

	SE _D	CD
Soil	1.99	3.94
Depth	2.57	5.09

Table 22. Concentration of urea (ppm) in soils at different depths and treatments (Pooled analysis)

Soils	Concentration of urea	Depth (cm)	Concentration of urea	Treatment	Concentration of urea
Sandy clay loam	13.62	10	13.47	T ₁	0.35
Loamy sand	18.28	20	13.43	T ₂	17.69
Sandy clay	8.20	30	19.08	T ₃	15.82
		40	11.57	T ₄	11.60
		50	9.28		
Mean			13.37		11.37

	SE _D	CD
Soil	1.99	3.94
Depth	2.57	5.09
Treatment	2.30	4.55

it was observed that the concentration of urea was significantly higher at 10 cm (11.82 ppm), 20 cm (5.36 ppm), 50 cm (4.25 ppm) and 20 cm (5.34 ppm) depths for T₁, T₂, T₃ and T₄ treatments respectively. The urea transport was found to be cease on the eight day.

4.3.4 Pooled analysis on the urea concentration in the soil columns of sandy clay loam, Loamy sand and Sandy clay soils (Table 22)

The statistical analysis of the pooled data on the movement of urea in sandy clay loam, loamy sand and sandy clay soils revealed that the concentration of urea in its original form was found to be significantly higher in the loamy sand (18.28 ppm) soil than in the sandy clay loam (13.62 ppm) and sandy clay soils (8.20 ppm).

Among the four simulated water treatments given to the soils, the normal rainfall condition was found to be significantly favourable for the urea transport in soil and the least favourable was the saturated condition. The influence of the T₃ and T₄ treatments on the urea concentration in soil was on par with each other.

The concentration of urea was found to be significantly higher at the upper depths namely 10 cm (13.47 ppm), 20 cm (13.43 ppm) and 30 cm (19.08 ppm) than at the lower depths 40 cm (11.57 ppm) and 50 cm (9.28 ppm) depths of the soil column.

Table 23. Concentration of urea (ppm) in different soils and treatments in (pooled analysis)

Treatment	Sandy clay loam soil	Loamy sand soil	Sandy clay soil
T ₁	10.46	6.36	8.20
T ₂	23.45	14.41	15.22
T ₃	16.75	23.38	7.32
T ₄	3.84	18.92	2.05
Mean	13.63	18.27	8.20

	SE _D	CD
Soil	1.99	3.94
Treatment	2.30	4.55

Table 24. Concentration of urea (ppm) at different depths under different treatments (Pooled analysis)

Depth (cm)	Treatment				Mean
	T ₁	T ₂	T ₃	T ₄	
10	8.08	9.54	27.56	0.70	11.48
20	5.72	23.77	13.09	11.15	14.43
30	12.41	27.81	21.31	14.78	19.08
40	11.98	14.62	8.16	11.50	11.57
50	3.54	12.73	8.96	11.88	9.28
Mean	8.35	17.69	15.81	10.00	---

	SE _D	CD
Depths	2.57	5.09
Treatments	2.30	4.55

**4.3.4.1. Interaction between the soils and treatments
(Table 23)**

The concentration of urea in the soil was found to be significantly higher for the sandy clay loam soil in the T₁ (10.46 ppm) treatment than the other soils. In T₂ treatment also the sandy clay loam soil was found to have more urea than the other soils. Under the T₃ and T₄ treatments, the loamy sand soil was found to have significant influence on the urea concentration compared to other soils.

The interaction of the sandy clay soil with T₃ and T₄ treatments in retaining the applied urea in soil was found to be least and similarly for the loamy sand, its interaction with the T₁ and T₂ treatments was found to be least. For the sandy clay soil, its interaction with T₃ (16.75 ppm) and for the sandy clay loam soil, its interaction with T₂ (15.22 ppm) treatments with the concentration of urea in soil was found to be significant at 5% level and the two treatments were on par with each other.

For the T₁ treatment the concentration of urea was found to be significantly higher at 30 cm (12.41 ppm), but on par with the concentration at 40 cm (11.98 ppm), 10 cm (8.09 ppm), 20 cm (5.72 ppm) and 50 cm (3.54 ppm) depths of the soil column (Table 24).

In T₂ treatment the concentration of urea was found to be significantly higher at 30 cm (27.81 ppm) depth and on par with 20 cm (23.77 ppm) depth of the soil column.

In T₃ treatment, the concentration of urea was found to be significantly higher at 10 cm (27.56 ppm) depth followed by 30 cm (21.31 ppm) and 20 cm (13.09 ppm). 50 cm (8.96 ppm) and 40 cm (8.16 ppm) depths of the soil columns. For the T₄ treatment, the concentration of urea in soil was found to be significantly higher at 30 cm (14.78 ppm) which was on par with the concentration at 20 cm (11.15 ppm), 40 cm (11.50 ppm) and 50 cm (11.88 ppm) depths of the soil column.

4.3.4.2. Interaction among the soils, the depths and the treatments (Table 25)

The concentration of urea at 10 cm depth of the soil column under the T₁ treatment was found to be significantly higher for the sandy clay loam soil than the other two soils which were on par. A similar trend was observed at 20 cm depth of the soils also. However at 50 cm depth, there was no significant difference among the soils in retaining the applied urea.

For the T₂ treatment, urea concentration was found to be significantly higher at 40 cm and 50 cm depth for sandy clay loam soil, and at 20 cm and 30 cm depths for the loamy sand and the sandy clay soils.

For the T₃ treatment and for the 10, 20, 40, and 50 cm depths of the soils, the loamy sand soil was found to be significantly better in retaining the applied urea than the other two soils.

For T₄ treatment the loamy sand soil was found to have significantly higher concentration of applied urea in all the depths than the other two soils.

4.4. Urea hydrolysis

The purpose of the study was not either budgetting the urea-N and accounting the transformations into the other forms of nitrogen, nor the transformations of urea, but accounting the urea transport in its original form with reference to the temporal and spatial variations in soils. Hence a simple incubation study was conducted on the urea hydrolysis in the sandy clay loam, loamy sand and sandy clay soils.

Urea hydrolysis in sandy clay loam, Loamy sand and sandy clay soils

The data on urea hydrolysis was preceeded according to the following equation and presented in Table 26.

$$\ln (a-x) = \ln (a) - kt$$

where

a = initial concentration of urea - N

x = decrease in nitrogen concentration upto time t

k = specific rate constant

Table 26. Regression lines of $\log(a-x)$ vs time, r^2 , reaction coefficient and $t_{1/2}$ for different soils

Soil	Regression Line	R^2	K (days ⁻¹)	$t_{1/2}$ (days)
Loamy sand	$Y=3.3593 - 0.8159x$	0.8572	1.879	0.90
Sandy clay loam	$Y=3.0433 - 0.4491x$	0.8394	1.018	1.56
Sandy clay	$Y=3.0625 - 0.4267x$	0.9676	0.983	1.62

$Y = \log_{10}(a-x)$ i.e., log of unhydrolysed urea - N (ppm)

X = time intervals (days)

The urea hydrolysis was found to be more in loamy sand with 0.90 day as half life period than the sandy clay loam ($t_{1/2} = 1.56$) and sandy clay ($t_{1/2} = 1.62$) soils. It was found to be in support of the findings for the life period for urea in the three soils under the present study.

4.5. Prediction of the temporal variation of the concentration of urea at different depths of the soil columns

Miscible displacement experiments in soil columns of finite lengths can lead to a better understanding of the physical, chemical and micro biological processes that control solute dispersion in a soil. The studies based primarily upon laboratory soil columns have been analysed through the use of convective - dispersion equation (CDE) with parameter assumed to be deterministic. Many mathematical models have been developed to describe the displacement of a fluid and its dissolved constituents through a porous medium.

A general equation that have proved to be particularly useful in the laboratory studies to define and analyse the one dimensional leaching characteristics in the presence of irreversible microbiological transformations is the convective dispersion equation (CDE).

$$\frac{\partial c}{\partial t} = D \frac{\partial^2 c}{\partial x^2} - v \frac{\partial c}{\partial x} + \phi \text{ ----- (1)}$$

Where C is the concentration of the solute

v is the pore water velocity

D is the dispersion coefficient associated with the diffusion and hydrodynamic dispersion,

x is the distance

t is the time

ϕ is the net rate at which the solute is being irreversibly produced or used.

Analytical solutions for such equations are numerous. Literature are in abundance for the usage of breakthrough curves (BTC) for parameter estimation in the convective - dispersion model of solute transport. Use of analytical solutions under field conditions is often limited because of the complexity in estimating the dispersion coefficient.

The objectives in the present study is to describe the concentration of urea at different depths for various textured soils under different simulated rainfall

Table 28. Predicted equations for temporal variations of urea concentration at various depths of soils

I. Loamy sand soil			
(a) Treatment I: Saturated condition			
Depth (cms)	Predicted equation		
			R²
10	Log Y = - 0.3082 + 15.9347X ₁ + 4.8230X ₂ + 2.7330X ₃		
			0.98
20	Log Y = 21.4360 - 42.4788X ₁ - 23.7111X ₂ + 3.5222X ₃		
			0.92
30	Log Y = 16.6045 - 36.9680X ₁ - 19.3563X ₂ + 3.4175X ₃		
			0.95
40	Log Y = 27.2737 - 58.5687X ₁ - 32.5615X ₂ + 5.2953X ₃		
			0.95
50	Log Y = 19.1008 - 39.3252X ₁ - 22.4144X ₂ + 3.4440X ₃		
			0.76
(b) Treatment II: Normal rainfall condition			
10	Log Y = 21.0962 - 33.1469X ₁ - 20.4629X ₂ + 1.8902X ₃		
			0.93
20	Log Y = 15.1382 - 35.0197X ₁ - 15.4061X ₂ + 3.2298X ₃		
			0.99
30	Log Y = 14.0994 - 35.9398X ₁ - 14.3218X ₂ + 3.5514X ₃		
			0.99
40	Log Y = 39.3392 - 86.6933X ₁ - 46.1764X ₂ + 7.9650X ₃		
			0.95
50	Log Y = 41.0371 - 88.1249X ₁ - 48.9934X ₂ + 1.9676X ₃		
			0.97
(C) Treatment III: Excess of rainfall condition			
10	Log Y = 28.0233 - 67.6418X ₁ - 30.7948X ₂ + 6.5431X ₃		
			0.96
20	Log Y = - 6.7687 + 7.8925X ₁ + 10.4500X ₂ - 0.3331X ₃		
			0.99
30	Log Y = 32.7888 - 74.7578X ₁ - 37.5961X ₂ + 7.0079X ₃		
			0.96
40	Log Y = 17.9102 - 31.7710X ₁ - 20.2438X ₂ + 2.3296X ₃		
			0.99
50	Log Y = 49.1826 - 105.6168X ₁ - 58.7181X ₂ + 9.5491X ₃		
			0.95
(D) Treatment IV: Flooded condition			
10	Log Y = 0.9901 + 2.1042X ₁ + 2.6612X ₂ - 0.6001X ₃		
			0.94
20	Log Y = - 9.5744 + 13.3828X ₁ + 13.9904X ₂ - 0.7988X ₃		
			1.00
30	Log Y = 0.25077 - 8.0116X ₁ + 2.3658X ₂ + 1.1524X ₃		
			0.99
40	Log Y = -15.1186 + 24.7623X ₁ + 20.7970X ₂ - 1.7970X ₃		
			0.99
50	Log Y = - 5.4412 + 4.0573X ₁ + 9.2164X ₂ - 0.0700X ₃		
			0.99

Table 29. Predicted equations for the temporal variations of urea concentration at various depths of the soils

III. Sandy clay soil			
(a) Treatment I: Saturated condition			
Depth (cm)	Predicted equation		
			R ²
10	Log Y =	1.3148 - 1.1916X ₁ + 0.0477X ₂ + 0.3283X ₃	0.65
20	Log Y =	- 2.4399 + 9.5326X ₁ + 3.3870X ₂ - 0.8962X ₃	0.53
30	Log Y =	- 0.9562 + 0.1648X ₁ + 1.5393X ₂ + 0.1036X ₃	0.96
40	Log Y =	0.2750 - 1.4927X ₁ - 0.7856X ₂ + 0.4047X ₃	0.68
50	Log Y =	- 1.4937 + 0.0273X ₁ - 2.5717X ₂ + 0.1956X ₃	0.94
(b) Treatment II: Normal rainfall condition			
10	Log Y =	4.8667 - 7.8823X ₁ - 3.1274X ₂ + 0.5145X ₃	0.74
20	Log Y =	0.6034 - 3.8990X ₁ + 2.4120X ₂ + 0.6648X ₃	0.90
30	Log Y =	- 2.9971 + 1.2424X ₁ + 6.3625X ₂ + 0.1926X ₃	0.77
40	Log Y =	3.2433 - 2.0415X ₁ - 3.2484X ₂ + 0.0773X ₃	0.88
50	Log Y =	- 2.6608 + 4.8412X ₁ + 4.1381X ₂ - 0.3086X ₃	0.27
(c) Treatment III: Excess of rainfall condition			
10	Log Y =	2.0306 - 4.3452X ₁ + 0.4690X ₂ + 0.3273X ₃	0.90
20	Log Y =	1.4183 - 0.0953X ₁ + 0.0086X ₂ - 0.1778X ₃	0.53
30	Log Y =	- 1.2011 + 3.1860X ₁ + 2.5881X ₂ - 0.3086X ₃	0.51
40	Log Y =	3.3500 - 7.8253X ₁ - 3.3496X ₂ - 0.7890X ₃	0.32
50	Log Y =	1.9939 + 5.6764X ₁ + 2.2079X ₂ - 0.3315X ₃	0.81
(d) Treatment IV: Flooded condition			
10	Log Y =	1.1219 + 4.9192X ₁ - 0.4395X ₂ - 0.8789X ₃	0.48
20	Log Y =	4.1841 - 7.3231X ₁ - 5.0056X ₂ + 0.6317X ₃	0.32
30	Log Y =	- 0.3239 + 4.0309X ₁ - 1.1106X ₂ - 0.4046X ₃	0.25
40	Log Y =	- 0.0147 - 2.0716X ₁ + 0.9261X ₂ + 0.3098X ₃	0.91
50	Log Y =	- 0.2632 + 0.0178X ₁ + 0.1950X ₂ + 0.0811X ₃	0.18

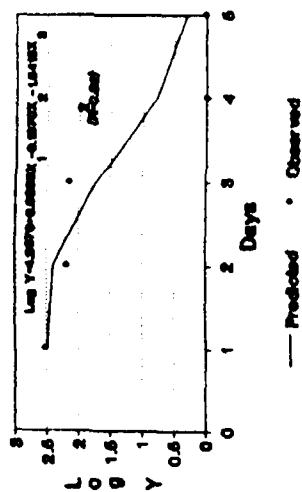
Table 30. Predicted equations for temporal variation for pooled value of urea concentration in 50 cm depth of soil columns under different water treatments.

(a) Sandy clay loam soil				
Treat- ments	Predicted equation			R ²
T ₁	Log Y =	- 4.7576 + 26.7912X ₁ + 10.9077X ₂ - 3.8085X ₃		0.99
T ₂	Log Y =	2.1990 + 0.9182X ₁ + 1.2304X ₂ - 0.2778X ₃		0.95
T ₃	Log Y =	2.3311 + 1.3869X ₁ + 0.9834X ₂ - 0.5709X ₃		0.93
T ₄	Log Y =	1.1679 + 5.0412X ₁ + 1.2963X ₂ - 1.1306X ₃		0.80
(b) Loamy sand soil				
T ₁	Log Y =	16.7965 - 32.3185X ₁ - 18.3359X ₂ + 2.5992X ₃		0.96
T ₂	Log Y =	23.5128 - 48.5582X ₁ - 25.0969X ₂ + 4.1135X ₃		0.99
T ₃	Log Y =	28.1710 - 66.0065X ₁ - 31.6675X ₂ + 6.2835X ₃		0.99
T ₄	Log Y =	- 2.5446 - 1.8079X ₁ + 5.6314X ₂ + 0.5800X ₃		0.99
(c) Sandy clay soil				
T ₁	Log Y =	0.4069 - 1.5290X ₁ + 0.02989X ₂ + 0.3413X ₃		0.69
T ₂	Log Y =	0.0358 - 2.2137X ₁ + 2.5165X ₂ + 0.4051X ₃		0.93
T ₃	Log Y =	- 0.5564 + 0.2457X ₁ + 2.0417X ₂ + 0.0907X ₃		0.76
T ₄	Log Y =	2.0884 - 1.9622X ₁ - 1.6820X ₂ + 0.0299X ₃		0.32
T ₁ = Saturated condition				
T ₂ = Normal rainfall condition				
T ₃ = Excess of rainfall condition				
T ₄ = Flooded condition				

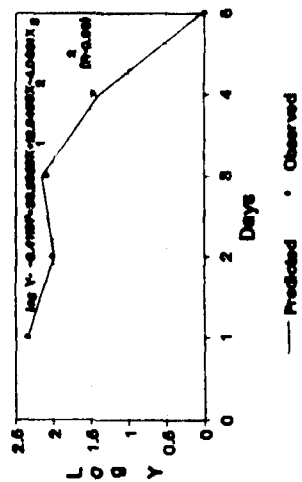
Fig 8 Concentration of Urea at Different Depths and Days

Sandy Clay Loam Soil : Saturated Condition

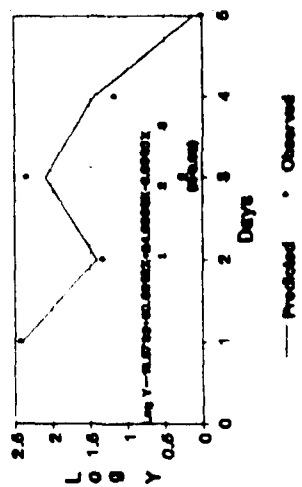
(a) 10 cm



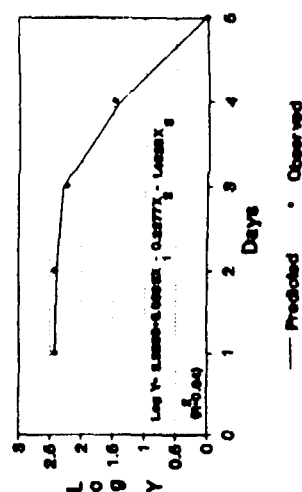
(b) 20 cm



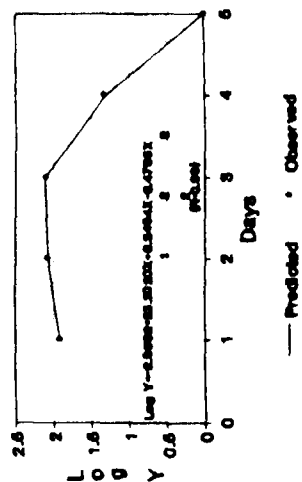
(c) 30 cm



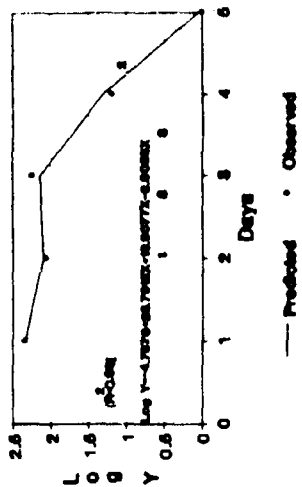
(d) 40 cm



(e) 50 cm



(f) Mean for 0-50 cm soil column



Y-Concentration of Urea in ppm

Fig.9 Concentration of Urea at Different Depths and Days
Sandy Clay Loam Soil : Normal Rainfall Condition

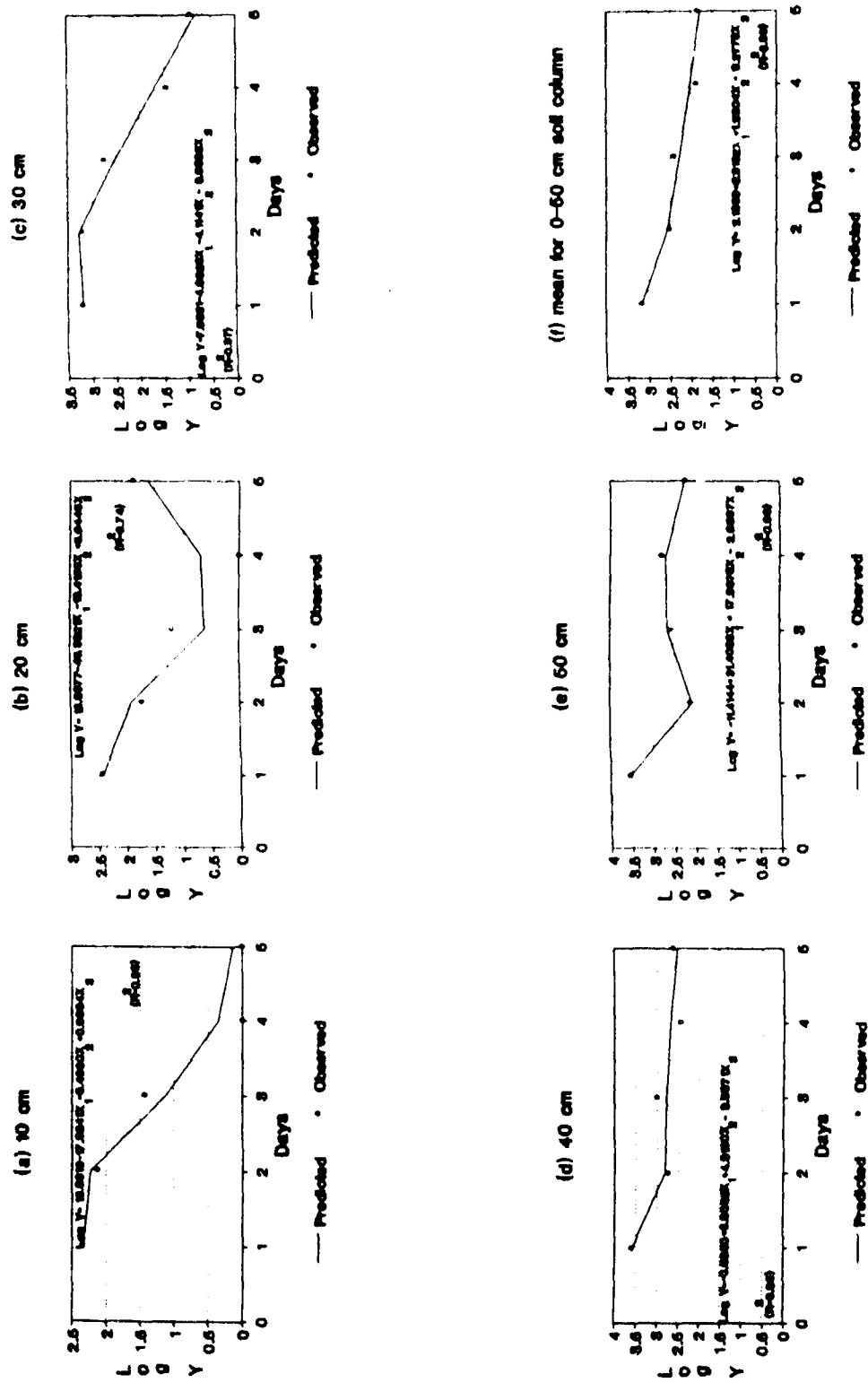
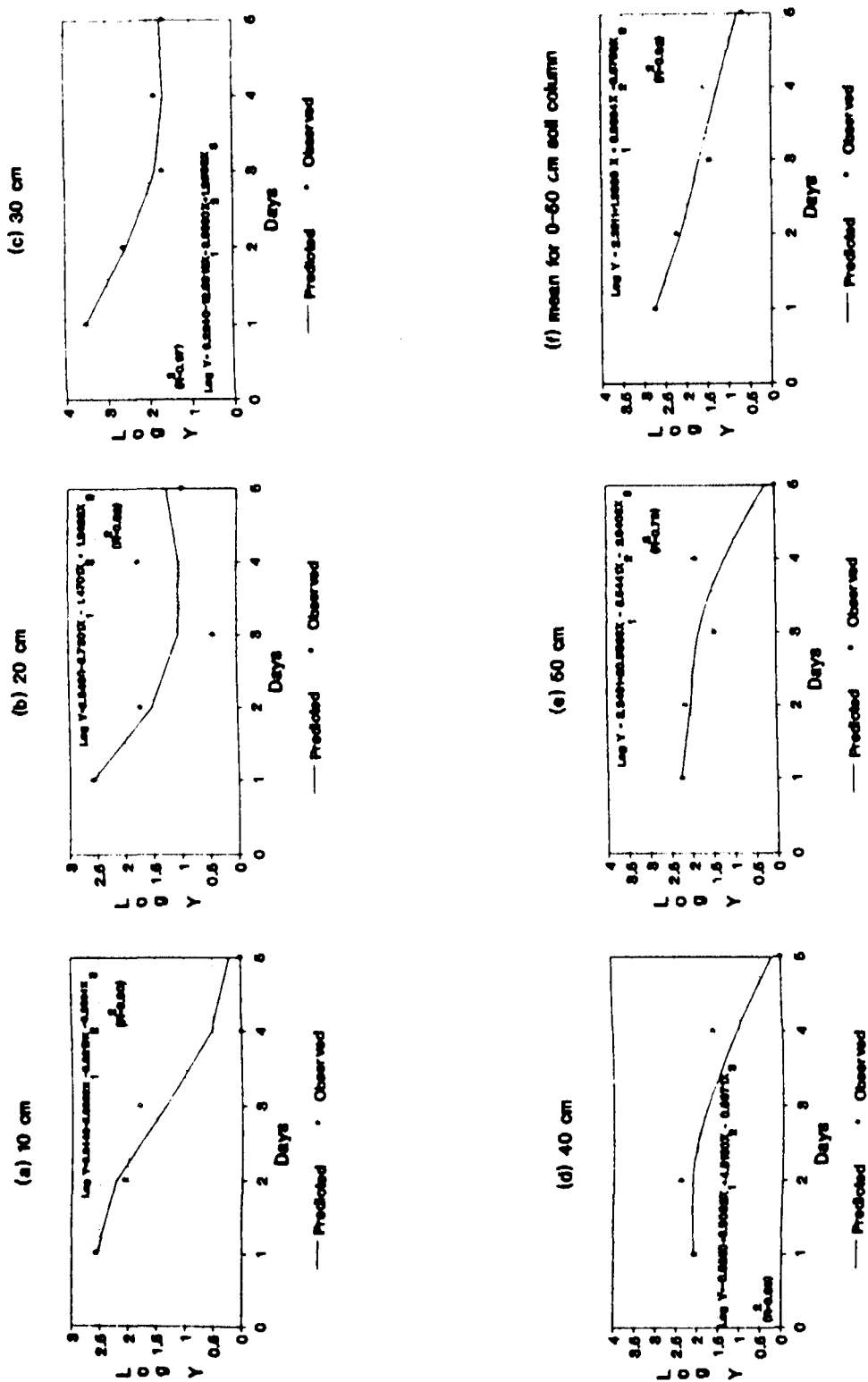
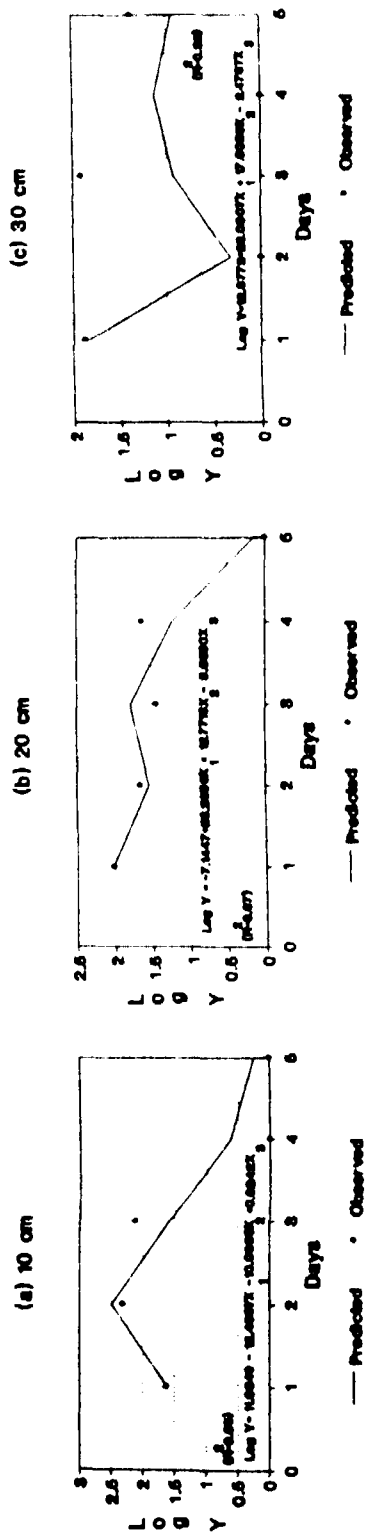


Fig.10 Concentration of Urea at Different Depths and Days
Sandy Clay Loam Soil : Excess of Rainfall Condition

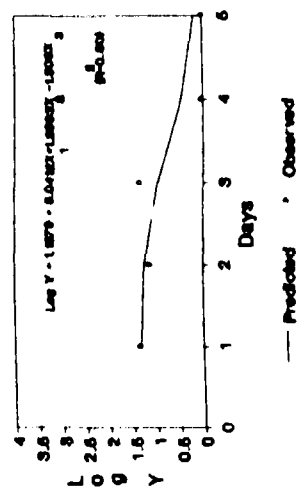


Y-Concentration of Urea in ppm

Fig.11 Concentration of Urea at Different Depths and Days
Sandy Clay Loam Soil : Flooded Condition

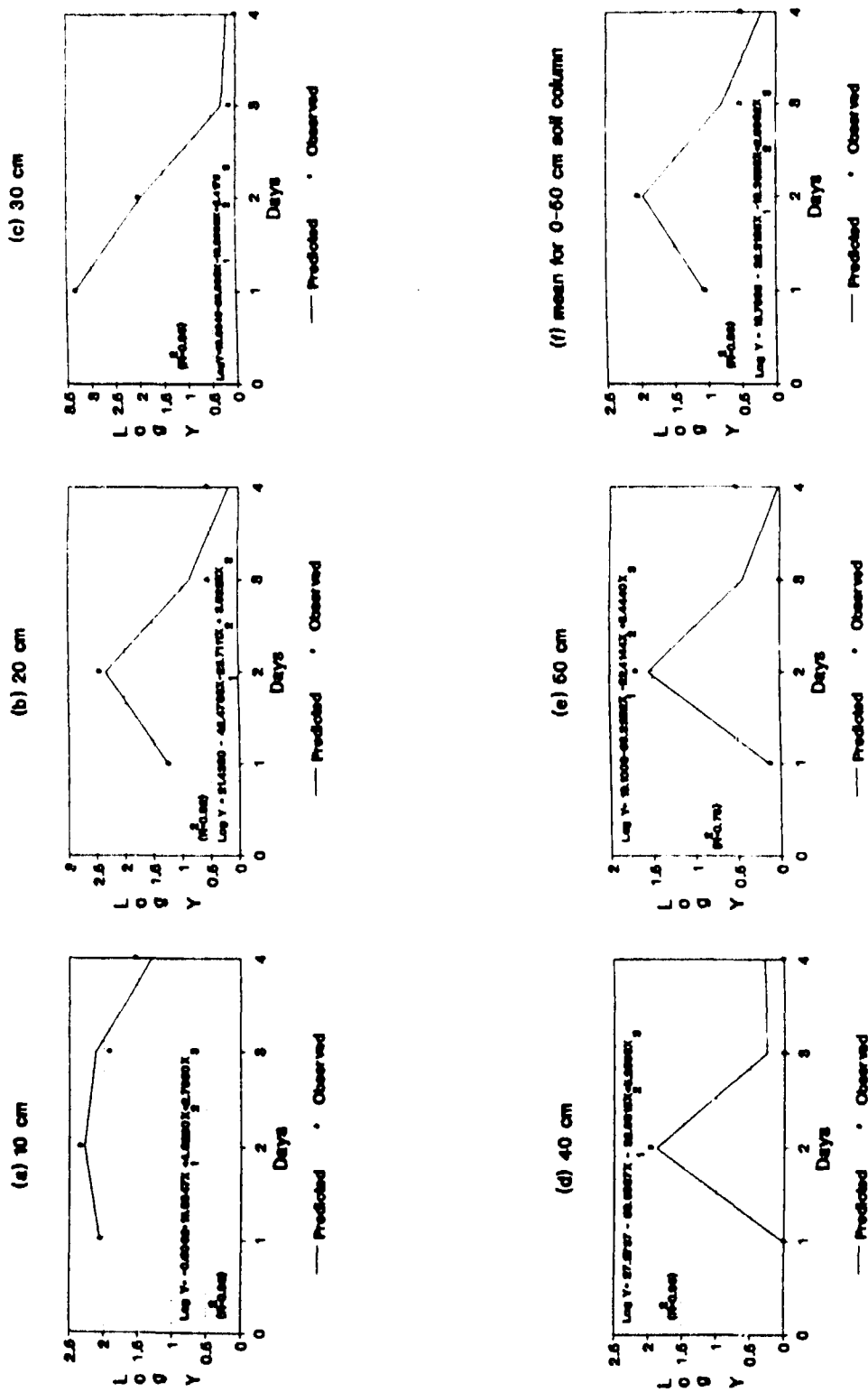


(f) mean for 0-60 cm soil column



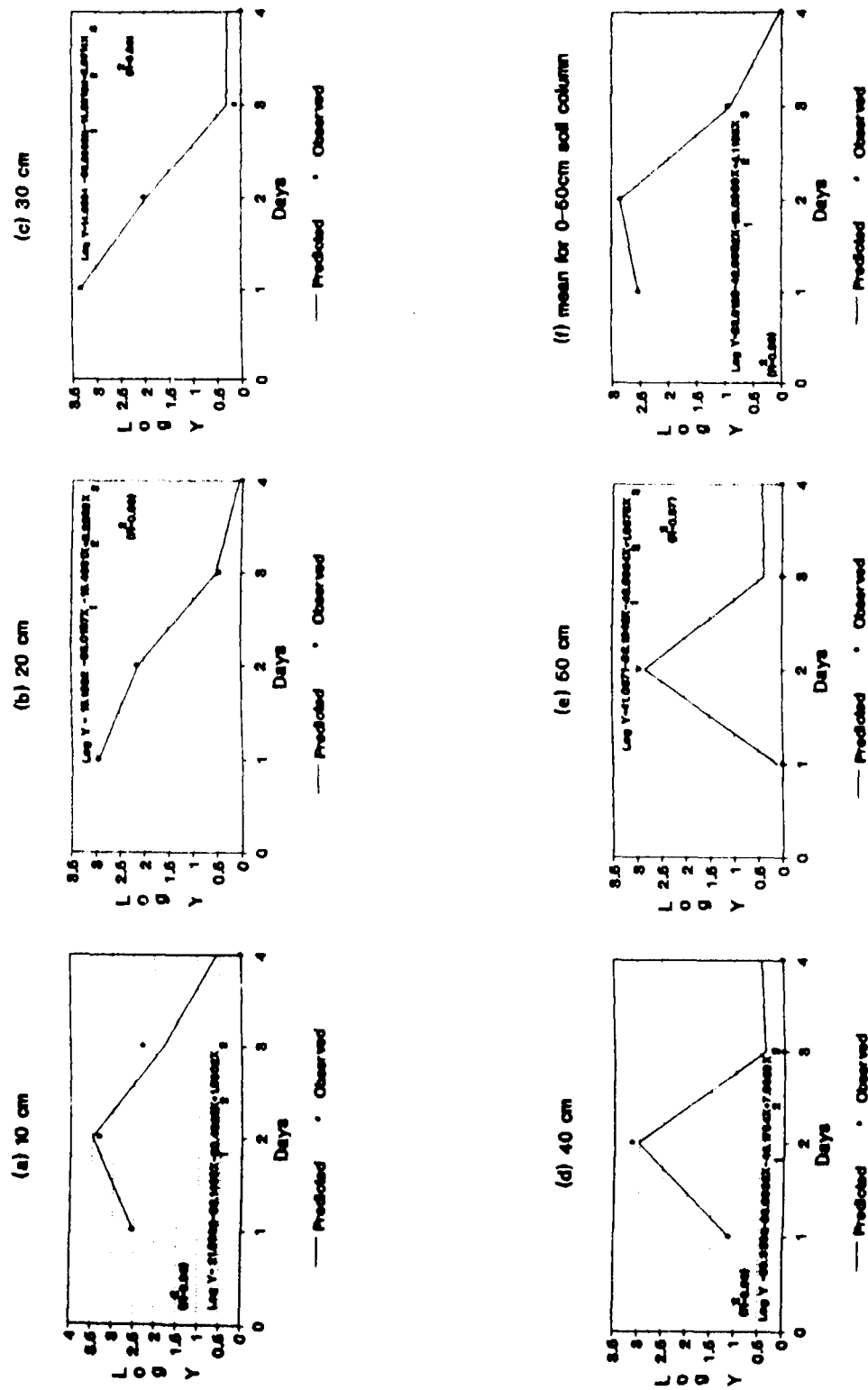
Y-Concentration of Urea in ppm

Fig.12 Concentration of Urea at Different Depths and Days
Loamy Sand Soil : Saturated Condition



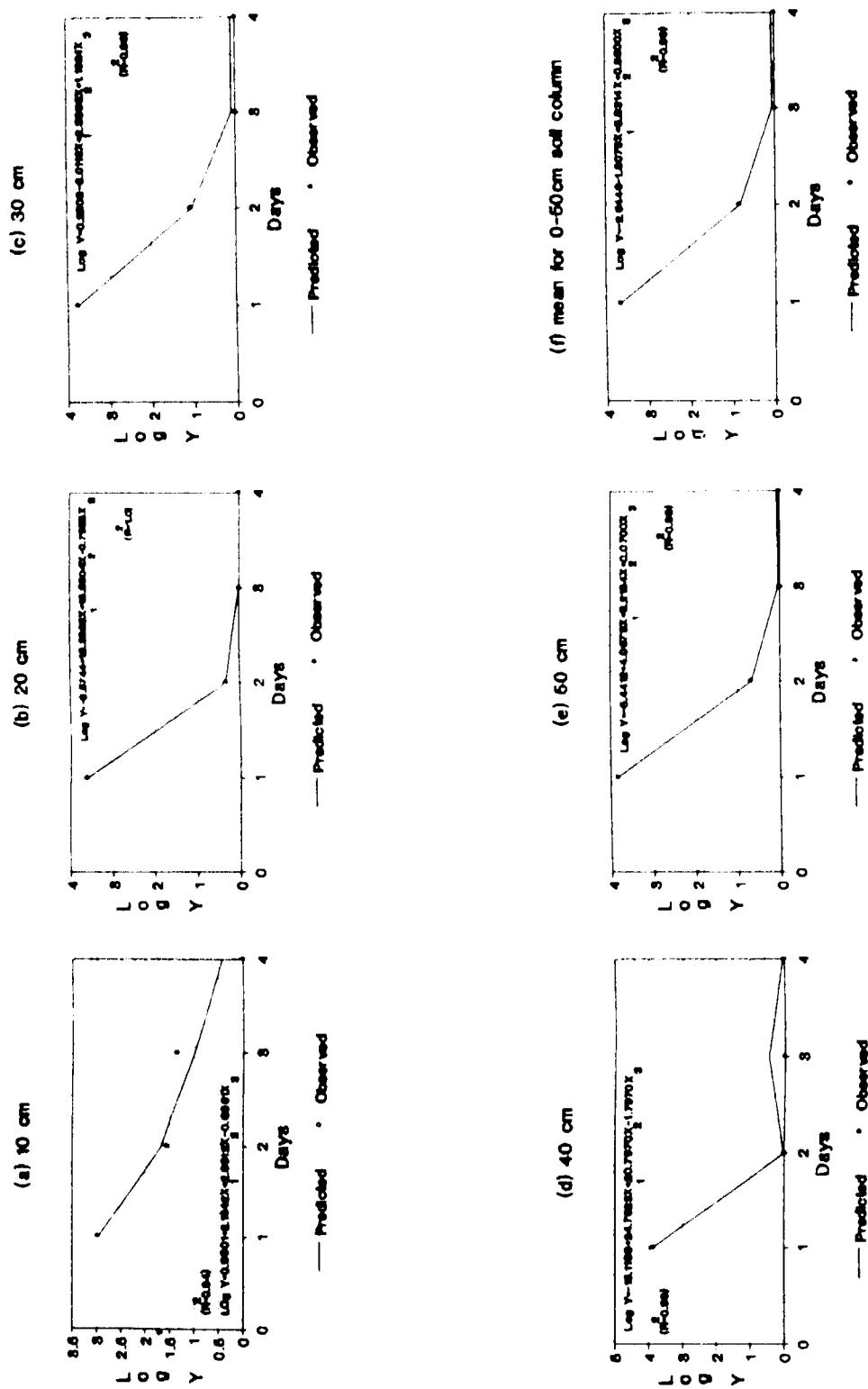
Y-Concentration of Urea in ppm

Fig.13 Concentration of Urea at Different Depths and Days
Loamy Sand Soil : Normal Rainfall Condition



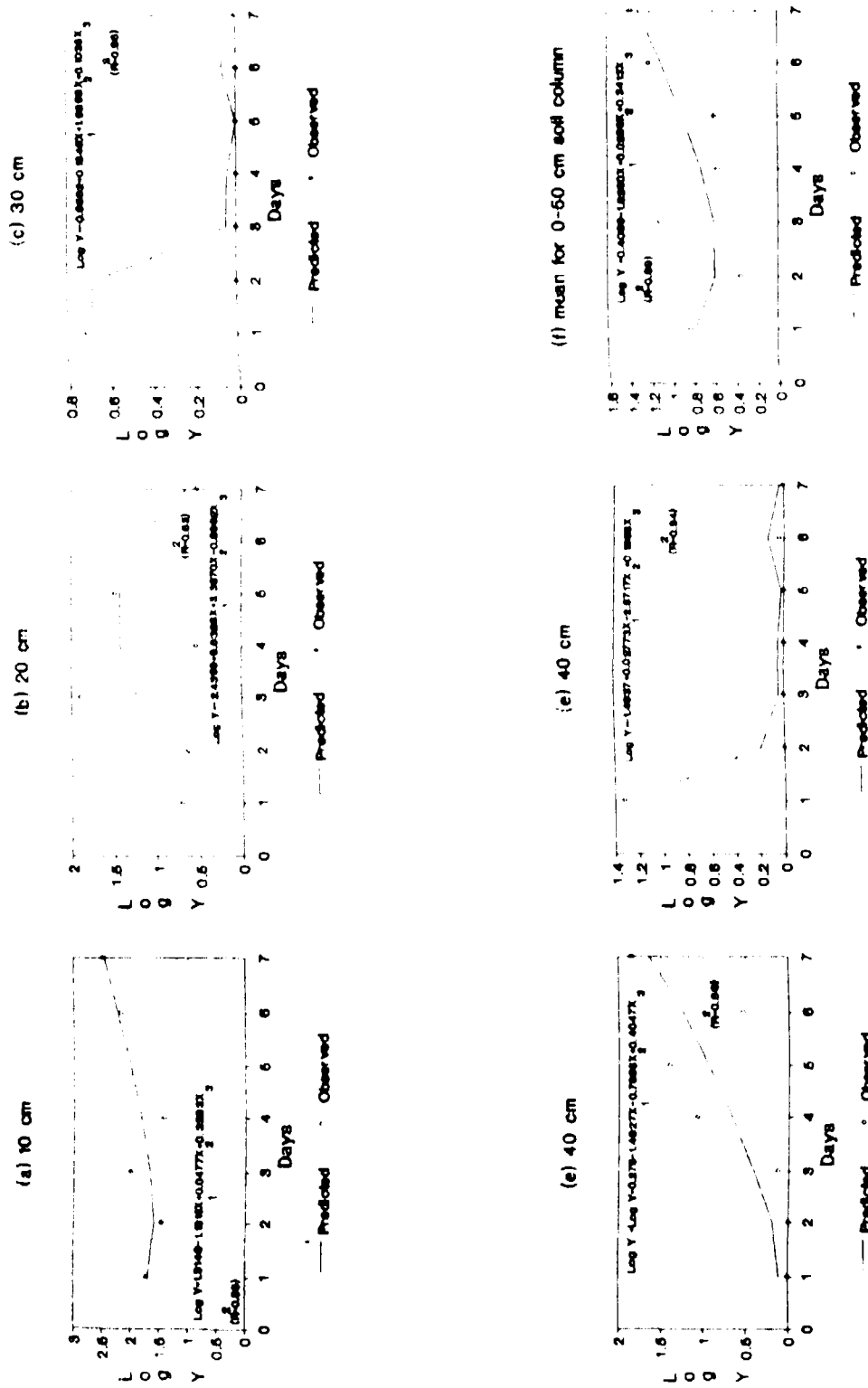
Y-Concentration of Urea in ppm

Fig.15 Concentration of Urea at Different Depths and Days
Loamy Sand Soil : Flooded Condition



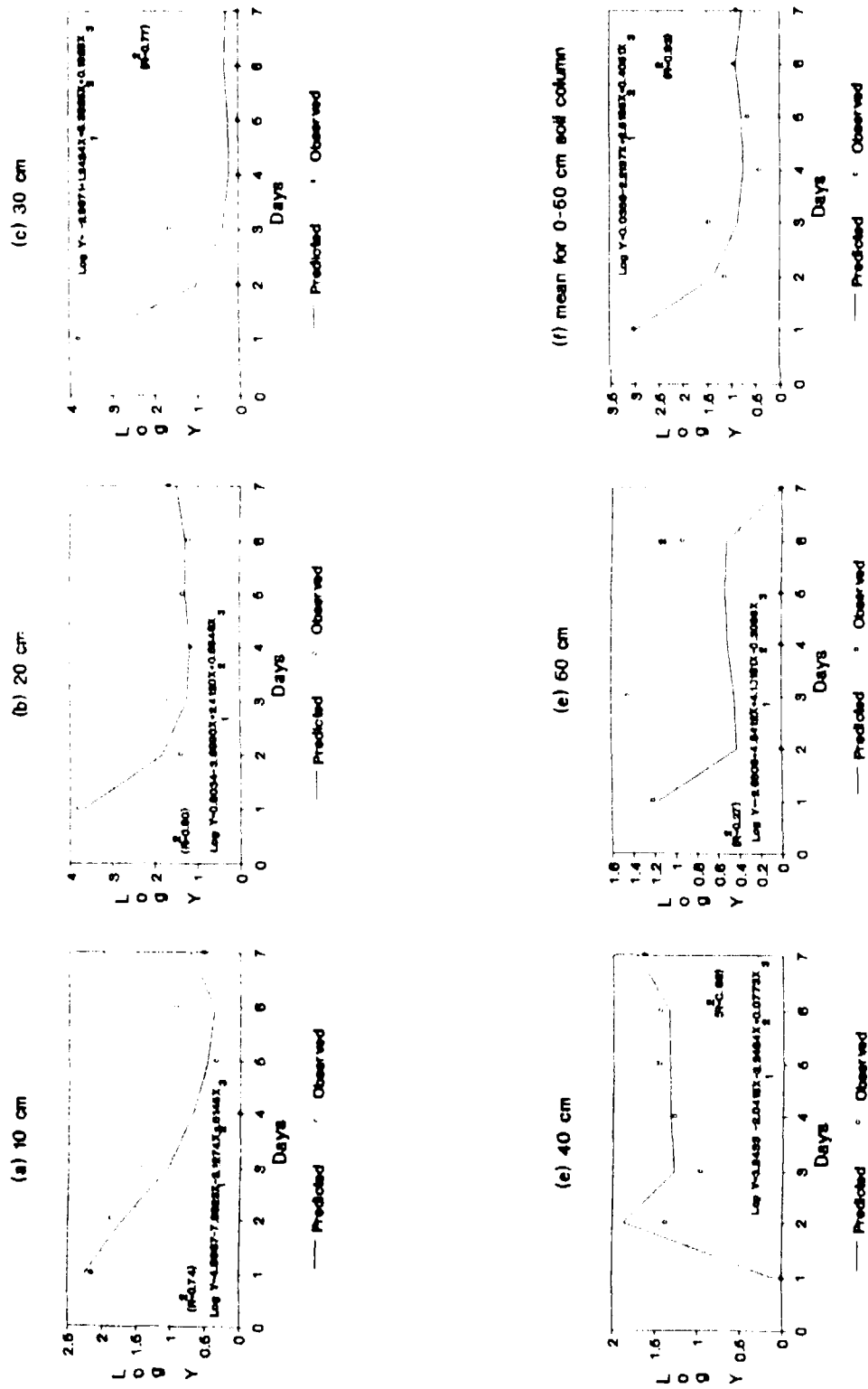
Y-Concentration of Urea in ppm

Fig.16 Concentration of Urea at Different Depths and Days
Sandy Clay Soil : Saturated Condition



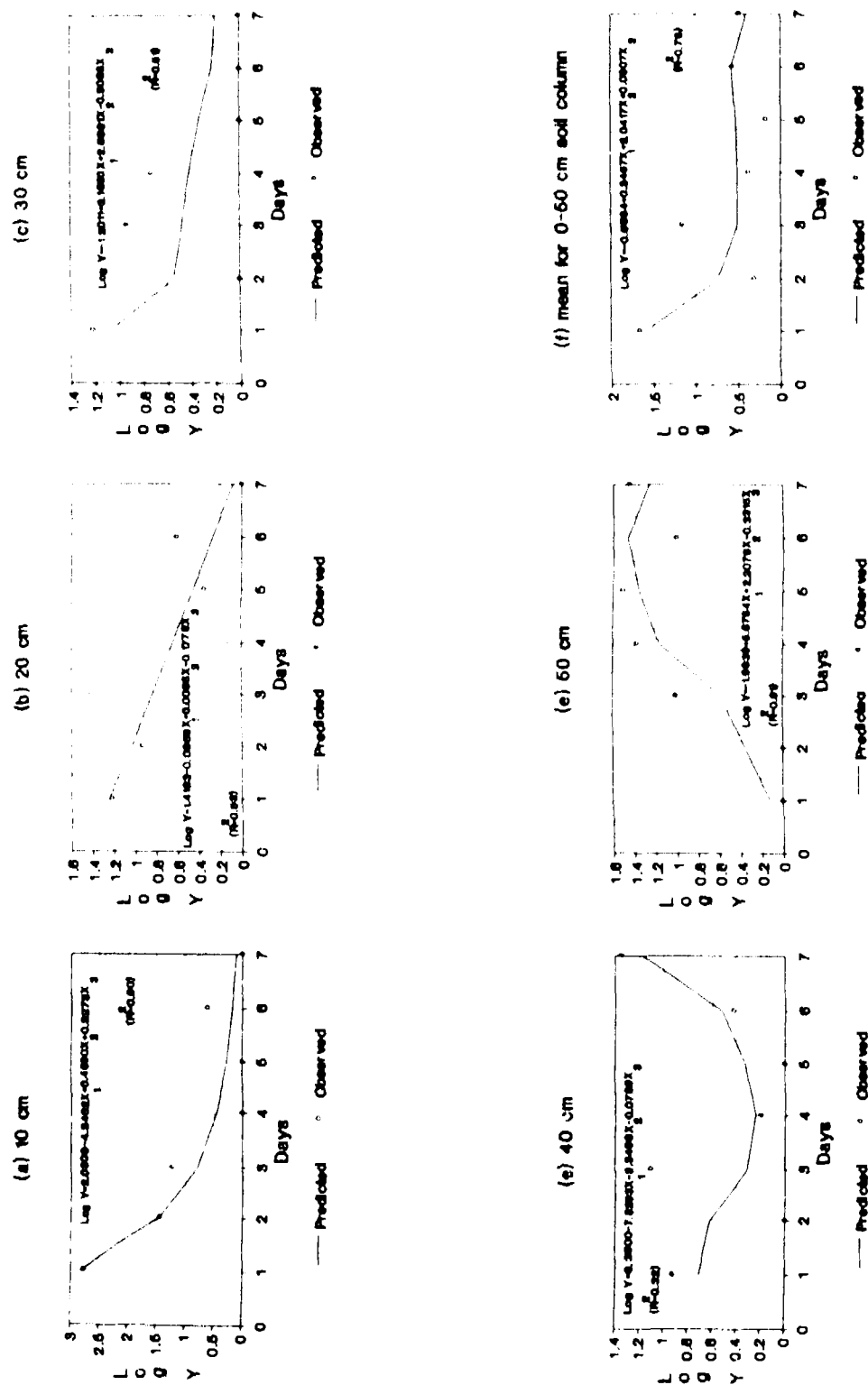
Y-Concentration of Urea in ppm

Fig.17 Concentration of Urea at Different Depths and Days
Sandy Clay Soil : Normal Rainfall Condition



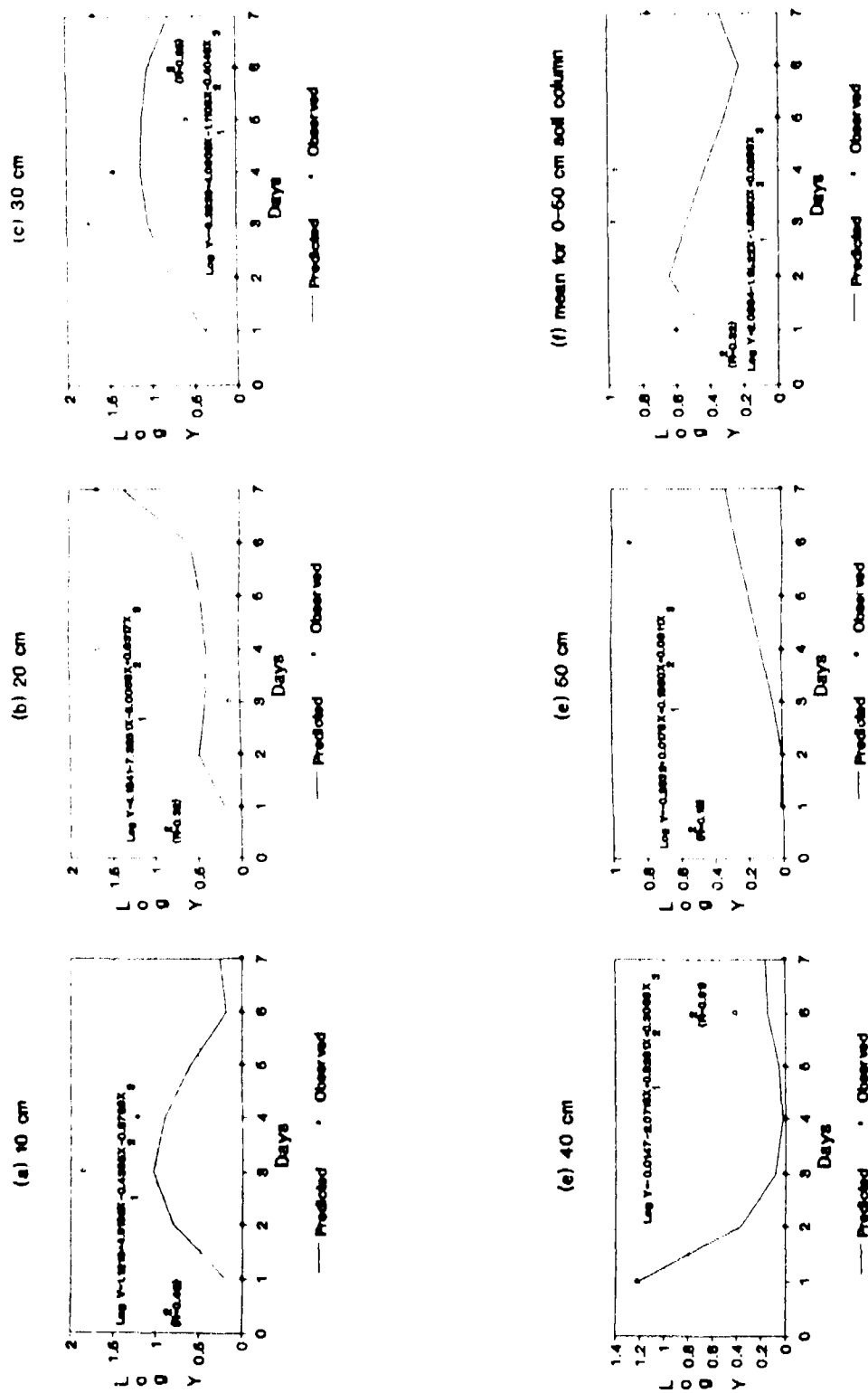
Y-Concentration of Urea in ppm

Fig.18 Concentration of Urea at Different Depths and Days
Sandy Clay Soil : Excess of Rainfall Condition



Y-Concentration of Urea in ppm

Fig.19 Concentration of Urea at Different Depths and Days
Sandy Clay Soil : Flooded Condition



Y-Concentration of Urea in ppm

Fig.20 Mean urea concentration at different depths in Sandy Clay Loam Soil

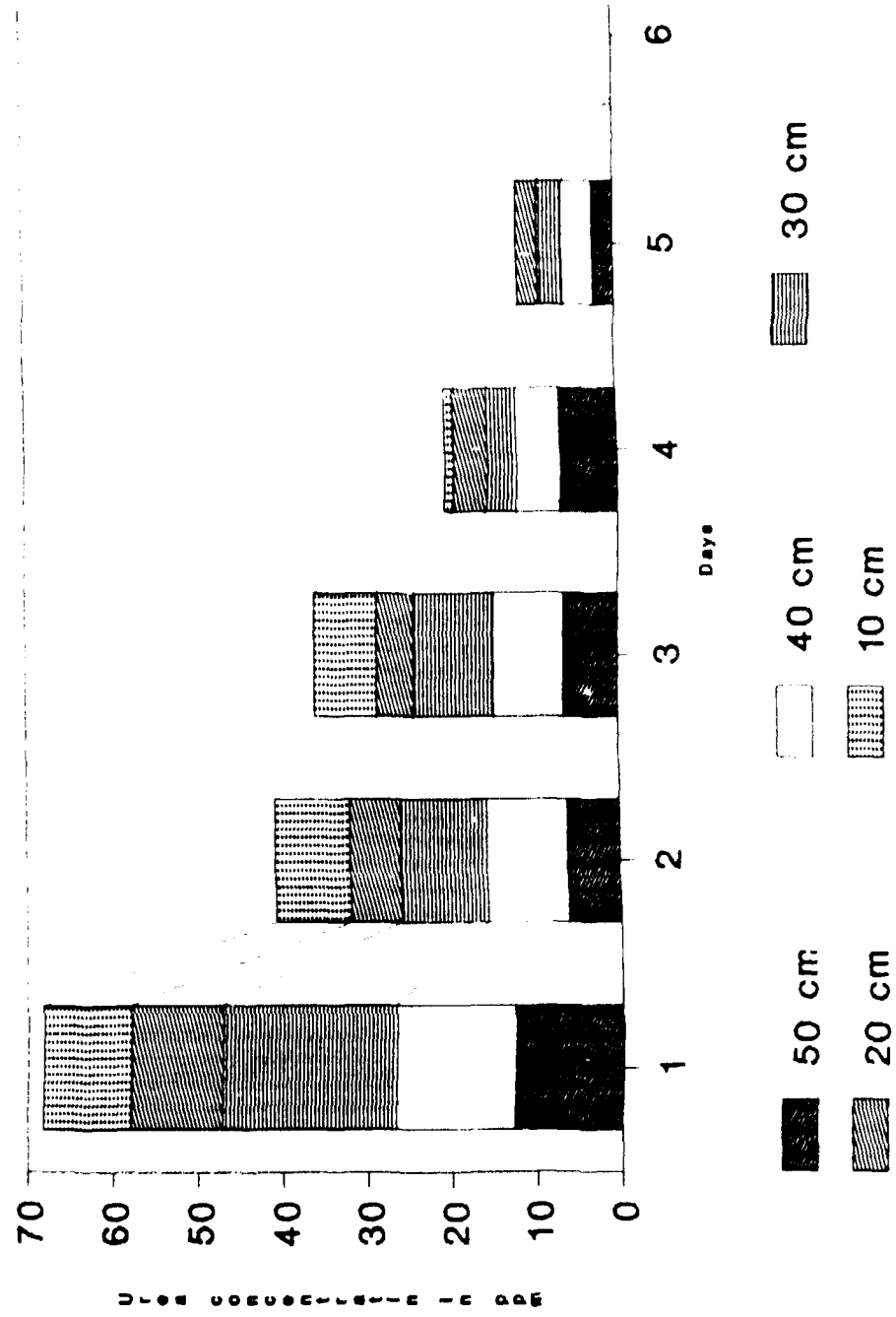


Fig.20.a Mean urea concentration at different depths in loamy Sand Soil.

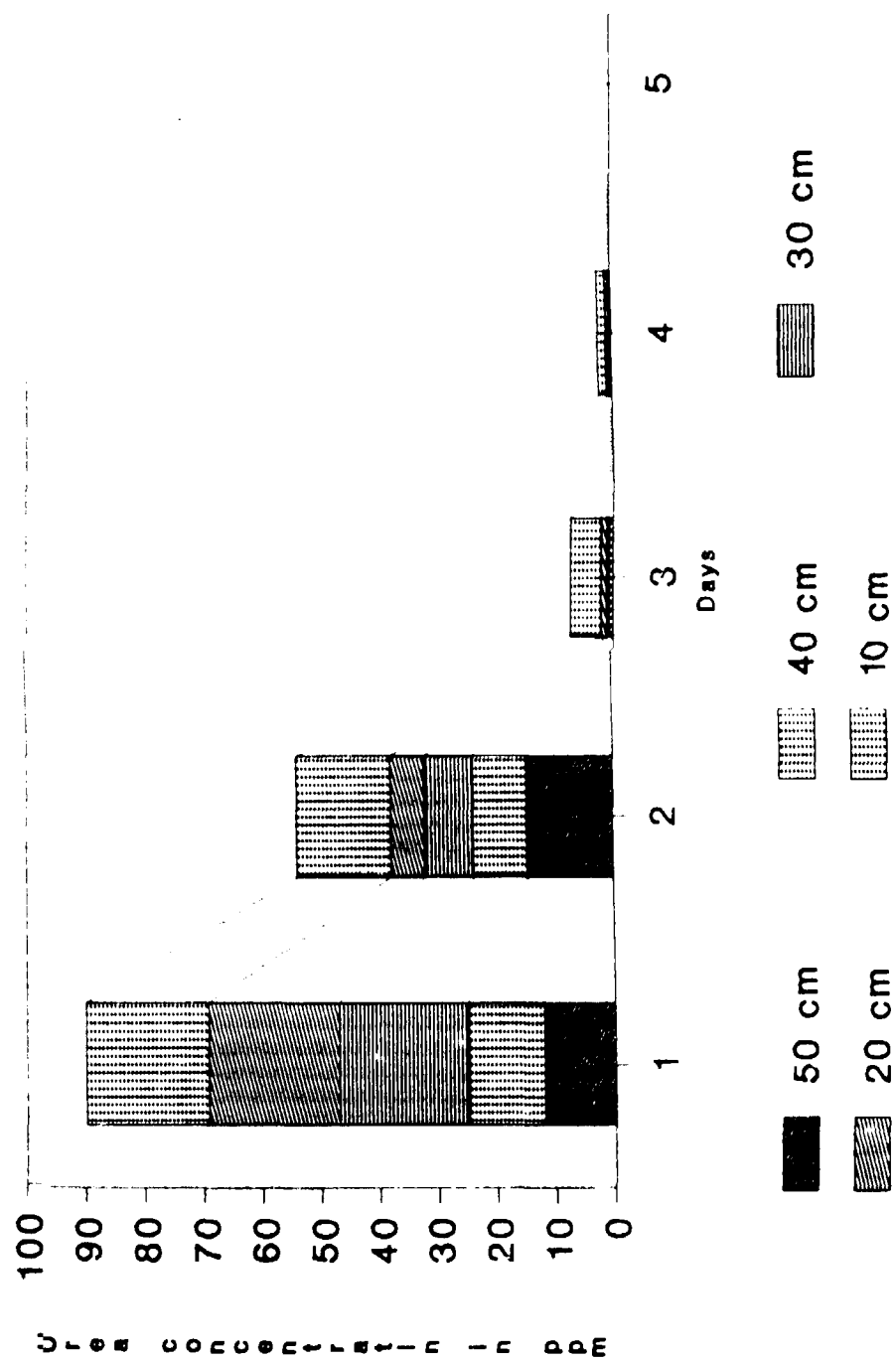


Fig 20.b Mean urea concentration at different depths in Sandy clay Soil.

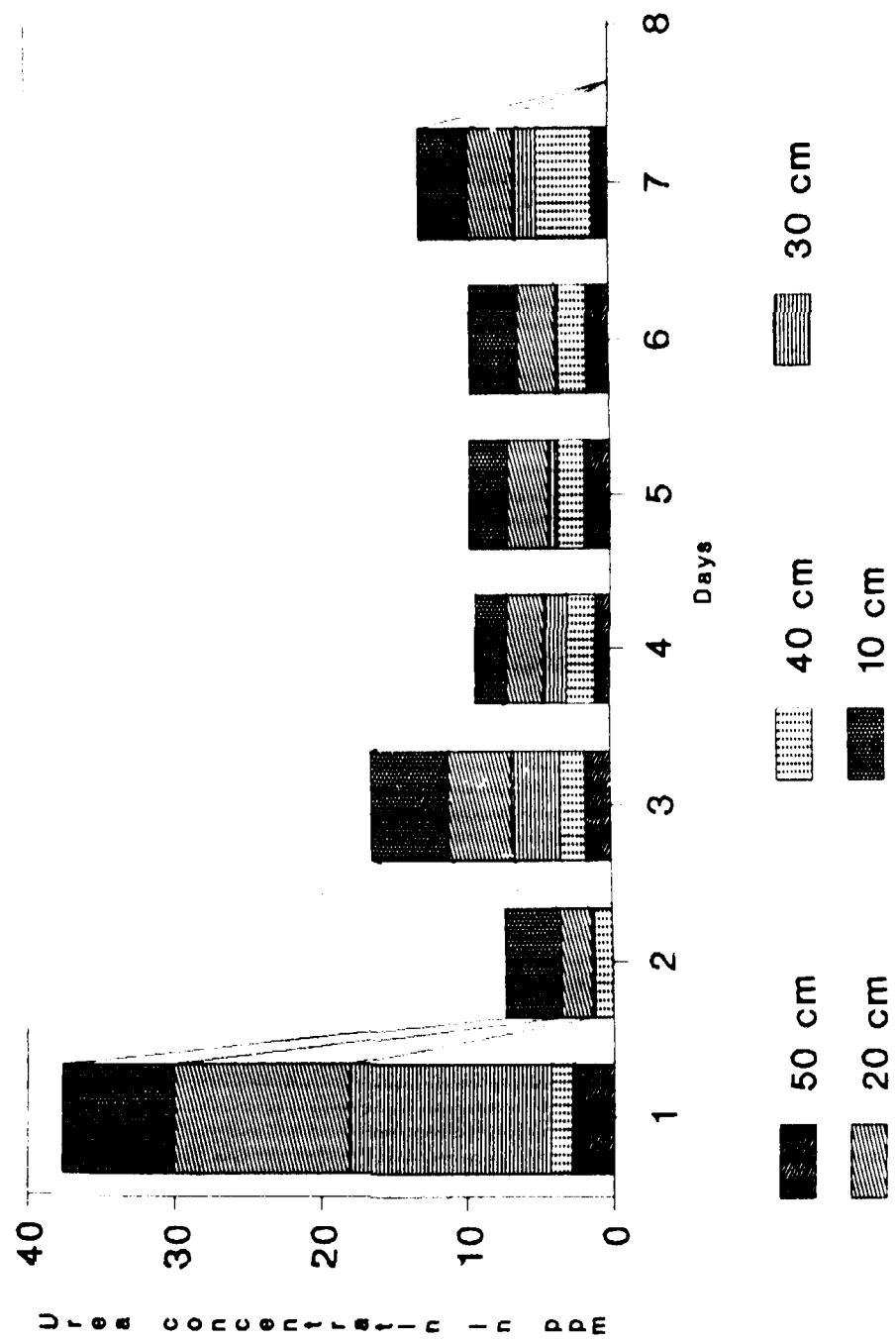
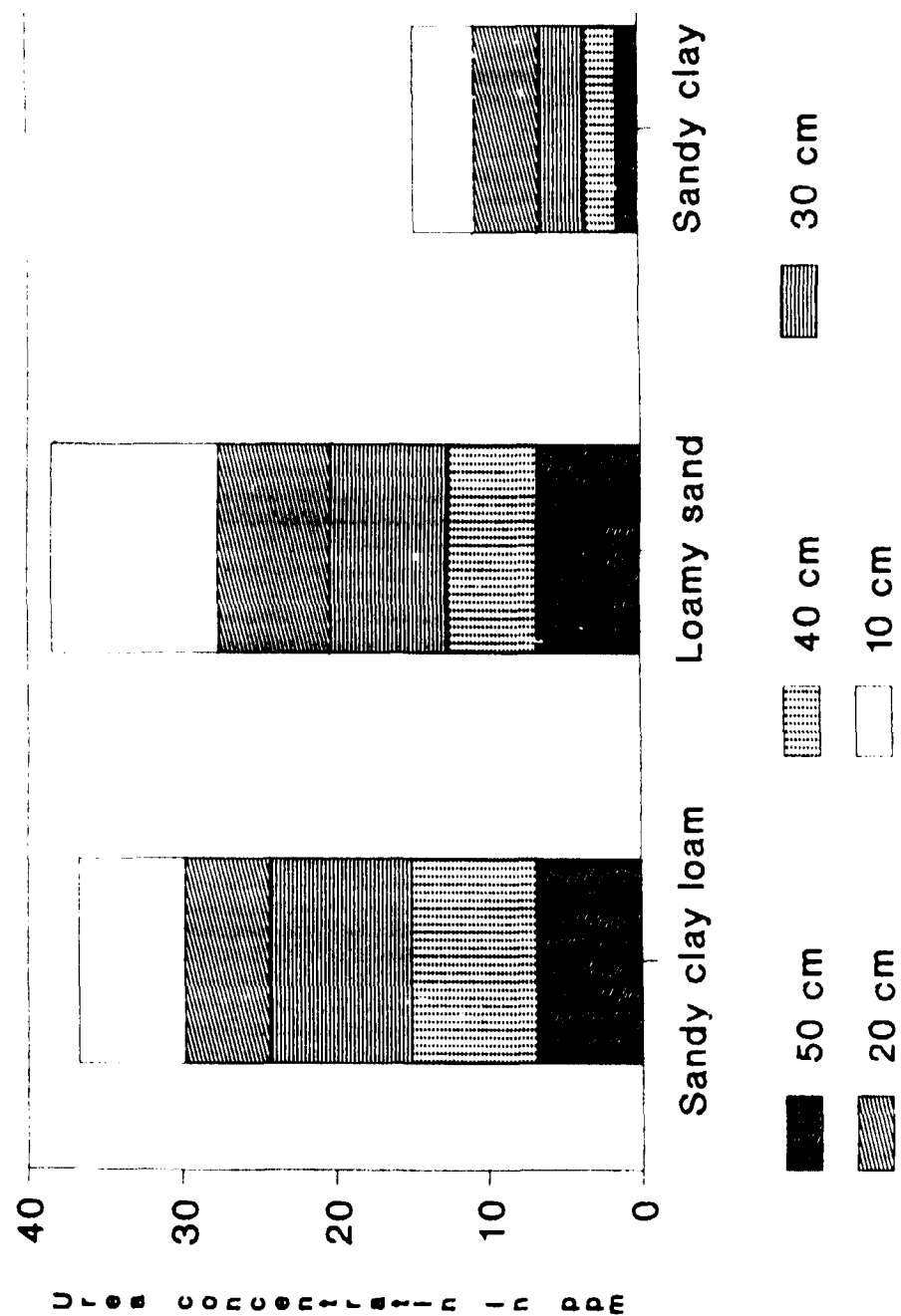


Fig.20.c Mean urea concentration(Pooled)
at different depths of soil columns



conditions. Therefore, it is proposed to use a very simple model to predict the urea concentration at various depths against days and the determination of the parameters are not of interest in the present investigation.

Taking $\Phi = 0$, the CDE takes the form

$$\frac{\partial c}{\partial t} = D \frac{\partial^2 c}{\partial x^2} \quad (2)$$

A solution of the above equation has the form

$$c(x,t) = \frac{\alpha}{\sqrt{t}} \exp \left[-(x-vt)^2 / 4 Dt \right]$$

where α is constant

Thus the functional relationship, for a particular depth, between concentration and time takes the form (Scatter diagram)

$$\log c(t) = f(\log t^{1/2}, 1/t, t)$$

we have fitted the equation of the form

$$\log c(t) = a_0 + a_1 \log t^{1/2} + a_2(1/t) + a_3(t)$$

$$\text{i.e., } \log c(t) = a_0 + a_1 x_1 + a_2 x_2 + a_3 x_3$$

$$\text{where } x_1 = \log t^{1/2}, x_2 = 1/t; x_3 = t$$

where the parameters a_0 , a_1 , a_2 and a_3 have been determined from least squares principle. It is observed that such a simple model describes the temporal variations of log concentrations for each depth, adequately well.

The set of equations arrived at for each depth of the various soils under each treatment are presented in the Tables 27 to 30. Graphs were constructed for the logarithmic values of the concentration of urea in each depth

against the days of urea transport for the actual and predicted values. The graphs for the sandy clay loam soil, Loamy sand soils and sandy clay soils for five soil depths under four water treatments are presented in figures 8 to 19.

4.6. Relationship between the physical properties of soils and urea transport

It is a well established fact that the movement of soil-air, soil-water and solutes particularly fertilizer in soil medium are being regulated by the soil-physical environment especially the textural and structural properties of soil. Hence an attempt was made in this study to work out the relationship between the various physical properties of soils with the urea concentration in soils.

In order to study the relationship, the following important physical properties of the soils namely 1) percentage of total sand 2) percentage of coarse sand 3) percentage of fine sand 4) percentage of silt 5) percentage of clay 6) Bulk density 7) Hydraulic conductivity 8) percentage of moisture 9) percentage of water stable aggregates 10) percentage of capillary pore space 11) percentage of non-capillary pore space 12) percentage of total porespace 13) 1/3 bar moisture and 14) 15 bar moisture were statistically analysed with the urea concentration at five depths viz. 10, 20, 30, 40 and 50 cm of the soil column of the sandy clay loam, Loamy sand and sandy clay soils under the following four simulated water treatments, namely

saturated normal rainfall, excess of rainfall and flooded conditions.

In order to find out the relationship of physical properties with urea concentration, correlation coefficients were worked out and the results were presented in Table 31.

Based on the significant correlations, some of the physical properties were selected for further study. Among the various physical properties considered, the following were found to have significant correlation with the urea concentration in the soils (Table 31).

1. percentage of total sand (x_1)
2. percentage of coarse sand (x_2)
3. percentage of Fine sand (x_3)
4. percentage of clay (x_4)
5. Hydraulic conductivity (x_5)
6. Bulk Density (x_6) and
7. percentage of water stable aggregates (x_7)

The notations in the parentheses are used for describing the concerned physical properties for the text.

4.6.1. Relationship between the physical properties of soils and the urea concentration (Table 31)

4.6.1.1. Percentage of total sand (x_1)

The percentage of sand was found to have a close relationship with the urea concentration in soils and

Table 31. Correlation coefficients of various physical properties of soil and urea concentration.

Sl.No.	Name of the physical properties	Correlation coefficient
1.	Total sand (per cent)	0.7740 ⁺
2.	Coarse sand (per cent)	-0.5160 ⁺
3.	Fine sand (per cent)	0.8400 ⁺⁺
4.	Silt (per cent)	0.0549 ^{NS}
5.	Clay (per cent)	-0.6360 ⁺
6.	Capillary porosity (per cent)	0.0661 ^{NS}
7.	Non-capillary porosity (per cent)	-0.2790 ^{NS}
8.	Total porosity (per cent)	-0.0954 ^{NS}
9.	Hydraulic conductivity (cm hr ⁻¹)	0.6190
10.	Bulk Density (gm cm ⁻³)	-0.8300 ⁺⁺
11.	Water stable aggregates (per cent)	-0.6370 ⁺
12.	Moisture (per cent)	-0.1355 ^{NS}
13.	Moisture at 1/3 bar (per cent)	-0.4211 ^{NS}
14.	Moisture at 15 bar (per cent)	0.0845 ^{NS}

NS = Non-significant

+ = Significant at 5% level

++ = Significant at 1% level

the correlation coefficient (0.7740) worked out for this variable was significant at 5% level.

4.6.1.2 Percentage of coarse sand (x_2)

This variable was found to have a significant negative correlation (-0.5160) with urea concentration at 5% level.

4.6.1.3. Percentage of fine sand (x_3)

The percentage of fine sand was found to have a highly significant positive correlation (0.8400) at 1% level with the concentration of urea in the soils.

4.6.1.4. Percentage of clay (x_4)

The physical property of the soil namely percentage of clay was found to have a significant negative correlation (-0.6360) with the dependent variable at 5% level.

4.6.1.5. Hydraulic conductivity (x_5)

The hydraulic conductivity of the soil was found to have a significant correlation (0.619) at 5% level with urea concentration.

4.6.1.6 Bulk density (x_6)

This physical attribute was found to have a highly significant negative correlation (-0.83) at 1% level with the concentration of urea in the soils.

4.6.1.7 Percentage of water stable aggregates (x_7)

One of the important physical properties of soil namely the percentage of water stable aggregates was found to have a negative correlation (-0.6370) with the concentration of urea, significant at 5% level.

Eventhough the selected independent variables were found to have significant correlations with the dependent variable, their contribution in combination with each other would have to be taken into account for their total contribution towards the transport of urea in soils. Hence the data was further subjected to statistical analysis.

4.6.2. Inter correlation among the physical properties of the soils

The inter association among the various physical attributes is presented in Table 32.

4.6.2.1. Percentage of sand (x_1)

The first independent variable x_1 was found to have a highly significant correlation at 1% level with all the variables, except x_2 . But its correlation with the variables x_4 , x_6 and x_7 were found to be negative.

4.6.2.2. Percentage of coarse sand (x_2)

The second variable x_2 was found to have a significant correlation at 5% level only with x_3 (-0.565) and it was found to be negative. Its interrelation with

Table 32. Correlation matrix : Independent variables (physical properties of soils) and dependent variable (concentration of urea in soil)

Charac- ters		Total sand (per cent)	Coarse sand (per cent)	Fine sand (per cent)	Clay (per cent)	Hydraulic conductivity (cm hr ⁻¹)	Bulk density (gm cm ⁻³)	Water stable aggregates (per cent)
	Y	(X ₁)	(X ₂)	(X ₃)	(X ₄)	(X ₅)	(X ₆)	(X ₇)
r	1.0000	0.7740 ⁺	-0.5160 ⁺	0.8400 ⁺	-0.6360 ⁺	0.6190 ⁺⁺	-0.8300 ⁺⁺	-0.6370 ⁺
X ₁	0.7740 ⁺	(1.0000)	-0.2510 ^{NS}	0.9410 ⁺⁺	-0.9250 ⁺⁺	0.9060 ⁺⁺	-0.8310 ⁺⁺	-0.8320 ⁺⁺
X ₂	-0.5160 ⁺	-0.2510 ^{NS}	(1.0000)	-0.5650 ⁺⁺	0.2790 ^{NS}	-0.0260 ^{NS}	0.4260 ^{NS}	0.2880 ^{NS}
X ₃	0.8410 ⁺	0.9410 ⁺⁺	-0.5650 ⁺	(1.0000)	-0.8850 ⁺⁺	0.7810 ⁺	-0.6590 ⁺⁺	-0.8100 ⁺⁺
X ₄	-0.6360 ⁺	-0.9250 ⁺⁺	0.2790 ^{NS}	-0.8850 ⁺⁺	(1.0000)	-0.8410 ⁺⁺	0.7640 ⁺	0.7910 ⁺
X ₅	0.6190 ⁺	0.9060 ⁺⁺	-0.0260 ^{NS}	0.7810 ⁺	-0.8410 ⁺⁺	(1.0000)	-0.7580 ⁺	-0.7380 ⁺
X ₆	-0.8300 ⁺⁺	-0.8310 ⁺⁺	0.4260 ^{NS}	-0.6590 ⁺⁺	0.7640 ⁺	-0.7580 ⁺	(1.0000)	0.5600 ⁺
X ₇	-0.6370 ⁺	-0.8320 ⁺⁺	0.2880 ^{NS}	-0.8100 ⁺⁺	0.7910 ⁺	-0.7380 ⁺	0.5600 ⁺	(1.0000)

X₁ = Total sand (per cent)

NS = Non-significant

X₂ = coarse sand (per cent)

+ = Significant at 5% level

X₃ = Fine sand (per cent)

++ = Significant at 1% level

X₄ = Clay (per cent)

X₅ = Hydraulic conductivity (cm hr⁻¹)

X₆ = Bulk density (gm cm⁻³)

X₇ = Water stable aggregates (per cent)

r = the concentration of urea in soil (ppm)

other variables considered was found to be statistically non significant.

4.6.2.3. Percentage of fine sand (x_3)

The third variable x_3 was found to have a highly significant correlation at 1% level with the variables x_1 (0.941), x_4 (-0.885), x_6 (-0.859), and x_7 (-0.810) while at 5% level with the other variables x_2 (-0.565) and x_5 (0.781) respectively.

4.6.2.4. Percentage of clay (x_4)

The fourth variable x_4 was found to have a highly significant negative correlation at 1% level with the variables x_1 (-0.925), x_3 (-0.885) and x_5 (-0.841) and significant positive correlation at 5% level with x_6 (0.764) and x_7 (0.791).

4.6.2.5. Hydraulic conductivity (x_5)

The fifth variable x_5 was found to have a highly significant positive correlation at 1% level with x_1 (0.906) and negative correlation with the variable x_4 (-0.841). It was also found to have a positive correlation at 5% level with x_3 (0.781) and negative correlation with x_6 (-0.758) and x_7 (-0.7300).

4.6.2.6. Bulk density (x_6)

The sixth variable x_6 was found to have significant negative correlation at 1% level with x_1

(0.831) and x_3 (-0.859) at 5% level with the variable x_5 (-0.758). It was also found to have a significant positive correlation at 5% level with the other variables x_4 (0.764) and x_7 (0.568).

4.6.2.7 Percentage of water stable aggregates (x_7)

The last variable x_7 selected for the study was found to have a highly negative significant correlation at 1% level with x_1 (-0.832) and x_3 (-0.810) and at 5% level with the variable x_5 (-0.773). It was found to have a significantly positive correlation with the other variables namely x_4 (0.791) and x_6 (0.568).

4.6.3. Path analysis (Table 33)

Simple correlation analysis, more often than not, gives the degree of association between the dependent and independent variables. Especially when there are several interrelated variables present, one can not get clear version (many time an errornean's version) as to which of these independent variables significantly influence the dependent variable, as it only gives the total contribution.

Path analysis comes handy in this situation, as it partitions the total correlation into several components as direct and indirect effects via each variable. To put it in a nutshell, the path ananlysis reveals how the total correlation of each independent variable with the dependent variable is built up via the various interrelated

Table 33. Path coefficient analysis : Direct and indirect effects of physical properties of soils on transport of urea in soils

Characters	Effects via						
	Total sand (per cent)	Coarse sand (per cent)	Fine sand (per cent)	Clay (per cent)	Hydraulic conductivity (cm hr ⁻¹)	Bulk density (g cc ⁻¹)	Water stable aggregates (per cent)
	(X ₁)	(X ₂)	(X ₃)	(X ₄)	(X ₅)	(X ₆)	(X ₇)
Total sand (X ₁) (per cent)	(0.5258)	0.0737	6.3307	-0.5899	3.3011	-3.3366	-5.5318
Coarse sand (X ₂) (per cent)	0.1322	(-0.2936)	-3.8052	0.1774	-0.094	1.7105	1.9215
Fine sand (X ₃) (per cent)	0.4952	0.1659	(6.7348)	-0.5650	2.8456	-3.4491	-5.3655
Clay (X ₄) (per cent)	-0.4872	-0.0820	-5.9671	(0.6377)	-1.0642	1.0676	5.2592
Hydraulic conductivity (X ₅) (cm hr ⁻¹)	0.4773	0.0076	5.2599	-0.5861	(3.6436)	-3.0435	5.1395
Bulk density (X ₆) (g cc ⁻¹)	-0.4378	-0.1251	-5.7852	0.4872	-2.7618	(4.0152)	3.7765
Water stable aggregates (X ₇) (per cent)	-0.4383	-0.0849	-5.4552	0.5044	-2.8165	2.2806	(6.6488)

Figures in paranthesis indicate the direct effects and rest being indirect effects

variables and gives a list of dominant variables which really influence the dependent variable.

In order to find out the dominant physical properties which really influence the urea concentration in the soils, a path analysis was carried out by taking only the variables which had significant correlation with the concentration of urea in the soils.

The important physical properties of the soil considered for the study are 1) percentage of total sand (x_1) 2) percentage of coarse sand (x_2), 3) percentage of fine sand (x_3) percentage of clay (x_4), Hydraulic conductivity (x_5), Bulk density (x_6) and percentage of water stable aggregates (x_7). The matrix of direct and indirect effects of the various physical attributes is presented in Table 33.

4.6.3.1. Percentage of sand (x_1)

The correlation coefficient for the variable x_1 (0.774) with Y was built in by its direct effect as well its positive indirect effects through the percentage of fine sand (6.3307), the hydraulic conductivity (3.3011) and negative indirect effects via the percentage of water stable aggregates (-5.5318), the bulk density (-3.3366), and the percentage of clay (-0.5899).

4.6.3.2 Percentage of coarse sand (x_2)

The correlation coefficient for the percentage of coarse sand (-0.5160) with the urea concentration was not mainly built in by its direct effect (-0.2930), but through its negative indirect effect via the percentage of fine sand (3.8052) and the percentage of total sand (-0.1322) and the positive indirect effect via the percentage of water stable aggregates (1.9215), the bulk density (1.7105) and the percentage of clay (0.1779).

4.6.3.3. Percentage of fine sand (x_3)

The correlation coefficient for the percentage of fine sand (0.8400) with the urea concentration was highly significant at 1% level and was mainly built in by its direct effect (6.7348) and partly by the positive indirect effects through the hydraulic conductivity (2.8456), the percentage of sand (0.4952), and the percentage of coarse sand (0.1659) and the negative indirect effects through the percentage of water stable aggregates (-5.3855), the bulk density (-3.4491) and the percentage of clay (-0.5650).

4.6.3.4 Percentage of clay (x_4)

The correlation coefficient for the percentage of clay (-0.6360) with the concentration of urea in the soils was built in by its own direct effect (0.6377) and also largely by its positive indirect effects via the percentage of water stable aggregates (5.2592) and the bulk density

(3.0676) and the negative indirect effects through the hydraulic conductivity (-3.0642), the percentage of fine sand (-5.9671) and the percentage of sand (-0.4873).

4.6.3.5. Hydraulic conductivity (x_5)

The correlation coefficient (0.6198) for the hydraulic conductivity with the urea transport was built in largely by its (3.6436) direct effect as well as its positive indirect effects through the percentage of fine sand (5.2599), the percentage of sand (0.4773) and the percentage of water stable aggregates (5.1395) and by its negative indirect effect through the percentage clay (-0.5863).

4.6.3.6 Bulk density (x_6)

The correlation coefficient (-0.8300) for the bulk density with the urea concentration was built in largely by its direct effect (4.0152) and its positive indirect effects through the percentage of water stable Aggregates (3.7765), the percentage of clay (0.4872) and the negative indirect effects via the percentage of fine sand (-5.7852), the hydraulic conductivity (-2.7618) and the percentage of the sand (-0.4378).

4.6.3.7 Percentage of water stable aggregates (x_7)

The correlation coefficient (-0.6370) for the percentage of water stable aggregates with the urea transport was largely built in by its direct effect (6.6488) and its negative indirect effects via percentage of fine sand

(-5.4552), the hydraulic conductivity (-2.8165) and the percentage of sand (-0.4383) and partly by its positive indirect effects via the Bulk density (2.2806), and the percentage of clay (0.5044).

The path analysis provides a parsimonious summary on the significantly influencing physical properties of the soils in the transport of urea and ranks them according to their merit, so that, if we want to limit the number of properties for the study and the improvement of urea transport in soils then we can lay hands on the following properties in the order of their merit namely

1. Percentage of fine sand
2. Percentage of water stable aggregates
3. Bulk density
4. Hydraulic conductivity
5. Percentage of clay content
6. Percentage of total sand and
7. Percentage of coarse sand

4.6.4. Path Analysis of the textural properties of the soils with urea transport in soils (Table 34)

As many literature revealed that the textural property of soil was one of the main factors for the solute movement in soils, an attempt was made to understand the direct and indirect effects of the various textural properties on the urea transport. Path analysis was carried out on the textural properties of the soils only.

Table 34. Path coefficient analysis : Direct and indirect effects of textural properties of soils on urea concentration in soil

Characters	Total sand (per cent) (X_1)	Coarse sand (per cent) (X_2)	Fine sand (per cent) (X_3)	Clay (per cent) (X_4)	Correlation with urea concentration in soil
Total sand (X_1) (per cent)	(-0.2098)	-0.8621	1.6720	-0.6260	0.7740 [*]
Coarse sand (X_2) (per cent)	0.0527	(0.2475)	-1.0050	0.1860	-0.5160 [*]
Fine sand (X_3) (per cent)	-0.1473	-0.1398	(1.7788)	-0.5996	0.8400 ^{**}
Clay (X_4) (per cent)	0.1441	0.0640	-1.5760	(0.6768)	-0.6760 [*]

Figures in parenthesis indicate the direct effects and rest being indirect effects.

* = Significant at 5% level

** = Significant at 1% level

The matrix of direct and indirect effects for the structural properties is presented in Table 34.

4.6.4.1 Percentage of total sand (x_1)

The correlation coefficient for the percentage of sand (0.774) with the concentration of urea was significant at 5% level and was built in by its negative direct effect (-0.2098) and large positive effect via the percentage of fine sand (1.6720) and the moderate negative effect through the percentage of clay, (-0.6260).

4.6.4.2. Percentage of coarse sand (x_2)

The correlation coefficient for the percentage of coarse sand (-0.5160) was found to have a negative correlation at 5% level with the urea concentration in soils and this was built in by its direct effect (0.2475) and mainly by its negative indirect effect via the percentage of fine sand (-1.0050) and the positive indirect effect through the percentage of clay (0.1888).

4.6.4.3. Percentage of fine sand (x_3)

The correlation coefficient for the percentage of fine sand (0.8400) with the concentration of urea was built in largely by its direct effect (1.7788) and partly by its negative indirect effects through the percentage of clay (-0.5996) and the percentage of sand (-0.1973) and the percentage of coarse sand (-0.1398).

Discussion

CHAPTER V

DISCUSSION

Among the nitrogenous fertilizers, urea is the major source in India as well as other developing countries (Manickam, 1988) which is more susceptible to various losses. The knowledge on the fate of urea applied in soils is quite essential for the effective utilisation of the principal N fertilizer. Literature on the transformation of urea is exhaustive, but on the transport of urea is limited. The important factors affecting the transport of urea in soils are, soil texture, urea application rate, initial soil moisture, and the rate and method of application of water (Vinod Kumar and Ritcher, 1989). Eventhough several studies were conducted on the factors cited, the literature on the systematic study on the transport of urea in soil is limited. Hence an attempt was made in the present study for the quantification of urea movement in soils with reference to soil texture, and the rate of application of water.

The transport of applied urea through the columns of sandy clay loam, lomy sand and sandy clay soils were subjected to saturated and simulated rain fall and flooded conditions. The study covered the following aspects

1. Spatial and temporal variations in the concentration of urea in the different textured soils.

et al. (1978). This observation was in corroboration with the results of Broadbent (1958), Kumar and Wagenet(1985); and Singh and Bajwa (1986). They have reported that mobility of urea is quite high in sandy, sandy loam and loamy sand soils than the soils with higher clay content.

Perhaps, the loamy sand may provide a better textural condition for transport of urea than the sandy clay loam and sandy clay soils. As per the findings of the present study, the increase in the fine sand as well as the sand and decrease in the coarse sand, clay content and water stable aggregates might have favoured the urea transport in soils. The higher hydraulic conductivity and lower bulk density of the soil might have also influenced the urea transport. The loamy sand was found to possess all the favourable points in support of good urea transport property. Moreover, referring to the precise method of fixing the textural class of a soil from its mechanical analysis represented by the three fractions by means of triangular coordinates as devised by the U.S.D.A., the texture loamy sand lies in between sandy and sandy loam classes, and the sandy clay loam comes next in the increasing order of clay fraction. The arrangement of the texture in the triangle is itself in order of supporting the findings of the study. Sing et al (1984) reported that the depth of water front following infiltration in a dry sandy and sandy loam soils were more or less same in all rates of water applications. The large pores or combinations of large pores give rise to a certain

amount of channeling (Gardner et al 1956). Anyhow, the transport of solute will also be influenced by the structural and hydro dynamic properties of the soils.

Among the four simulated water conditions studied, the normal rainfall condition was found to be favourable for urea transport than the saturated condition followed by the excess of rainfall and flooded conditions. Singh et al (1984) studied the effects of different rates of irrigation water application (5, 7.5, 10 and 15 cm) in initially dry and wet (10% moisture) sandy and sandy loam soils. The depth of urea penetration immediately and 24 hrs after application of water increased with increasing water application rates. The study on the different initial moisture contents in a sandy loam soil by Tewatia (1986) revealed that the depth of movement of NH_4^+ and NO_3^- increased with increasing moisture content. Eventhough the excess of rainfall and flooded conditions are better water input conditions than the normal rainfall condition, they are comparatively less favourable for urea transport than the normal rainfall condition. This may be due to the reason that the first flush of water passing fast through the fertilizer zone might not have dissolved it, and that once the movement of fresh water is initiated, the wetting front will tend to occur preferentially through the higher velocity pathways Okereke, (1984). The speed of water movement may be sometimes high such that it will move as water without solved solute. Dahiya and Abrol (1974) and Singh et al (1979) also

found that the maximum chloride concentration lagged behind the wetting front. Following the infiltration, it appears that in the initially wet soil, the infiltration water more or less displaced the initial water to form the wetting front. This means that the wetting front was not created by the invading water, but by the original water present in the soil which was free from urea. Following infiltration, the depth of water front in the initially wet sandy soil was found to be less than in the initially wet sandy loam soil which may be due to more total water content present in latter case. Similar trend was reported by Singh et al (1980).

Several laboratory (Kirda et al., 1973; Dahiya and Abrol; 1974) and field studies (Miller et al., 1965; Warrick et al., 1971; Dahiya, 1980) are in support of the result of the present investigation and reveal that the displacement of non reactive solutes with a given quantity of water was deeper at lower rates of water application. It is obvious that, the physical properties of soil are not only different for different textured soils but also different for the different depths of the soils. Hence, it will be more appropriate to discuss the transport of urea at different depths of the varied textured soils with reference to their varying physical properties.

The maximum concentration of urea was recorded in the first day of transport for all the soils and the concentration was found to decrease with days. This is in

greater in loamy sandy with 0.90 day as half-life period than sandy clay loam ($t_{1/2} = 1.56$) and sandy clay ($t_{1/2} = 1.62$) soils. It was found to be in support of the findings for that the total life period of urea in the soils considered in the following order.

Sandy clay > sandy clay loam > loamy sand

Saravanan (1990) reported that owing to the heavy texture (32% clay) and high organic matter content of the soil, the hydrolysed NH_4^+ N from urea was more in Adanur series as compared to the open textured, Madukkur sandy loam soil. Similarly, variation in hydrolysis of urea for texturally different soils was reported by Kumar and Wagenet (1984). Farooqui et al (1983) observed a complete hydrolysis of urea within 11 days and found that mineralisation potential of soil under aerobic condition was more than the anaerobic situation. Hence the variations in urea concentration observed in different soils might be due to the different movement pattern as influenced by the soil properties and also by the kinetics of urea hydrolysis.

5.1.1 Spatial variation in urea concentration of sandy clay loam, loamy sand and sandy clay soils

5.1.1.1 Sandy clay loam soil

The depth mean urea concentration of urea in the sandy clay loam soil was found to be significantly higher in lower depths viz. 30 cm (9.32 ppm), 40 cm (8.13 ppm), and

50 cm (6.88 ppm) than in the upper depths 10 cm (5.50 ppm) and 20 cm (5.49 ppm) of the soil columns.

The present study revealed that the percentage of sand and the percentage of fine sand have a significant correlation with the concentration of urea in different depth of the soils. Among the two, the latter was found to have a highly significant correlation with the urea concentration in soil besides having a significant direct effect on the urea transport. Since the percentage of fine sand and the percentage of sand are more in 30-50 cm depth, the concentration of urea is higher at 30-50 cm depth than at the upper depth of the sandy clay loam soil.

5.1.1.2 Interaction of depths with treatments

Under the normal rainfall situation and the saturated condition, the concentration of urea was found to be more at 40 cm depth in sandy clay loam soil. These conditions are favourable for transport of urea only upto 40 cm depth in its soil. It was found that the normal rainfall condition was better than the saturated condition for transport of urea. Musa (1968) reported that for higher application of water in sandy clay loam soil, the urea was washed down from surface layer and distributed in the lower depth. For the excess of rainfall condition, there was no appreciable change in the concentration of urea among the various depths except at 30 cm depth of the soil where the concentration was high. The hydraulic conductivity of the

soil is more upto 30 cm depth than at the lower depths and the bulk density is low upto 30 cm than at the lower depths. These may be the reasons for the movement of urea upto 30 cm and decrease there after. Under flooded condition, the concentration of urea was found to be higher at 10 cm depth and then decreased with depths. This may be due to the fact that the wetting front was not created by the invading water, but the original water present in the soil which was free from urea, (Singh et al. 1984).

5.1.2.1 Urea transport in loamy sand soil

The depth mean concentration of urea in the loamy sand soil was found to be significantly higher at 10 cm (10.87 ppm) depth followed by 50 cm (7.77 ppm) and 30 cm (7.74 ppm) and 20 cm (7.34 ppm) which were on par with each other and 40 cm (5.69 ppm) depth of the soil column.

Eventhough the percentage of fine sand is more or less same in all the depths, the percentage of total sand which was one of the important factors favourable for urea transport is found to be more in the 0-30 cm depth than 30-50 cm depth of the soil column. Moreover the bulk density of the 10-30 cm soil column is lesser than that of the 30-50 cm depth of soil columns and the hydraulic conductivity of the 10-30 cm depth of the soil column is higher than that of the 30-50 cm soil depths. The results of the present study revealed that, the bulk density and the hydraulic conductivity of the soil are found to have a significant

correlation with the concentration of urea in soils. This reason may be attributed for the higher concentration of urea in the upper depths of the loamy sand soil.

5.1.2.2 Interaction of depths with treatments

Under all simulated rainfall conditions, the concentration of urea was found to be higher at 10 cm depth and for the flooded condition it was found to be higher at 40 cm depth in loamy sand soil. As per the results of the present study, the concentration of urea has registered a highly negative significant correlation with the percentage of clay, the percentage of stable aggregates, the bulk density and a positive correlation with the Hydraulic conductivity of the soil. The percentage of clay content at 0-10 cm depth was found to be very meagre than at the other depths. The bulk density is lesser and the hydraulic conductivity is higher in 10 cm depth than at the lower depths. Perhaps this may be the reason for the higher concentration at 10 cm depth of the soil column than in the other depths. Since the soil is found to have favourable physical properties, the urea movement to lower depths for all the rainfall conditions except the saturated conditions was found to be favourable. This may be due to the higher percolation rate in the soil (Vlek 1980).

5.1.3.1 Urea transport in sandy clay soil

The concentration of urea in the sandy clay soil was found to be significantly higher at the upper depths namely 10cm (3.51 ppm), 20cm (3.68 ppm), and 30 cm (2.66 PPM) than at the lower depth 40 cm (1.73 ppm) and 50 cm (1.25 ppm) depth of the soil columns.

The favourable physical properties of the soil for urea transport have found to be the percentage of fine sand, the percentage of sand, the hydraulic conductivity which had significant positive correlation, while the percentage of coarse sand the percentage of clay, the bulk density and the water stable aggregates had significant negative correlation with the urea concentration in soil. In the case of the sandy clay soil, the factors with positive correlation viz., the percentage of sand and the hydraulic conductivity were found to be higher and the factors with negative correlation except the percentage of water stable aggregates, were found to be lesser in the 0-30 cm depth than the 30-40 cm depth of the soil column. Perhaps, the indirect negative effects of the water stable aggregates through the fine sand, the hydraulic conductivity and the sand and its indirect positive effects through the bulk density and the percentage of clay may contribute for the higher concentration at 10-30 cm depth than 30-50 cm depth of the sandy clay soil.

5.1.3.2 Interaction of depth with treatments

Under the saturated and excess of rainfall conditions, the concentration of urea was found to be higher at 10 cm depth and for the normal rainfall and flooded condition it was found to be higher at 20 cm and 30 cm depths of the soil column respectively. At 10 cm depth, the favourable physical properties namely the percentage of fine sand and sand were found to be higher and the percentage of clay was found to be lower than at other depths. This might be the reason for the higher concentration of urea at 10 cm depth. The higher value for the hydraulic conductivity at 10 cm depth and the higher supply of water under flooded condition may be the reason for the higher concentration of 20 cm and 30 cm depths of the sandy clay soil.

5.1.3.3 Interaction among the depth, treatment and days

Because of the complex nature of the soil matrix, and the different spatial and temporal variation of solute in soil and that too under different treatments, the interpretation for the concentration of urea at different depths of soils can only be given with the help of mathematical tools. The prediction model is separately discussed.

5.2. Mathematical model to describe the temporal variations of urea of different depths of the soil columns

Much of the research being conducted today in soil physics is directed towards developing tools for dealing

with the complex problems in the soils. One of the major tools under development is the solute transport model. In its simplest form a solute transport model may be nothing more than a guide for interpreting measurements while in the most complex form it may seek to describe the space and time dependence of all phases of every chemical species in the soil-water system. Solute transport models differ greatly in complexity and utility, ranging from simple steady-state models which ignore chemical reactions, to complex dynamic models which include all major soil-solution reaction. The method of solving the general equation will mainly depend upon the purpose of the experiment.

One of the objectives of the present study is to describe the transport of urea in various time at a particular depth of the soil column and not of determining the deterministic parameters such as diffusion coefficient, pore water velocity, etc. The prediction of the concentration of any solute will be generally arrived at with the help of the convection dispersion equation (CDE) or break through curves (BTC). The process of prediction was enroute through the determination of the deterministic parameters, which were found to be tedious and time consuming. Hence an attempt was made to predict the temporal variation in the concentration of urea in soil with the help of some functional relationship between the concentration of urea and the time of transport. The goodness of fit was found to be satisfactory for the simple model constructed and

thus the findings was found to be in support of the relationship assumed. The limitation of the simple model is that, it can't be used for the determination of the deterministic parameters.

Miscible displacement studies based primarily upon the laboratory soil columns have been generally analyzed through the use of convective diffusion equations (CDE) with parameters assumed to be deterministic. Many mathematical models have been developed to describe the displacement of a fluid and its dissolved constituents through a porous medium. A general equation that has proved to be particularly useful in the laboratory studies to define and analyse the one dimensional leaching characteristics in the presence of irreversible microbiological transformations is the convective-dispersion equation. Miscible displacement experiments in soil column of finite length can lead to a better understanding of the physical, chemical and microbial processes that control solute dispersion in a soil. (Misra et al. 1974; Starr and Paralange, 1975). The transport of a solute through soil has the form (Neilson et al. 1974).

$$\frac{\partial c}{\partial t} = D \frac{\partial^2 c}{\partial x^2} - u \frac{\partial c}{\partial x} + \lambda \text{ ----- (1)}$$

where C is the concentration of solute,

u the pore water velocity (cm sec^{-1}),

D the dispersion coefficient ($\text{cm}^2 \text{sec}^{-1}$),

associated with diffusion and hydrodynamic dispersion;

x the distance (cm)
 t the time (sec.) and
 ϕ is the net time rate at which the solute is
 being irreversibly produced or used.

As quoted by Mahendra Singh (1984), urea behaves as a non-reacting ion like Cl with respect to its movement with soil water before it is hydrolysed. Therefore ϕ can be assumed to be zero.

For the case where ϕ is describing a microbiological transformations (eg., nitrification or denitrification), the rate can be determined from continuous flow experiments if the number of organisms as well as the solution concentration profile are known (McLaren, 1976) or if the microbial numbers are unknown, the rate can be estimated by the method of Starr and Parlange (1975).

The method of solving the general equation will mainly depend upon the purpose of the experiment. Investigations of the dispersive aspect of solute movement have received the maximum attentions, for example the effect of substrates and dispersion coefficients. In such case, if the solute is just a means of investigating the pore medium, a chemical species is selected for which $\phi=0$ e.g. chloride on tritiated water. On the other hand, experimental conditions are established so that the initial and boundary conditions are simple enough to enable the general equation to be solved by analytical methods. Then the work consists of

adjusting a theoretical curve to experimental points in order to get parameters of interest such as dispersion coefficient and porosity (Laudelout and Dufery, 1977).

The solution of the above equation is given by numerous authors for different set of boundary conditions. Both analytical tools and numerical methods have been employed to arrive at the solutions.

The work of Parlange et al (1975), Amoozegar-Fard, et al (1982) and Yamaguchi et al (1989) reveals that a solution for the equation

$$\frac{\partial c}{\partial t} = D \frac{\partial^2 c}{\partial x^2} - v \frac{\partial c}{\partial x} \quad \text{-----}(2)$$

$$\text{is } C(x, t) = \frac{\omega}{\sqrt{t}} e^{-((x-vt)^2 / 4Dt)} \quad \text{-----}(3)$$

where ω is a constant.

It is very tedious to determine the required parameters. For example for P (Peclet Number) = 4, the profile length has been divided into 50 increments and the time into 100 increments per pore volume. This means that 100 systems of 50 equations with 50 unknowns must be solved to simulate the percolation of one pore volume Dufey (1979).

The nature of the miscible displacement method is such that the determination of apparent dispersion coefficients at low moisture contents and flow velocities are difficult and time consuming (Paetzold et al., 1978).

Numerous tests have shown that the slope method is relatively insensitive to the chosen values of the time increment. A too - small value of the time increment can give numerical problems around the section of the BTC where the steepest slopes appear, and too-large values of time interval means using a relatively, larger time interval to estimate each slope, thereby creating an unacceptable error (Yamaguchi, et al., 1989).

The use of deterministic convective dispersion equations to analyse field studies of leaching had yielded highly skewed relative frequency distributions of pore velocities and apparent diffusior coefficients (Amoozegar-Fard, et al., 1982). The present study only considered the well established functional relationship of the urea concentration with time at different depths for the simple model constructed in the study.

Moreover, this study does not focus its attention on the determination of parameters, but rather attempts to in describe the transport of urea for various time intervals at a particular depth of the soil column. Using eqution (3), we have the following functional relationship for the lograthimic concentration of a solute at a particular depth with time.

$$\log (c) = f(\log t^{1/2}, 1/t, t) \text{ -----(4)}$$

Thus the equation takes the form

$$\log c(t) = a_0 + a_1 \log t^{1/2} + a_2 t^{-1} + a_3 t \text{ -----(5)}$$

$$\text{i.e } \log c = a_0 + a_1 x_1 + a_2 x_2 + a_3 x_3 \text{ -----(6)}$$

where $x_1 = \log t^{1/2}$, $x_2 = t^{-1}$, $x_3 = t$ and the constants a_0 , a_1 , a_2 and a_3 have been determined by least squares principle. Surprisingly it was found that the temporal variations of the concentration of urea for each depth has been adequately described for all the soils studied under various rainfall conditions.

The model has been found to be comparatively better suited for the sandy clay loam and loamy sand soils, than the sandy clay soil. Perhaps simplicity of the model and the omission of the higher terms in the functional relationship may be the reason. Since the determination of the various parameters which widely vary in the field conditions is not involved, the simple equation may be further developed for the field study. Is it worth while to develop complex numerical solutions or would the use of less sophisticated, but simple numerical equations for urea movement be better, only experience can answer.

5.3. The relationship between the physical properties of soils and urea transport.

Among the fourteen important physical properties of soils considered for the study, the following seven properties were found to be favourable for urea transport in soils.

Percentage of total sand (0.7740), content of fine sand (0.8400) and the hydraulic conductivity (0.6190) were found to have significant positive correlations, while

percentage of coarse sand (-0.5160), percentage of clay (-0.6360), bulk density (-0.83) and percentage of water stable aggregates (-0.6370) were found to have significant negative correlations with the urea concentration at different depths of soils for different days and water treatments.

It is a well established fact that the identified physical properties of soil will influence the water and solute movement in soils. The literature in support of the finding is in abundance (Baver 1934, 1935, 1956, Dakshinamurthi, 1967, Hillel 1980 Broadbent et al, 1958, Haque and Ibrahim, 1965; Kumar and Wagenet, 1985, Singh and Bajwa, 1986, Subashchandra Bose 1971, Singh et al 1984, Yoder, 1936, cornfield, 1955, Van Bevel, 1950 Katou et al 1990; Sodek et al 1989, Snivastva et al 1990, Sperschmeider et al 1990, Ryusuke Hatamo et al 1991, Verma et al 1990, Van Wesenbeeck et al 1991, Jaynes, 1991, Mackie-Dawson et al 1990, Shouse et al 1990). But these studies did not indicate the relationship between soil properties and movement of urea which is not only subjected to movement inside the soil column but also enzymatic hydrolysis.

The present study revealed that the direct and indirect effects of the selected physical properties for the transport of urea in soils as detailed below.

5.3.1 Percentage of total sand

The percentage of sand found to influence the transport of urea by its direct as well as its indirect

positive effects through the hydraulic conductivity, the percentage of fine sand and indirect negative effects through the percentage of clay, the bulk density and the percentage of water stable aggregates. Its inter correlation with the above properties were found to be significant at 1% level. These indicate the dominant role played by the sand fraction of the soil in urea mobility.

5.3.2 Percentage of coarse sand

The coarse sand influence the transport of urea partly by its direct effect as well as mainly by its negative indirect effects through the percentage of fine sand. Its inter correlation with the percentage of fine sand (-0.565) was found to be significant at 5% level.

5.3.3 Content of fine sand

The fine sand was found to be ranked number one in its contribution towards the urea transport in the soils studied. Percolation is principally through the macropores and the large interstitial space between the aggregates and soil granules. Therefore it depends mainly on the relative number and continuity of the pore spaces. This may be the reason in support of the contribution by fine sand. The percentage of fine sand contributions to the transport of urea mainly by its own effect as well as its indirect effects through the other significant physical properties of the soils. Its inter correlation with all the physical properties were found to be significant.

5.3.4 Percentage of clay

The percentage of clay was found to be an important contributory factor for the transport of applied urea in soil. It influences the transport by its own negative effect and also largely by its negative indirect effects through other textural fractions, and the hydraulic conductivity and its positive indirect effects through the physical properties of the soil namely the bulk density, and the percentage of water stable aggregates. Its intercorrelation with all the physical properties except the percentage of coarse sand were found to be significant.

5.3.5 Hydraulic conductivity

The contribution of the hydraulic conductivity to the transport of urea in soil was observed not only by its direct effect but also largely by its positive indirect effect through percentage of fine sand, percentage of sand and its negative indirect effects through the percentage of water stable aggregates. Its intercorrelation with all the physical properties were found to be significant.

5.3.6 Bulk density

Like the percentage of fine sand, the bulk density was found to be an important parameter in influencing the urea mobility in the soils studied. Apart from its direct effect, it influences the transport of urea in soil by positive indirect effects through the percentage of water

stable aggregates, the percentage of clay and indirect negative effects through the percentage of fine sand, the percentage of sand the hydraulic conductivity properties. Its inter correlation with the physical properties were found to be significant.

5.3.7 Percentage of water stable aggregates

Water stable aggregates found to influence the urea transport in soil by its own effect as well as its negative indirect effects through the percentage of sand, the percentage of fine sand, the hydraulic conductivity and partly through its positive indirect effect through the percentage of clay and the bulk density. Its inter correlation with all the physical properties was found to be significant. It seems that the clay acted both as binding material of coarser mechanical separates as well as a stabilising agent against the action of water on aggregated material (Subash Chandra Bose, 1971). Jamison (1953) found that increased aggregation in three soils of various textural classes to result in the decrease of available water. Hillel (1980) showed that increased aggregation can decrease the micropore volume and decrease the water content at field capacity, thus decreasing available water.

5.3.8 Textural properties of soils and urea transport

The study on the relationship between the textural properties of soil with urea transport revealed that the percentage of fine sand was found to be an important soil

fraction followed by the clay, and the coarse sand in the order of their merit. Any increase in the properties of the percentage of fine sand may directly influence the urea transport in soil whereas a decrease in the proportion of the percentage of sand, the percentage of coarse sand, and the percentage of clay may indirectly help the process. A thorough study on the different textural fractions mixed with various proportions with the urea transport will be of much use in establishing definite trends in the future.

Summary and Conclusion

CHAPTER VI

SUMMARY AND CONCLUSION

The need of the day is to maximize the agricultural crop production and the key to the success is to build up a high fertility status in soil. It is felt important that the pathways for the success is to be routed through the physical fertility of the soil for the simple reason that, it constitutes the soil physical environment and administrates the department of the supply of the vital requirements of the plant community. The physical properties of the soil play an important role not only in the constitution of the physical environment but also in the movement of air, water, temperature and solutes in the soil. The present study was undertaken with the scope of understanding the functional relectionship between the movement of urea in soils and their physical properties.

(a) Much of the research being conducted to-day in soil-physics is directed towards developing tools for dealing with the complex problems connected with solute movement in soil. One of the objectives of the present study is also to study the spatial and temporal variations in the concentration of the applied urea in the soils.

(b) One of the major tools under development is the solute transport model. Solute transport models differ greatly in complexity and utility, ranging from simple steady-state models which ignore chemical reactions, to

complex dynamic models which include all major soil-solution reactions. The present study is aimed at in the construction of a simple model for the temporal variations in the concentration of urea at different depths of soil.

(c) Eventhough all the physical properties of a soil are important for any solute movement in the soil, some of them are playing a dominant role end they have to be identified for better physical fertility management practices. One of the objectives of the present study is to identify the important physical properties that significantly influence the urea transport in the soils.

6.1. Summary of the work done

A column study was conducted for urea transport in sandy clay loam, Loamy sand and sandy clay soils. Under four simulated moisture conditions namely,

- (1) Application of urea in the saturated condition
- (2) Normal rain fall that followed the application of urea
- (3) Excess of rain fall that followed the application of urea and
- (4) Application of urea in the flooded condition

A single level of urea (100kg ha^{-1}) was applied to all the soil columns.

The concentration of urea at different depths viz., 10, 20, 30, 40 and 50cm depths of the soil columns were periodically estimated with a time interval of 24 hours till its existence.

All the important physical properties of the three soils were estimated for all the depths of the soil columns. In addition, the general properties of the surface soils were also studied.

A simple mathematical model was constructed to describe the temporal variations in the concentration of urea at different depths of the soils with the help of least square principle. The functional relationship for the lograthemic concentration of urea at a particular depth with time was worked out as follows for all the soils.

$$\log c(t) = a_0 + a_1 \log t^{1/2} + a_2 t^{-1} + a_3 t$$

where a_0 , a_1 , a_2 and a_3 are the constants that were found out by least square principle.

c is the concentration of urea in ppm and

t is the time

The set of equations thus arrived at were used to plot the graphs for the lograthemic values of the concentration of urea in each depth against the day of urea transport for the actual and predicted values.

A statistical analysis was carried out to understand the relationship between the physical properties of the soils and the urea transport.

In order to identify the dominant physical properties which really influence the urea transport in the soils, a path analysis was carried out by considering the selected physical properties which had significant correlation with the concentration of urea in the soils. The direct and indirect effects of the physical properties of the soils on the urea transport were estimated.

A study was carried out to understand the relationship among the textural properties of the soils in connection with the urea transport. A path analysis was separately carried out only with the textural properties of the soils and the concentration of urea in the soils.

Based on the path analysis, the best textural component namely the fine sand (per cent) was selected and a simple equation describing the relationship between the number one ranked textural property and the concentration of urea in the soil was fitted.

6.2. Summary of the results

(a) The presence of urea in the soil columns was found to be in existence for five, four and seven days in sandy clay loam, loamy sand and sandy clay soils respectively. The life period for urea in the three soils

under observation was found to be greater for sandy clay than the sandy clay loam and Loamy sandy soils. The maximum concentration of urea was recorded in the first day of transport for all the soils and the concentration was found to decrease with days. The depth mean average of the urea concentration was found to be greater in loamy sand than the sandy clay loam soil and it was comparatively lesser in sandy clay soil than the other soils. The statistical analysis on the study reveals that the interaction among the parameters namely soil, depth, treatment and days were found to be significant.

The statistical analysis on the pooled data on the three soils revealed that the normal rainfall condition was found to be significantly favourable for the urea transport in soils and the least favourable for the urea transport was found to be the saturated condition. The contributions of the normal rainfall and excess of rainfall conditions on the concentration of urea in soils were on par with each other. The separate study on the different soils studied revealed that the normal rainfall condition was found to be favourable for the urea movement in sandy clay loam and sandy clay soils, whereas the flooded condition was found to be favourable for Loamy sand soil. The movement of urea in the soils under observation was found to be in the following order.

Loamy sand soil > sandy clay loam soil > sandy clay soil.

All the textural and structural properties of the three soils at different depths and the general properties of the surface depths and the general properties of the surface samples were analysed. The available nitrogen, phosphorus, potassium and organic carbon (per cent) were found to be more in sandy clay than sandy clay loam and loamy soils, and it was found to be lesser in the Loamy sand soil. The pH value for the sandy clay soil was found to be higher than the sandy clay loam and loamy sand soils.

The infiltration rate was found to be higher for the loamy sand soil than the sandy clay loam and the sandy clay soils.

The three soils can be ranked as follows based on the combination of the higher values of the fine sand (per cent), the total sand (per cent), and the hydraulic conductivity and the lower values of the clay (per cent), the water stable aggregates (per cent) and the bulk density.

1. Sandy loam soil
2. Sandy clay loam soil and
3. Sandy clay soil.

A simple mathematical model was constructed for the prediction of the temporal variation in urea concentration at different depths of the three soils subjected to 1. the saturated 2. normal rainfall 3. excess of rainfall and 4. flooded conditions. The model adequately

describes the temporal variations in the concentration of urea at different depths of the three soils under different treatments. Using the least square principles, the predicted values for the concentration of urea at each depth was worked out for all the three soils. Graphs were plotted for the logarithmic values of the concentration of urea in each depth against the days of urea transport for the actual and predicted values.

The model was found to be comparatively better suited for the loamy sand and sandy clay loam soils than the sandy clay soil.

The statistical analysis of the data on the physical properties of the soils and the concentration of urea at different depths of the soil columns revealed that the physical properties selected for the study was found to have a highly significant correlation at 0.1% level with the urea concentration.

Among the various physical properties considered, the followings were found to have significant correlation with the urea concentration in the soils viz.,

1. Total sand (per cent),
2. Coarse sand (per cent),
3. Fine sand (per cent),
4. Clay (per cent),
5. Hydraulic conductivity,
6. Bulk density and

7. Water stable aggregates (per cent).

The inter correlation among the properties were also worked out.

A path analysis was carried out by only taking the variables which had significant correlation with the concentration of urea in the soils.

It was found that, the contribution of the various physical properties considered towards the concentration of urea in soils were made by their direct as well as indirect effects through the other physical parameters.

As many literature has revealed that the textural properties of soil was one of the main factor for any solute movement, a path analysis was carried out with the urea concentration in the soils. The study revealed that the four textural properties of soils can be ranked as follows on the basis of their merits of contribution for urea transport in the soils.

1. Fine sand (per cent),
2. Clay (per cent),
3. Total sand (per cent),
4. coarse sand (per cent).

It was observed that fine sand (per cent) was found to be a main component among the teaxtural properties of the soils in influencing the urea transport in soils. Any

increase in the proportion of the fine sand (per cent) and the total sand (per cent) may directly help the urea transport in soils, whereas a decrease in the proportion of coarse sand (per cent) and clay (per cent) may indirectly help the process. A thorough study on this aspect only can confirm the results.

6.3. Conclusions drawn

The following conclusions were drawn from the study.

1. The movement of applied urea was found to be there for five days in sandy clay loam, four days in loamy sand and seven days in sandy clay soils. The life and half life periods for urea in the soils were found to be in the following order.

sandy clay soil > sandy clay loam soil > loamy sand soil

2. The depth mean average of the urea concentration was found to be greater in loamy sand than the sandy clay loam and it was comparatively less in the sandy clay soil.

3. Maximum concentration of urea was recorded in the first day of Urea transport for all the soils and the concentration was found to be decreased with days.

4. The concentration of Urea was found to be significantly higher at the upper depths namely 10, 20 and

30 cm than the lower depths viz., 40 and 50 cm of the soil columns.

5. Among the four water treatments, the normal rainfall condition was found to be favourable for urea transport in soils than the other treatments and the least favourable was found to be the saturated condition.

6. The saturated and simulated normal rainfall conditions were found to be favourable for urea transport in sandy clay loam and sandy clay soils whereas the excess of rainfall and flooded conditions were found to be⁶⁰ favourable for the lomy sand soil.

7. A simple mathematical model (Least square model) was constructed for the prediction of the temporal variations in the log concentration of urea for each depth. The model was found to be in good fit with the observed values.

8. Among the various physical properties of the soils studied, the percentage of fine sand, the bulk density, the percentage of sand, the percentage of clay, the hydraulic conductivity, and the percentage of coarse sand were found to have significant correlations with the concentration of urea in the soils. These physical properties were found to influence the urea transport in soils.

9. The textural properties of the soils are listed according to their merits of contribution towards the

urea transport in soils.

- (1) Fine sand (per cent)
- (2) clay (per cent)
- (3) Total sand (per cent)
- (4) coarse sand (per cent)

References

R E F E R E N C E S

- ICRIP. 1989. Progress report of the All India coordinated Rice Improvement programme, Directorate of Rice Development, Hyderabad, India.
- Alexander, M. 1965. Nitrification. In: Soil Nitrogen (Ed.) W.V. Bartholomew and F.E. Clark. Agronomy series 10, Amer. Soc. Agron. Inc., Madison, Wisconsin, U.S.A., 615, PP.
- Amoozegar-Fard., D.R. Nielson, and A.W. Warrick, 1982. Soil Solute concentration distributions for spatially varying pore water velocities and apparent diffusion coefficients. *Soil Sci. Amer. J.*, 46:3-8.
- Arnon, I. 1972. Crop production in dry region (Book) Lenard Hill, London.
- Baker, J. 1987. Distribution of N in a simulated profile of a podosolic gray luvisol following urea fertilization *Can. J. Soil Sci.* 67:271-80. Balwinder Singh and M.S. Bajwa, 1986. Studies on urea by Hydrolysis in salt affected soils. *Fert. Res.* 8:231-240
- Bauder, J. and R.P. Schmeider, 1979 Nitrate-Nitrogen Leaching following urea fertilization and irrigation. *Soil. Sci. Soc. Amer. J.*, Vol. 43.
- Bauder, J.W. and Montgomery, B.R. 1980. In Urea transformation and fertilizer efficiency, *Agron. J.* 72,593-96.
- Bouldin, D.R., and B.V. alimango. 1976. Volatilisation losses from IRRI paddies following broadcast application of fertilizer nitrogen. Int. In : Nitrogen economy of flooded rice soils. PP. 77-98. (Ed.) S.K. De Datta, and W.H. Patrick Jr., Martinus Nijhoff Publishers. The Netherlands.
- Baver, L.D. 1934. A classification of soil structure and its relationship to main groups *Soil Survey Assoc. Bull.*, XVI:107-109.
- Baver, L.D. 1935. Factors contributing to the genesis of soil micro structure. *Amer. soil Survey Assoc. Bull.*, XVI:55-56.

- Baver, L.D. 1956. Soil Physics. Ed.3. John Willey and Sons, Inc., New York. 123-135.
- Baver, L.D., W.H. Gardner and W.R. Gardner 1972. Soil Physics. Wiley Eastern Limited, New Delhi.
- Bear, J. 1979. Hydraulic of ground water. H. McGraw Hill, Inc., New York.
- Beese, F., and wierenga, P.J. 1980. Solute transport through soil with adsorption and root uptake computed with transient and a constant-flux model. Soil. Sci., 129, 245-252.
- Beri, V., Brar, SS., Sekhom, G.S.S. Ghuman, B.S. 1978. Extent of urea leaching in soils and its biochemical control J. Indian Soc. Soil. Sci., 26,116.
- Biggar, J.W., and Nielsen, D.R. 1967.. Miscible displacement and leaching phenomenon Agron. Monogr. 11, 254-274.
- Biggar, J.W., and D.R. Nielsen, 1976. Spatial variability of the Leaching characteristics of a field soil water, Res. 12:78-84.
- Biggar, J.W., and D.R. Nielsen, 1962. Miscible displacement. II. Behaviour of tracers. Soil. Sci. Soc. Amer. Proc., 26:125-128.
- Biggar, J.W., and D.R. Nielsen. 1967. Miscible displacement and leaching phenomena. In : R.M. Hagan, H.R. Haise, and T.W. Edminster (Eds.), Irrigation of agricultural lands. Agron. Monog. No.11. American Society of Agronomy, Madison, PP. 254-274.
- Boast, C.W. 1973. Modelling the movement of chemicals in soil by water. Soil Sci., 115, 224-230.
- Bouwneester, R.J.B., P.L.G. Vlek and J.M. Stumpe, 1985. Effect of environmental factors an ammonia volatilization from a urea fertilized soil. Soil Sci. Soc. Amer.J., 49(2):376-381.

- Bremner, J.M. and R.L. Mulavamey, 1978. Urease activity in soils. In *soil Enzymes*, PP. 149-196. (Ed.) R.G. Burns, Academic Press, London.
- Bresler, E. 1967. A model for tracing salt distribution in the soil profile *Soil sci.*, 104, 227-233.
- Bresler, E., and G. Dagam. 1981. Convective and pore scale dispersive solute transport in unsaturated heterogeneous field. *Water Resour. Res.*, 17, 1683-1693.
- Broadbent, F.E., G.M. Leil and K.B. Tyler. 1958. Transformations and movement of urea in soils. *Soil Sci. Soc. Amer. Proc.* 22:303-307.
- Byrnes, B.H., N.K. Savant, and E.T. Craswell. 1963. Effect of a Urease inhibitor PPD on the efficiency of urea applied to rice. *Soil Sci. Soc. Amer. J.*, 47:270-274.
- Campbell, C.A., R.J.K. Myers, V.R. Catchpoole, I. Vallis and K.L. Weier. 1984. Laboratory study of transformation and recovery of Urea-N in three queensland soils. *Aust. J. Soil. Res.*, 22:433-441.
- Carpena, A.O., Ortuno, A. and Coste, Y.F. 1965. An. Edafol. Agnobiol. 24:51-70. As quotation Transformation and transport of urea in soils. *Crop Res* 2(1):66-129(1989).
- Chin, W., and W. Kroomtie. 1963. Urea hydrolysis and subsequent loss of ammonia. *Soil Sci. Soc. Amer. Proc.* 34:859-862.
- Cornfield, A.H. 1955. The measurement of structure and factors affecting it. *J. Sci. Food Agric.*, 6:3356-360.
- Craswell, E.T., and P.L.G. Vlek. 1979. Fate of fertilizer N applied to wetland rice. In: *Nitrogen and Rice*. PP. 175-192. Int. Rice Res. Inst., Los Banos, Phillippines.
- Craswell, E.T., S.K. De Datta, W.N. Obcemea and Hartanty. 1981. Time and mode of nitrogen fertilizer application to tropical wetland rice. *Fert. Res.*, 2:247-259.

- Dagan, G., and Bneselr, E. 1979. Solute dispersion in unsaturated soil at field scale. *Soil Sci. Soc. Am. J.*, 43:461-46.
- Dahiya, I.S. and I.P. Abrol. 1974. Redistribution of surface salts by treatment and steady infiltration as water in to dry soil. *J. Ind. Soil Sci. Soc.* 22:209-216.
- Dahiya, I.S. Mhinder Singh, Mahendra Singh and S. Hajrasuliha. 1980. Simultaneous transport of surface-applied salts and water through unsaturated soils as affected by infiltration, Redistribution, and Evaporation. *Soil Sci. Soc. Am. J.*, Vol. 44:223-227.
- Dakshinamurthi, C. I. Gupta, R.P. 1967 practicals in soil physics, Indian Agricultural Research Institute, New Delhi.
- Dakshinamurthi, C., and R.P. Gupta. 1968 Practicals in soil physics. Indian Agricultural Research Institute., New Delhi.
- Dalal, R.C. 1975. Urease activity in some Trinidad soils. *Soil Biol. Bio chem.*, 7: 5-8.
- De Datta, S.K. 1981. Increasing fertilizer nitrogen efficiency by minimising losses in tropical wetland rice soils. *Madras Agric. J.*, 67: 54-63.
- De Datta, S.K. 1986. Improving nitrogen fertilizer efficiency in lowland rice in tropical Asia. *Fert.Res.*, 9:171-181.
- Dewey, D.R and K.H.L.U. 1959. A correlation and path coefficient analysis of components of crested wheat grass seed production. *Agron. J.* 47: 477-83.
- Douglas, L.A and Bremner, J.M. (1971). A rapid method of evaluating different compounds as inhibitors of urease activity in soils. *Soil Biol. Biochem* 3: 309-15.
- Douglas, L.A and J.M. Bremner. 1970 Extraction and Calorimetric determination of urea in soil. *Soil Sci. Soc. Am. Proc.*, 34: 859-861.

- Dufey, J.H. 1979. Mathematical modelling of complex reactions and solute movement through soils. In modelling Nitrogen from farm waste, Applied Science Publishers Ltd., London
- El-Wali, A.M.O., Grand, F.L. and Gascho, G.J. 1980. Nitrogen Leaching from soil and uptake by sugarcane from various urea-based fertilizers. *Soil Sci. Amer. Proc.* Vol. 44: 119-122.
- Elprince, A.M., and P.R. Day. 1977. Fitting solute break through equations to data using two adjustable parameters. *Soil sci. Soc. Amer. J.* 41: 39-41.
- Farmer, W.J., and Ahlrichs, J.L. 1969. Infrared studies of the Mechanism Adsorption of urea-d₄₅ Methyl urea-d₃₅ and I.I. Dimethylurea-d₂ by montmorillonite. *Soil Sci. Soc. Amer. Proc.* Vol. 33, 254-258.
- Farooqui, M.A.R., M. Hamif and C.J. De Mooy. 1983. Nitrogen mineralisation potential and urea hydrolysis under aerobic and anaerobic conditions. *Commun. Soil Sci. pl anal.*, 14(1): 29-47.
- Fenn, L.B., Matocha, J.E., and Wu, B. 1981. A comparison of calcium carbonate precipitation and pH depression on calcium reduced ammonium loss from surface applied urea. *Soil Soc. Amer. J.*, 45: 1128-1131.
- Fenn, L.B. and S. Miyamoto, 1981, Ammonia loss and associated reactions of urea in calcareous soils. *Soil Sci. Soc. Amer. J.*, 45: 537-540.
- Ferguson, R.B., Kissel, D.E., Koelliker, J.K., and Basel, W. 1984. Ammonia volatilization from surface applied urea: Effect of hydrogen ion buffering capacity. *Soil Sci. Soc. Amer. J.*, 48: 578-582.
- Fernando, V., and Roberts, G.R. 1975. Improvements in the method for the determination of ammonia volatilized from soil fertilized with urea. *Pl. Soil.*, 42: 287-291.
- Foster, N.W. ; Beauchamp E.G. ; Corke, C.T. Reactions of ¹⁵N labelled urea with jack pine forest floor materials. *Soil Biology and Biochemistry* (1985) 17(5) 699-703.
- Gandhi, A.P. and K.V. Paliwal, 1976. Mineralization and gaseous loss of nitrogen from urea and ammonium sulphate in seed-affecting soil. *Pl. Soil.*, 45: 247-255.

- Gardner, W.R. 1956. Calculation of capillary conductivity from pressure plate outflow data. *J. Soil. Soc. Amer. Proc.*, 20:317-320.
- Gardner, W.R. 1965. Movement of nitrogen in soil *Agron. Monogr.* 10:550-572.
- Gasser, J.K. 1964. Some factors affecting the losses of ammonia from urea and ammonium sulphate applied to soils *J. Soil. Sci.*, 15:258-272.
- Ghuman, B.S. and Prihar, S.S. 1980. Chloride displacement by water in homogeneous columns of three soils. *Soil Sci. Soc. Amer. J.*, 44:17-21.
- Gould, W.D., F.D. Cook and G.R. Webster, 1973. Factors affecting urea hydrolysis in several Alberta soils. *Can. Soil.* 38:393-401.
- Gould, W.D., C. Hagedorn and R.G.L. McCready, 1986. Urea transformations and fertilizer efficiency in soil. *Adv. Agron.*, 40:209-238.
- Gupta, R.P. and G. Dakshinamurthi. 1981. Procedure for physical analysis of soils and collection of Agrometeorological Data. Division of Agricultural Physics, IARI, New Delhi.
- Gupta, S.K., T.N. Chaudhary and R.N. Pandey. 1982. Nitrate movement in sandy soil under varying water and fertilizers management. Irrigation 38±0.5cm water at rates of 5.5, 7.5 and 9.5 cm per irrigation (light, medium and heavy irrigation) 150 Kg Nitrogen/ha and urea. *Ausfr. J. Soil. Res.* 1982, 20,255.
- Hameed Khan, H. 1990. Studies on urea hydrolysis and Ammonia Volatilization from soils. Thesis Abstract. 1990. **Tamil Nadu Agricultural University, Coimbatore.**
- Haque and Ibrahim, M. 1965. In Transformation and transport of urea in soil mixed Kumar et al. (Ed.,) *Crop Res.* 2(1):66-129. (1989).

- Henks, R.J., A. Klute, and E. Bresler, A numeric method for estimating infiltration, redistribution, drainage and evaporation of water from soil water Resour. Res., 5, 1064-1069, 1969.
- Hillel, D. 1980. Soil Water : Content and potential. In fundamentals of soil physics, Academic press, New York.
- Hillel, D. 1982. Introduction to soil physics. Academic press, New York.
- Holland, P.T. and During, C. 1977. Movement of nitrate-N and transformation of urea-N under field conditions. N.Z.J. Agric. Res. 20:479-488.
- Ibrahim, M.E. Awadalla, E.A., Badrel-Dim, M.M and Kossim, A.S. 1984. Z. Pfianzenerhaehr Bodenkd 147:177-186. As quoted by vinod kumar and J. Richter in Transformation and transport of urea in soils. Crop Res 2(1):66-129. (1989).
- Islam, M.M., M. Kebir and N.I. Bhuiyan. 1985. Response of rice to Zinc and sulphur IRRN 9(5):24.
- Ivano, P. 1981. Agrokhmiya 16:80-88. In Transformation and transport of urea in soils. Vinod kumar et al Crop. Res. 2(1):66-129. (1989).
- Jamison, V.C. 1953. Changes in air-water relationships due to structural improvement of soils. Soil Sci. 76:143-151.
- Jawahar, D., M. Guruswamy, and K.S. Subramanian. 1990. Effect of Zn on nutrient uptake and yield of rice. Abstr. paper presented in National seminar on rice farming systems. March 15-16, 1990. Agri. College and Res. Instt., Madurai. PP. 28.
- Jayaramamoorthy, S., T.S. Manickam, C.K. Rajagopal and K. Natarajan. 1985. Role of sulphur on the utilisation of nitrogen in rice. Proc. National seminar on sulphur in agriculture. October 18-19, 1985. Tamil Nadu Agri. Univ., Coimbatore. PP. 175.
- Jaynes, D.B. 1991. Field study of Bromacil transport under continued-flood irrigation. Soil Sci. Soc. Amer. J. 55:658-664

Kandaswamy, P., and K. Arulmozhiselvan. 1985. Effect of application of gypsum on availability and utilisation of sulphur and nitrogen in rice. Proc. National seminar on sulphur in agriculture. October 18-19, 1985. Tamil Nadu Agri. Univ., Coimbatore. PP. 178.

Katou, H. Akiyama, R. 1990. Solute dispersion during unsteady leaching as affected by aggregate size and soil water content. *Soil Sci. and Plant Nutrition* 36 (1) 53-64.

Kirda, C., D.H. Nielsen, and J.W. Biggar. 1973. Simultaneous transport of chloride and water during infiltration. *Soil Sci. Soc. Amer. Proc.* 37:339-345.

Kiss, S., M. Dragam-Bularda and Radulescu. 1975. Biological significance of enzymes accumulated in soil. *Adv. Agron.* 27:25-82.

Knop, K and Mastaler, L. 1970. Zentbl. Bact. Parasitkde. Abt. 11. 124:532-40. In Transformations and transport of urea in soils, Vinod Kumar et al, (Ed.) *Crop. Res.* 2(1):66-129P, (1989).

Kool, J.B., J.C. Parker and H.M. Van Genuchten. 1987. Parameter estimation for unsaturated flow and transport models-a review. *J. Hydrol. (Amsterdam)*. 91:255-293.

Krishnappa, A.M., and J.E. Shinde. 1980. Fate of ^{15}N labelled urea fertilizer under conditions of tropical flooded rice culture. In: *Soil N as a fertilizer pollutent*, IAEA, STI, PUB/535, 127-143.

Kumar, V., and R.J. Wagenet. 1984. Urease activity and kinetics of urea transformation on soils. *Soil Sci.*, 137:263-269.

Kumar, V. and Wagenet, R.J. 1985. Salt effects on urea hydrolysis and nitrification during leaching through laboratory soil columns. *Plant soil* 85, 219-227.

Ladd, J.N. 1976. Origin and range of enzymes in soils. PP.51-96. In: *Soil Enzymes* (Ed.) R.G. Burns. Academic Press. London.

*Laudelout, H and Dufey, J.E. 1977. Analyse numerique des experiences de lixiviation en soil homogene *Annales Agronomiques*, 28 (1) 65-73.

Lippold, H., Heber, R., and Foster, I. 1975. In urea transformations and fertilizer efficiency (Ed.) W.D. Gould, et al Ad. Agron. 4., 237P. Arch. Acker-Pflanzenbau Bodem Kd. 19. 619-630.

Luxmoore, R.J., and sharma, M.L. (1980). Runoff responses to soil heterogeneity. Water Resour. Res. 16. 675-684.

Mackie-Dawson, L.A., P. Millard and D. Robinson., 1990. Nutrient uptake by potato crops grown on two soils with contrasting physical properties. Plant Soil 125 : 159-169 (1990).

Mahendrappa, J.K., Smith, R.L. and Christianson, A.T. 1977. Nitrification Organisms Affected by climatic Region in Western United States. Soil Sci. Soc. Amer. Proc. Vol. 30:60-62.

Machendra Singh, D.S. Yadav and Vinodkumar. 1984. Leaching and transformation of urea in dry and wet soils as affected by irrigation water plant and soil. 81, 411-420.

Manickam, T.S., and P.P. Ramaswamy. 1987. Fate and efficiency of urea based fertilizers in India. Final tech. report of the TNAU-ICAR-USDA project, Tamil Nadu Agri. Univ., Coimbatore.

Manickam, T.S. 1988. Nitrogen Fertilizer Efficiency Project Report. Indo-US STI programme, Tamil Nadu Agricultural University., Coimbatore.

Manickam, T.S. and K. Natarajan. 1990. Nitrogen efficiency studies using ^{15}N techniques under flooded paddy condition. Abstr. paper presented in National seminar on Rice Farming systems. March 15-16, 1990. Agricultural college and Research Institute., Madurai. PP. 22.

Mann, J.S. 1969. M.Sc. Thesis, Deph of soil science, H.A.U. Hisar, India.

McLaren, A.D. 1976. Rate constants for nitrification and denitrification in soils. Radiat and Environ. Biophys. 13:43-48.

Miller, R.J., J.W. Biggar and D.R. Nielsen, 1965. Chloride displacement in pamoche clay loam in relation to water movement and distribution. Water Resour. Res., 1:63-73.

Lippold, H., Heber, R., and Foster, I. 1975. In urea transformations and fertilizer efficiency (Ed.) W.D. Gould, et al Ad. Agron. 4., 237P. Arch. Acker-Pflanzenbau Bodem Kd. 19, 619-630.

Luxmoore, R.J., and sharma, M.L. (1980). Runoff responses to soil heterogeneity. Water Resour. Res. 16, 675-684.

Mackie-Dawson, D.A., P. Millard and D. Robinson., 1990. Nutrient uptake by potato crops grown on two soils with contrasting physical properties. Plant Soil 125 ; 159-169 (1990).

Mahendrappa, J.K., Smith, R.L. and Christianson, A.T. 1977. Nitrification Organisms Affected by climatic Region in Western United States. Soil Sci. Soc. Amer. Proc. Vol. 30:60-62.

Machendra Singh, D.S. Yadav and Vinodkumar. 1984. Leaching and transformation of urea in dry and wet soils as affected by irrigation water plant and soil. 81, 411-420.

Manickam, T.S., and P.P. Ramaswamy. 1987. Fate and efficiency of urea based fertilizers in India. Final tech. report of the TNAU-ICAR-USDA project, Tamil Nadu Agril. Univ., Coimbatore.

Manickam, T.S. 1988. Nitrogen Fertilizer Efficiency Project Report. Indo-US STI programme, Tamil Nadu Agricultural University., Coimbatore.

Manickam, T.S. and K. Natarajan. 1990. Nitrogen efficiency studies using ^{15}N techniques under flooded paddy condition. Abstr. paper presented in National seminar on Rice Farming systems. March 15-16, 1990. Agricultural college and Research Institute., Madurai. PP. 22.

Mann, J.S. 1969. M.Sc. Thesis, Deph of soil science, H.A.U. Hisar, India.

McLaren, A.D. 1976. Rate constants for nitrification and denitrification in soils. Radiat and Environ. Biophys. 13:43-48.

Miller, R.J., J.W. Biggar and D.R. Nielsen, 1965. Chloride displacement in pamoche clay loam in relation to water movement and distribution. Water Resour. Res., 1:63-73.

- Misra, C., D.R. Nielsen, and J.W. Biggar 1974. Nitrogen transformations in soil during leaching. III Nitrate reduction in soil columns. *Soil Sci.Soc.Amer.Proc.* 38:300-304.
- Mitsui, S. 1977. Recognition of the importance of denitrification and its impact on various improved and mechanized applications of nitrogen to rice plant. *ZProc. Int. seminar on soil Environmental and fertility Management (SEFMIA). Soc. Soil Sci and Mamure, Japan* 259-268P.
- Mohamed, I.H., D.R. Scooter, and P.E.H. Gregg. 1984. The short term fate of urea applied to Barley in a humid climate. I. Experiments. *Aust. J. Soil Res.*, 22:173-180.
- Moustafa, A. T.A and Khadr, M.S. 1983. In isotopes and radiation techniques in physics and irrigation studies, vienna, Austria, I.A.E.A., PP. 275-81.
- Musa, M.M. 1968. Nitrogenous fertilizer information in the sudan Gazira soil. I. Ammonia volatilization losses following surface application of urea and ammonium sulphate. *Plant soil*. 28, 413-21.
- NG, H.C. and Tay, T.H. 1977. *Proc. Conf. on Fertility and chem of Tropical soils Nov. 1973. Kula Lumpur, Malaysia, Malaysian Soc. Soil Sci.*, 161-66.
- Nielsen, D.R., and Biggar, I.W. 1961. Miscible displacement in soils. I. Experimental information. *Soil Sci. Soc. Amer. Proc.*, 25,1-5.
- Nielsen, D.R., and Biggar, J.W. 1963. Miscible displacement in soils. III. Theoretical considerations. *Soil Sci.Soc. Amer. Proc.*, 26,216-221.
- Nielsen, D.R. and Biggar, J.W. 1962. Miscible Displacement:3. *Soil Sci. Soc. Amer.Proc.*, 26:216-222.
- ommick, H., 1973. Assessment of volatilization loss of ammonia from surface applied urea in forest soil by ¹⁵N recovery Pl. *Soil*, 38;589-603.

- Okereke, G.U. and Meints, V.W, 1985. Immediate immobilization of labeled Ammonium sulphate and urea nitrogen in soils. *Soil Sci.* 140 (2) 105-109.
- Olsen, S.R., C.L. Cole, F.S. Wantanbe, and J.A. Dean. 1954. Estimation of available phosphorus in soils by extraction with sodium Bicarbonate USDA Circ. 939.
- Overrein, L.N. and P.G. Moe, 1967. Factors affecting urea hydrolysis and ammonia volatilization in soil. *Soil Sci. Amer. Proc.*, 31:57-61.
- Overrein, L.N. 1968. Lysimeter studies on Tracer Nitrogen in Forest Soil: I. Nitrogen Losses by Leaching and Volatilization after of urea-¹⁵N *Soil Sci.* 106. 280-290.
- Paetzold, R.F and H.D. Scott 1978. Determination of the appartment dispersion coefficient of solutes in unsaturated soils *Soil sci. soc. Amer.J.* 42:874-877.
- Pande, H.K and S.K. Mohanty. 1986. Consolidated report of ICAR coordinated project an chemistry of submerged soils under rice cultivation in high rainfall ureas 1980-85. CRR1, Cuttack, Orissa, India. 253P.
- Panse, V.G and P.V. Sukathme. 1967. Statistical methods for agricultural workers. Indian council of Agricultral Research. New Delhi.
- Parlange, J.Y. and J.L. Starr. 1975. Linear dispersion in finite columns. *Soil Sci. Soc. Amer. Proc.* 39:817-819.
- Parlange, J.Y., and J.L. Starr. 1978. Dispersion in soil columns. Effect of boundary conditions and irreversible reactions. *Soil Sci. Soc. Amer. J.* 42:15-18.
- Parker, J.C. and M. Th. Van Genuchten. 1934. Derminating transport parameters from Laboratory and field tracer experiments. *Virginia Agric. Exp. sten. Bull.* 84-3.
- PaulHeipman, 1974. Effect of urea fertilization on Nitirification in Forest soils of the Pacific North West. *Soil Sci.Soc. Amer.Proc.* Vol. 30: 664-667.

Paulson, K.N. and L.T. Kurtz, 1969. Locus of urease activity in soil. *Soil Sci. Soc. Amer.*, 33:897-901.

Piper, C.S. 1966. Soil and plant analysis Hams publishers, Bombay, India.

Prasad, R., G.B. Rajale, and B.A. Lakhdive. 1971. Nitrification retardants and slow nitrogen fertilizer. *Adv. Agrom.*, 23:337-383.

Praveen-Kumar, R.K. Aggarwaal and B.M. sharma 1990. Effect of method of application of urea, Time and Depth of Water application on movement of urea in an Acid sandy soil *Indian Soc. Soil. Sci. Vol.* 38:394-403.

Protasov, P.V and Karosteleva, G.D, 1972 *Agrokhmiya* 10:27-31 in Transformation and transport of ura in soils, Vinod kumar et al. (Ed). *Crop Res.* 1(2): 66-129 (1989).

Rao, P.S.c., D.E. Kelston, R.E. Jessup and J.M. Davidson. 1980 Solute transport in aggregated perous media: theretical and experimental evaluation. *Soil Sci. Soc. Amer.J.*44: 1139-1146.

Rao, K.V., and J.E. Shindi. 1985 Transformation of ¹⁵N labelled urea nad its modified farms in tropical wetland rice culture. *Pl.Soil*, 85:413-121.

Ramanathan, K.M., and A. Saravanan. 1985. Effect of nitrogen sources in combinatin with gypsum, zinc sulphate and sulphur on rice yield. *Proc. National seminar on sulphur in agriculture.* October 18-19, 1985. *Tamil Nadu Agrl. Univ.*, Coimbatore. pp. 139-142.

Rana, D.S., Biji singh, M.L. Kapur and A.L. Bhandari. 1984. Relative efficiency of new urea based nitrogen fertilizers for rice grown in light textured soil. *J. Indian Soc. Soil sci.*, 32: 284-287.

Reddy. K.R., and W.H. Patrick, J.N. 1986. Fate of fertilizer nitrogen in the rice root zone. *Soil Sci. Soc. Amer.J.*,50:649-651.

Keynolds, C.M. Wolf D.C and Ambruster, J.A, 1985.Factors related to urea hydrolysis in soils.*Soil Sci. Soc. Amer.J.* 49:104-88.

- Richards, L.A., 1931. Capillary conduction of liquids through porous medium. **Physics (NY)** 1:318-33.
- Ryusuke Hatano and Toshio Sakuma, 1991. A plate model for solute transport through aggregated soil columns. II. Experimental results and application of the model. **Geoderma**, 50:25-36.
- Sadeghi, A.M., D.E. Kissel and M.L. Cabrera 1988 Temperature effects on urea diffusion coefficients and urea movement in soil. **Soil Sci. Soc. Amer.J.** 52:46-49.
- Sadeghi, A.M., D.E. Kissel and M.L. Cabrera 1989 Estimating Molecular Diffusion coefficients of urea in unsaturated soil **Soil Sci. Soc. Amer.J.** 53:15-18.
- Sahu, S.K., and S.S. Pal. 1987. Response of modified forms of urea under lowland rice cultivation. **J. Indian Soc. Soil Sci.**, 35:146-148. Said, M.B., 1972. Adsorption of urea by some Sudan soils. **Plant Soil** 36:239-42.
- Sandanam, S., Krishnapillai, S. and Sabaratnam, J. 1978 Nitrification Ammonium Sulphate and urea in acid red yellow podzolic tea soil in Sri Lanka in relation to soil fertility **Plant Soil** 49: 9-22.
- Sankaran, S., and P. Balasubramaniam, 1985. Comparative efficiency of sulphur coated urea in lowland rice. Proc. National seminar on sulphur in agriculture. October 18-19, 1985. **Tamilnadu Agril. Univ., Coimbatore.** pp.175.
- Sannigrahi, A.K. and L.N. Mendal, 1982. Release of nitrogen from slow release fertilizers in water logged rice soils. **J. Indian Soc. Soil Sci.**, 30:534-536.
- Saravanan, A. Velu, V. and K.M. Ramanathan 1988 Effect of sources and methods of nitrogen applied on volatilisation loss of ammonia and yield of rice under submerged soils of Cavary delta. **Oryza**, 25: 143-148.
- Saravanan, A. 1990. ¹⁵N studies on Nitrogen use efficiency and Balance in rice-soil system. Thesis Abstract. 1991. Tamilnadu Agricultural university, Coimbatore.

Sarigumba, T.I., W.L. Pritahett and W.H. Smith, 1978. Transformation of urea in loamfine sand under four soil moisture regimes. **Abs. Soil fert.**, (1980), 7498.

Savant, N.K., James, A.F and Mcmcelellan, G.H. 1985. Effect of soil submergence urea hydrolysis **Soil Sci.** 140(2): 81-88.

Savant, N.K., A.F. James and G.J. Mc Clellem, 1987. Effect of soil bulk density on hydrolysis of surface applied urea in unsaturatead soils. **Fer.Res.**, 11: 221-229.

Shankhayan S.D. and U.C. Shukla, 1976. Rate of urea hydrolysis of five soils of India **Geoderma**. 16:171-178.

Shouse, P.J., T.J. Gerik, W.B. Russel and D.K. Gassel 1990. Spatial Distribution of Soil Particle size and Aggregate stability index in a clay soil.

Simpson, D.M. H. and S.W. Melstead, 1963. Urea hydrolysis and transformation in same Illinois soils. **Soil Sci. Soc. Amer. Proc.**, 27: 48-50.

Singh, M., I.S. Dahiya and M. Singh .1979. Simultaneous transport of surrace soils and water through unsaturated soils during infiltration and redistribution. **Commun Soil Sci. Plant Anal.** 10: 591-611.

Singh, M. and D.S. Yadav. 1981 Transformatin of urea and ammonium sulphate in different soils. **Pl. Soil.** 63: 511-515.

Singh, D. & Ghosh, A.B 1982. Evoluation of some soil test methods for estimation of plant utilizable potassium in soils **Fertil. News** , 38-42.

Singh, M., D.S. Yadav and V. Kumar. 1984. Leaching and transformation of urea in dry and wet soils as affected by irrigation water. **Pl. Soil**, 81: 411-414.

Singh., R. and P.H. Nye. 1984. Diffusion of urea, ammonium and soil alkalinity from surface applied urea. **Journal of Soil Science** 35, 529-538.

Singh, B., and M.S. Bajwa. 1986. Studies on the leaching of urea in sodic soils. **J. Agric. Sci.**, 106: 323-330.

- Skiba, UTE. and Wainwright, M. 1984 Urea hydrolysis and transformation in coastal due sands and soil. **Plant Soil** 82:117-23.
- Smiles, S.E. and J.R. Philip, 1978 Solute transport during absorption of water by soil: Laboratory studies and their practical implicatins. **Soil Sci. Soc. Amer.J.** 42:537-544.
- Sodek, F. III., Carisle, V.W., Harris, W.G. 1989. Relationship of maximum density and optimum moisture to particle size distribution for selected Florida soils. **Crop Sci. Soc. Of Florida** (1989) 48, 138-144.
- Soundarapandian, A., and S. Subbaiah. 1990 Effect of digested sewage sludge and zinc sulphate on nutrient availability and yield of rice. Abstr. paper presented in National Seminar on Rice Farming Systems. March 15-16, 1990. **Agri. College and Res. Instt., Madurai.** pp.36.
- Sperschneider, R., Broad, H.G., Hartze, K.K. 1990. The influence of different soil structures measured by penetrometer-on the transport of salts in rode side soils. **Milt eilungen der Deutschem Bodenkundichen Gesellschaft** 61, 145-148.
- Srivastva, A.K., Kumar, R. 1990. Textural structural relationship of some Indian Soils **Ind.Soc. of Soil Sci.** 38(2);293-296.
- Stanford, S., and L. English. 1949. use of flame photometer in rapid soil test for K and Ca. **Agron. J.** 41:446-447.
- Starr, J.L., and J.Y. parlange. 1975 Nemilinear denitrification Kinetics with continous flow in soil columns. **Soil Sci. Soc. Amer. Proc.** 39:875-880.
- Subash Chandra Bose, M. 1971. Comparative study of the structural attributes of Typical Black soils of Tamilnadu. Thesis Abstract. 1971., Post Graduate training centre, Agricultural College and Research Institute, Coimbatore.
- Subbiah, B.V., and G.L. Asija. 1956 A rapid procedure for estimation of available nitrogen in soils. **Curr. Sci.**, 25: 259-260.
- Subbiah, S., K.M. Ramanathan, R. Sureshkumar and K.K. Krishna moorthy. 1980. Nitrification inhibitor increase the efficiency of N for rice. **IL. Riso**, 29:227-272.

- Sujatha, M.P., and S. Subbiah. 1990. Direct and residual effect of phosphorus and zinc on soil properties and yield of rice. Abstr. Paper presented in National Seminar on Rice Farming Systems. March 15-16, 1990. Agril. College of Res. Institute., Madurai. pp.27.
- Tabatabai, M.A. 1973. Michaelis constants of urease in soils and soil fractions. *Soil Sci. Soc. Amer. Proc.* 37:707-710.
- Tanji, K.K., Dutt, G.R., Paul, J.L., and Domeen, L.D. (1967) Quality of percolating waters. *Hilgardia* 28, 307-318.
- Terman, G.L., 1979. Volatilization losses of ammonia from surface applied fertilizers organic amendments and crop residuals. *Adv. Agron* 31:189-123
- Tewatia, R.K. 1986. Ph.D. Thesis, Dept. of Soil Science, H.A.U., Hissar, India.
- Tiulin, A.F. 1928. Questions on Soil structure prem. *Agril. Exp. Stn. Div. Agr. Chem Report* 2: 77-122, 1928. As quoted in Baver's soil physics.
- Torello, W.A., Wehner, D.J., and Turgeon, A.J. 1983. Ammonia Volatilization from fertilized Turf grass stands. *Agron J.* Vol. 75, 454-456
- Van Bavel, C.H.M. 1950. Mean weight diameter of soil aggregates as a statistical index of aggregation. *Soil Sci. Soc. Amer. Proc.* 14:20-23.
- Van Genuchten, M. T.H., and Wierenga, P.J. 1976. Mass transfer studies in sorbing porous media I. Analytical solutions. *Soil Sci. Soc. Amer. J.*, 40, 473-480.
- Van Genuchten, M.T.H., and Wierenga, P.J. 1977. Mass transfer studies in sorbing porous media II. Experimental evaluation with tritium. *Soil. Sci. Soc. Amer. J.*, 41, 272-278.
- Van der pol, R.M., Wierenga, P.J., and Nielson, D.R. 1977. Solute movement in a field soil. *Soil Sci. Soc. Amer. J.*, 41, 10-13.

- Van Wessenbeck, I.J.; and R.G. Kachanuski, 1991. Spatial Scale dependence of In Situ solute transport *Soil Sci. Soc. Amer. J.* 55: 3-7.
- Velu, V. and K.M. Ramanathan. 1985. Nitrogen sources for lowland rice. *IRRN.*, 10(2):22.
- Velu, V., A. Saravanan, and K.M. Ramanathan, 1988. Leaching loss of nitrogen in clay loam soils of cauvery delta. *Oryza*, 25:374-379.
- Velu, V., 1989. Studies on N balance in rice soils of Thanjavur. Ph.D. Thesis. Tamil Nadu Agril. Univ., Coimbatore.
- Verma, S.K. and Ram K. Gupta, 1990. Redistribution of surface applied chloried in a montmorillonitic clay soil. *J. Ind. Soc. Soil. Sci.* 38: 6-14.
- Vinod Kumar., and Richter. J. 1989. Transformation and transport of urea in soils-A review. *Crop Res.* 2(1):66-129.
- Vlek, P.L.G. and E.T. Craswell. 1979. Effect of nitrogen source and management of NH_3 volatilisation losses from flooded rice soil systems. *Soil Sci. Soc. Amer. J.* 43:352-358.
- Vlek, P.L.G. B.H. Bryer and E.T. Craswell, 1980. Effect of Urea displacement on leaching loss of nitrogen from flooded rice soils. *Plant soil*, 54:441-449.
- Wagenet, R.J., W. Biggar, and D.R. Nelson, 1977. Tracing the transformations of urea fertilizer during leaching. *Soil Sci. Soc. Amer. Proc.*, 41:896-902.
- Wagenet, R.J. (1981). In M.J. Frissel and J.A. Van Veen (Eds.) Simulation of soil water and nitrogen behaviour in soil-plant systems. PP. 67-80. Center for Agric. Pub and Docum, Wageningen. The Netherlands.
- Walkley, A.J., and I.A. Black. 1935. An estimation of the method for determining soil organic matter and a proposed modification of the chromic acid titration method. *Soil Sci.*, 37:29-38.

- Warrick, A.W., J.W. Biggar and D.R. Nielsen. 1971. Simultaneous solute and water transfer in an unsaturated soil. **Water Resour. Res.** 7. 1216-1225.
- Warrick, A.W., and Amoozegar-Fared, A. 1979. Infiltration and drainage calculations using specially scaled hydraulic properties. **Water Resour. Res.** 15, 1116-1120.
- Watanabe, I., S.K. De Datta, and P.A. Roger. 1988. Nitrogen cycling in wetland rice soils. In: Advances in Nitrogen cycling in Agricultural Ecosystems. (Ed.) J.R. Wilson. Proc. Symposium on Advances in nitrogen cycling in agricultural ecosystem. **Brishame, Australia**. PP. 239-256.
- Wetselaar, R. 1972. Nitrate distribution in Tropical soils. Downward movement and accumulation of nitrate in the subsoil. **Plant soil XVI** no:1.
- Wierenga, P.J. 1977. Solute distribution profiles computed with steady state and transient water flow models. **Soil Sci. Soc. Amer. J.**, 41, 1050-1055.
- William, A. Jury 1978. Use of solute transport models to estimate salt balance below irrigated cropland. **Advances in irrigation**, Vol. 1, 87-104.
- Yamaguchi, T., Moldrup, P., and Yokosi., S. 1984. Using Break thorough curves for parameter estimation in the Convection-Dispersion model of solute transport. **Soil. Sci. Soc. Amer. J.**, 53:1635-1641.
- Yoder, R.E. 1936. A direct method of aggregate analysis and a study of the physical nature of erosion losses. **J. Amer. Soc. Agron.** 28:337-351.
- Zantua, M.I. and I.M. Bremner, 1975. Preservation of soil samples for assay of urease activity. **Soil Biochem** 7:297-299.
- Zamntua, M.I. and Bremner, J.M. 1977. Stability of urease in soils **Soil Biology and Biochemistry** 9, 135-140.

* Original not seen

