DYNAMICS OF NITROGEN IN NORMAL, SALINE AND SODIC SOILS

By

P.S. SANGWAN

Dissertation submitted to the Chaudhary Charan Singh Haryana Agricultural University in partial fulfilment of the requirements for the degree of:

DOCTOR OF PHILOSOPHY

in

SOIL SCIENCE

College of Agriculture
Chaudhary Charan Singh
Haryana Agricultural University
HISAR

1994

D E D I C A T E D

TO MY

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LATE SHRI RICHHPAL SINGH

CERTIFICATE - I

This is to certify that this dissertation entitled, "Dynamics of nitrogen in normal, saline and sodic soils" submitted for the degree of Ph.D. in the subject of Soil Science of the Chaudhary Charan Singh Haryana Agricultural University, is a bonafide research work carried out by Shri P.S. Sangwan under my supervision and that no part of this dissertation has been submitted for any other degree.

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

Vinod Kumar

(VINOD KUMAR)
MAJOR ADVISOR
Professor
Department of Soil Science

CERTIFICATE - II

This is to certify that this dissertation entitled, "Dynamics of nitrogen in normal, saline and sodic soils" submitted by Shri P.S. Sangwan to the Chaudhary Charan Singh Haryana Agricultural University in partial fulfilment of the requirements for the degree of Ph.D., in the subject of Soil Science, has been approved by the Student's Advisory Committee after an oral examination on the same, in collaboration with an External Examiner.

MAJOR ADVISOR 2.9.94

EXTERNAL EXAMINER 2/9/94

HEAD OF THE DEPARTMENT 12/9/94

14/9

DEAN, POSTGRADUATE STUDIES

ACKNOWLEDGEMENTS

I take this opportunity to express my deep sense of gratitude, indebtness and sincere thanks to Dr. Vinod Kumar, Professor of Soil Science and my Major Advisor, for his able guidance, constructive criticism, constant encouragement and especially creating in me a sense of independent thinking.

I wish to record my sincere appreciation for Dr.Mahendra Singh, Professor of Soil Science; Dr. P.S. Relan, Professor of Chemistry; Dr. S.S. Narwal, Professor of Agronomy and Dr. Lajpat Rai, Associate Professor of Mathematics and Statistics, members of my Advisory Committee, for having shown keen interest in my studies and research work.

I am highly grateful to Dr. R.S. Antil and Dr. J.P. Singh, Soil Chemists, who helped me a lot during the course of investigation. Their cooperation in every respect during the studies and research work is highly appreciated.

Thanks are due to Dr. S.R. Poonia, Professor and Head, Department of Soils Science, for providing me the necessary facilities during the course of investigation.

I owe my profound thanks to Dr. K.C. Banger, Department of Soil Science, for providing me scientific thoughts and valuable suggestions during preparation of this manuscript.

It is also a great pleasure to acknowledge the constant help I have received from my friends and colleagues. I cannot possibly make adequate acknowledgement to all of them, though I would like to make personal acknowledgement to Dr. J.S. Dhankhar; Dr. Sajjan K. Sharma; Dr. D.J. Dahiya; Dr. B.S. Duhan and Sh. H.R. Malik, who extended helping hands time and again.

I shall be failing in my duty, if I do not thank my wife Mrs. Vimla Sangwan and sons Gaurav and Vivek, whose patience, perserverance and smiles made my task easy.

Last but not the least, words can not adequately express my debt to my mother and elder brothers whose silent wishes constantly guided my efforts.

(R.S. SANGWAN)

Hisar
May 31, 1994

C O N T E N T S

CHAPTER - 1

INTRODUCTION

Salinity and sodicity are among the most common key limiting factors involved in the decline of fertility and hence productivity of millions of hectares of farm land world over. Saline and sodic soils occupy about 7 million hectares area in India. Out of 7 million hectares about 0.52 million hectares of land is affected by salts in Haryana (Abrol and Bhumbla, 1971). Indian soils, in general, and saline and sodic soils in particular are deficient in nitrogen. The requirement of nitrogen in these soils is relatively more because of high gaseous losses of ammonia (Sharma et al., 1992).

The efficiency of fertilizer nitrogen with best management practices generally does not exceed 50 per cent in upland conditions. The rest of the applied fertilizer nitrogen is either lost through leaching, denitification, ammonia volatilization, immobilized by soil microbes, fixed in soil or taken up by weeds. Under arid and semi-arid conditions the losses through ammonia volatilization significantly influence the efficiency of fertilizer nitrogen in different crops. The extent of such losses may vary depending upon the soil and environmental factors such as soil type, soil alkalinity, salinity, water regimes, type of nitrogen carrier, temperature, etc.

In India more than 82 per cent nitrogen is applied as urea. Urea has several advantages over other nitrogen fertilizers for example high N content, hence low cost of transportation and application, high solubility in water and non-corresive in nature when in solution which makes it suitable for spray application also. However, it also has some disadvantages as it is highly susceptible to leaching and gaseous losses. Therefore, during the last two decades, there has been great emphasis to understand its behaviour in different soils both in the presence and absence of the crops.

For efficient utilization of fertilizer urea, it is imperative to know its rate of transformation in soils. Urea, when applied to normal soils, gets hydrolyzed enzymatically by "Soil urease" ($NH_2CONH_2 + H_2O \xrightarrow{\text{urease}} (NH_4)_2CO_3 \longrightarrow 2\ NH_3 + CO_2 + H_2O$) resulting in the release of amonia (Bremner and Mulvaney, 1978) and an increase in soil pH (Overrein and Moe, 1967). The ammonium ions adsorbed on the surface of soil colloids and subsequently transformed into nitrate by nitrifiers. However, when urea is applied to saline-sodic soils, its transformation is delayed due to excessive salt concentration or pH effects on nitrifying organisms. Hydrolysis and nitrification processes have been reported to be adversely affected resulting in NO_2^- accumulation for a longer period in such soils. Thus, many reports are available which have demonstrated that increasing salinity depresses the processes of urea hydrolysis and nitrification but little is known about the effects of predominance of chlorides or sulphates salinities on urea hydrolysis and nitrification in soils.

The gaseous losses of ammonia from soil applied urea have been reported comparatively higher in saline-sodic soils to those in normal soils. Thus, availability of fertilizer nitrogen in salt affected soils becomes less to the crops. Therefore, losses of fertilizer nitrogen from problem soils are, however, of considerable concern to both for agriculturists and soil scientists. Scanty information is available on the effects of soil salinity on yield and uptake of both major and minor nutrients by different crops and their interactions with nitrogen in soil. The yields of crops are expected to be adversely affected in highly saline soils because of high salt concentration in soil solution which may cause low availability of both water and nutrients. An understanding of the processes by which added urea is transformed in salt affected soils, absorbed and used by plants, and lost from the plant soil system is, therefore, of prime importance from both agricultural and ecological viewpoints.

The deleterious effects of salts may be more pronounced in arid and semi-arid regions where underground waters are saline and sodic which are used for irrigation. However, no systematic information on the effects of type and levels of salinity on transformation, losses and availability of nitrogen is available. The present investigation is, therefore, undertaken to study the dynamics of fertilizer nitrogen in normal, saline and sodic soils, keeping following objectives in view:

1. Kinetics of hydrolysis of urea in normal, saline and sodic soils
2. Effect of type and levels of salinity and ESP levels on rate of nitrification of added urea in soils
3. Effect of different factors on ammonia volatilization losses in normal, saline and sodic soils
4. Effect of nitrogen and salinity levels on yield and uptake of nutrients in wheat

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CHAPTER - 2

REVIEW OF LITERATURE

The literature relevant to the field of investigation has been reviewed under the following heads:

1. Kinetics of urea transformation in normal, saline and sodic soils

   1A. Urea hydrylysis

   (i) Kinetics of urea hydrolysis in soils

   (ii) Effect of moisture content

   (iii) Effect of levels and type of salinity

   (iv) Effect of levels of alkalinity/ESP levels

   1B. Nitrification of urea

   (i) Effect of water content

   (ii) Effect of salinity levels

   (iii) Effect of type of salinity

   (iv) Effect of levels of sodicity

2. Effect of different salinity and ESP levels on ammonia volatilization losses from soils

   (i) Effect of soil texture

   (ii) Effect of sodicity levels

   (iii) Effect of salinity levels

3. Effect of salinity and N levels on yield, concentration and uptake of nutrients in wheat
   - (i) Effect of N and salinity on yield, concentration and uptake of N, p and K
   - (ii) Effect of N and salinity levels on concentration and uptake of Zn, Cu, Mn and Fe

1. Kinetics of urea transformation in normal, saline and sodic soils

(i) Kinetics of urea hydrolysis in soils

During the last two decades many studies concerning the behaviour of applied urea in soils have been done. Hydrolysis of urea in soil is catalyzed by urease which is produced by growing plants and soil micro-organisms. The hydrolytic activity of soil has been shown to be, primarily, due to extra-cellular urease complexed with soil colloids (Paulson et al., 1969 and Gould et al., 1973). A large number of factors such as soil type, moisture content, salinity, alkalinity, organic matter, etc., have been reported to have prime effect on the rate of urea hydrolysis in soils.

Simpson and Melsted (1963) reported that urea hydrolysis rates varied widely among different soils and different environmental conditions. They found that the hydrolysis of urea ranging from a minimum of 6 ppm N/day to a maximum of 225 ppm N/day. Carpena et al. (1965) observed more rapid hydrolysis of urea in loamy sand than sandy soil. Overrein and Moe (1967) observed that urea hydrolysis reaction behaved as a first order reaction. Similar results were observed by Sankhayan and Shukla (1976). Singh and Yadav (1981) reported that when urea was added @ 150 ppm, the per cent urea hydrolysed was 35.6 and 69 in sand and sandy loam soils, respectively, in 24 hours indicating a slow rate of urea hydrolysis in light textured soil than relatively heavier soils. However, in contrast, they further reported that the hydrolysis of urea did not follow zero or first order kinetics. Kumar and Wagenat (1984) studied the urease activity and kinetics of urea transformations in different soils. They reported that urea hydrolysis reaction followed a strong linear relationship when ct plotted verus t for the first 12 h, which is the characteristic of a first order reaction. Urease activity in soils provides a good index about the capacity of soils to hydrolyze urea. Singh et al. (1991) established relationship with various soil properties using different types of soils. They found that urease activity (ppm urea-N hydrolyzed h^{-1}) ranged from 2.0 to 26.2. Urease activity was positively correlated with CEC, organic carbon, silt and clay and was negatively correlated with sand. Many earlier workers; e.g., Dash et al. (1991) and Singh and Nye (1984) also observed positive correlation with soil clay, organic carbon, etc.

(ii) Effect of moisture content

Roberge and Knowles (1968) found a little decrease in urease activity as the moisture content increased from 60 to 140 per cent of full water holding capacity (WHC). Dalal (1975) observed that the urease activity increased upto 50 per cent of WHC which further decreased with subsequent increase in moisture level. However, Sankhayan and Shukla (1976) reported that urea hydrolysis was faster at 40% WHC than at 60% WHC. They also observed that most of the added urea was hydrolyzed within 24 h. Bremner and Mulvaney (1978) reported a non-significant effect of water levels (upto 1 ml water/g soil) on soil urease activity measured for a 5 h incubation period at 37°C. Vlek and Carter (1983) observed that urea hydrolysis increased with an increasing soil water content upto field capacity followed by a decreasing trend above field capacity.

However, reports on the effects of soil submergence on urea hydrolysis are divergent. Savant et al. (1985) studied the effects of soil submergence on hydrolysis of added urea with time in the flood water, the oxidized soil, and the reduced soil. They observed that during the first 12 h incubation, the apparent rates of urea hydrolysis were nearly the same for both the soil water levels. After 12 h, the urea hydrolysis in soil that was near field capacity proceeded at the same rate. However, they observed a slower hydrolysis rate in the soil that was near submergence for the period longer than 12 h. They further reported that depletion of O_2 presumably retarded the hydrolysis of urea under submerged soil conditions and O_2 could not diffuse into the soil and, after 12 h, the O_2 level probably decreased because of the consumption by the aerobic microorganisms. Yadav et al. (1987) found that the rate of urea hydrolysis increased with increasing moisture content from 20 per cent field capacity (F.C.) to 100 per cent F.C., and decreased at flooding. Hongprayoon et al. (1991), in contrast, reported that urea hydrolysis rates in the flooded soil columns increased with time and followed first order reaction kinetics. Gill et al. (1991) reported that urea hydrolysis was 5-6 times more rapid in aerobic than anaerobic soil conditions.

(iii) Effect of levels and type of salinity

Galstyan (1960) reported that saline soils containing high quantities of NaCl and Na_2SO_4 inhibited urease activity and showed no carbohydrase activity. The addition of salts to soils have been reported to result in decreased urease activity (Agarwal et al.,1971; Laura, 1974). Nitant (1974) observed that the hydrolysis of urea was delayed in saline-sodic soils in comparison to normal soils. Tucker (1976) reported that the total microbial activity in soils (as measured by CO_2 evaluation) was generally decreased as the soil salinity was increased. Mann (1979) reported that urea hydrolysis rates decreased with increasing salinity levels. There are quite a few reports available in the literature dealing with the effects of type of salinity on urea hydrolysis. Frankenberger and Bingham (1982) treated the soils with four rates of $CaCl_2$, NaCl and Na_2SO_4 salts to produce salinity levels ranging from 2.2 to 22 dSm^{-1}. They observed that soil enzyme activities decreased with increasing salinity levels. However, the degree of inhibition varied among the enzymes assayed and the nature and amounts of salt added. Reduced enzyme activities in saline soils may be due to the osmotic desiccation of microbial cells releasing enzymes which become vulnerable to attack by soil proteases. They also observed that the inhibition of soil enzyme activities by the salts decreased in the following order when compared at the same ECe level: NaCl > $CaCl_2$ > Na_2SO_4.

Kumar and Wagenet (1985) reported that increasing salinity levels upto 10 dSm^{-1} decreased the rate of hydrolysis of urea. Kumar et al. (1988) observed that increasing ECe from 0.33 to 16.64 dSm^{-1} in Rohtak soil decreased the rate of hydrolysis of urea. At 3 days, 97, 90 and 78 per cent of added urea was hydrolysed at 0.33, 4.33 and 16.64 dSm^{-1} ECe levels, respectively.

(iv) Effect of alkalinity/ESP levels

Soil pH values between 7 and 8 were reported to be optimum for highest urease activity (Roberge and Knowles, 1968). Pancholy and Rice (1973) found no correlation between soil urease activity and soil organic matter content or soil pH. They suggested that the type of organic matter was responsible for variations in soil urease activity. Zantua et al. (1977) reported that the urease activity was found to be positively correlated to organic carbon and total nitrogen (TN), but unrelated to pH.

Beri and Brar (1978) studied urease activity in nine soils varying in soil pH (7.3 to 10.6 pH). They reported that urease activity of different soils varied from 3.5 to 10.0 (ug urea-N hydrolysed g^{-1} soil h^{-1}). Soil pH, organic carbon and clay content were the factors influencing urease activity. Dash *et al*. (1981), in contrast, reported a negative correlation between urease activity and soil pH. Reynolds *et al*. (1985) reported that soil pH was not significantly correlated to urea hydrolysis rate. Kumar *et al*. (1988) reported that an increase in soil pH delayed the hydrolysis of urea. They further reported that at soil pH 8.5 and 9.0 all the added urea was hydrolysed within 3 days, however, at relatively higher soil pH (10.5) it took 6 days to hydrolyse all the added urea. However, Singh *et al*. (1991) reported that urease activity of different soils studied was negatively correlated with soil pH.

1 B Nitrification of urea

(i) Effect of water content

In general, the maximum rate of nitrification occurs at soil moisture potentials in the range of -10 to -33 KPa depending upon soil physical properties (Justic and Smith, 1962). At 0 KPa, nitrification is either absent or occurs at a very slow rate because of the shortage of O_2 in the soil system caused by excess water (Miller and Johnson, 1964 and Sabey, 1969). At soil moisture potential at permanent wilting point (-1500 KPa) the activity of nitrifiers was inhibited to a greater extent than that of ammonifiers (Dommergues, 1966).

Various workers have established that the optimum soil pore water potential (SPWP) for nitrogen mineralization was between -0.01 and 0.05 MPa and mineralization was strongly suppressed at SPWP <-1.5MPa (Reichman *et al*., 1966 and Cavalli Rodriguez, 1975).

Sahrawat (1982) reported that the nitrification of ammonium sulphate was fast at 50 per cent water holding capacity (WHC) and by the third week following addition 71 per cent of the added fertilizer nitrogen nitrified. However, at 100 and 200% WHC, the added fertilizer nitrogen remained mainly NH_4^+-N, although, there was some NO_3^--N at 100% WHC. But after 7 weeks of incubation no NO_3^--N was detected either at 100 or 200% WHC.

Myers et al. (1982) studied the mineralization of nitrogen in different soils at a range of moisture contents at constant temperature. They found that net nitrogen mineralization was linearly related to moisture contents in the available range (-0.03 to -4.0 MPa). The optimum moisture for net nitrogen mineralization corresponded to a soil SPWP of between -0.01 and -0.03 MPa, while the moisture content at which no nitrogen mineralization occurred was near to -4.0 MPa.

Malhi and McGill (1982) reported that there was an increase in the relative rate of nitrification with increasing soil moisture potential from -1500 to -33 KPa. Nitrification inhibited completely at 0 KPa soil moisture potential in all soils studied. These results indicated that an appreciable nitrification can be expected at permanent wilting point (-1500 KPa). They also observed that at a low NH_4^+-N concentration, nitrification was rapid and complete, but appeared to be inhibited at higher NH_4^+-N concentrations. The NO_2^--N accumulation was associated with higher concentrations of NH_4^+-N.

Yadav et al. (1987) incubated sandy loam soil at five moisture regimes (20, 40, 80, 100% F.C. and flooding). They found most of the added 200 ppm urea N was nitrified in 42 days. The nitrification rates were fast at 80 and 100% F.C. decreased at lower and higher water contents.

Sarkar et al. (1991) reported that NH_4^+-N under flooded soil moisture regimes was significantly higher than under saturation condition. They also observed that under flooded soil condition NO_3^--N was reduced to NO_2 but at saturation the NO_3^--N was higher than NH_4^+-N. Gill et al. (1991) reported that nitrification of urea completed within 50 days under anaerobic conditions whereas it took 20 days under aerobic conditions. Senapati et al. (1992) reported that the accumulation of NH_4^+-N in flooded soils was due to slower nitrification. The highest amounts of NO_3^--N were found in the soils at 40 per cent saturation and the lowest at flooding.

(ii) Effect of salinity levels

It has been reported that the presence of salts in soils causes a reduction in the activity of ammonifiers and nitrifiers. The mechanism of action of salts in reducing the level of enzymatic activities in soils may be attributed to (i) osmotic desiccation releasing intracellular enzymes that serve as substrates for soil protolytic enzymes, (ii) a salting out effect, modifying the ionic conformation of the active sites of enzymes; and (iii) specific ion toxicities causing nutritional imbalances for microbial growth and subsequent enzyme synthesis.

Divergent views have been reported on the effects of salinity on ammonification. Singh *et al.* (1969) and Agarwal *et al.* (1971) have reported an increase in ammonification, whereas others reported a decrease with increasing salinity (Ryan *et al.*, 1972). The effects of salinity on ammonification and nitrification have extensively been studied by Laura (1974-77). He reported that the total microbial activity in soils (as determined by CO_2 evolution) was generally depressed as soil salinity increased. He found no inhibition of ammonification even at 5.1 per cent of salts concentration in soil. In support to this he suggested that ammonification might be a chemical process rather than biological. He further observed that nitrification was retarded progressively with the increase in salinity levels. The process of nitrification was, however, believed to be due to autotrophic organisms. Several earlier workers also observed that nitrification is inhibited with the increase in salinity levels for e.g. Sindhu and Cornfield (1967), Agarwal *et al.* (1971) and Gandhi and Paliwal (1976).

McCormick and Wolf (1980) reported that NaCl applied @ 0.25 mg/g soil significantly reduced nitrification in sandy loam soil. Frankenberger and Bingham (1982) assessed the levels of soil urease activities that had a specific role in N cycle in soils. He observed that soil urease activities decreased with increasing salinity levels upto 22 dSm^{-1}, however, the degree of inhibition varied with the nature and amounts of added salts.

McClung and Frankenberger (1985) studied effects of different salinity levels on urea transformations, prepared artificial saline soils from three diverse soils by adding different amounts of salts which produced salinity levels ranging from 5 to 20 dSm^{-1}. They observed no apparent effect of salinity on ammonification of added urea in any of the three soils regardless of the amount and type of salts added. On the other hand, increasing levels of salinity decreased rates of nitrification in soils. They also reported that an appreciable amounts of NO_2^--N accumulated at higher salinity levels.

Kumar et al. (1988) studied the rate of ammonification and nitrification following addition of urea in soils of different salinity at constant temperature and moisture. They reported that nitrification and ammonification rates were less at higher salinity. Suraj Bhan et al. (1990) in an incubation study on added urea N transformations in saline soils (0 to 15 dSm^{-1}) observed that the content of NH_4^+-N decreased upto 12 days and increased from 24 to 42 days with increasing salinity levels. The increase in NH_4^+-N from 24 to 42 days with increasing salinity was due to poor nitrification in presence of higher salinity. However, from 6-42 days NO_2^--N increased with increasing salinity levels as compared to control. They further observed that NO_3^--N increased with increasing the incubation period and decreased with increasing salinity levels. At 42 days, NO_3-N decreased from 104 to 73 ppm at 0 and 15 dSm^{-1} salinity levels, respectively.

(iii) Effect of type of salinity

The adverse effects of salinity on N-transformations have been reported to be characterized by low osmotic potentials and high concentration of salts in soil solution. The inhibitory effect of salinity on ammonification and nitrification in soils is primarily associated with total salt concentrations. However, the effects of specific ions on nitrification are not well understood.

Johnson and Guenzi (1963) studied the effect of individual salt species on nitrification. They found that NaCl was the most toxic salt amongst all others studied. Sindhu and Cornfield (1967) observed that nitrification was completely inhibited by 1 to 2% NaCl at all moisture levels but ammonification continued even with 2% NaCl. In an incubation study, Agarwal et al. (1971) observed that the chlorides affected ammonification and nitrification more adversely than sulphates. They further stated that two salts containing the same cation but different anions transformed different amounts of N at an equivalent concentration in soil.

Broadbent and Nakashima (1971) and Westerman and Tucker (1974) reported that ammonification was less sensitive to salts than the nitrification. They further stated that the increasing NaCl concentrations in soil caused an accumulation of NH_4^+-N. Heilman (1975) carried out an incubation study in which variety of salts at different concentrations were used. He reported that chlorides as an anion in different salts inhibited nitrification at higher concentrations. Laura (1977) in a laboratory study determined effects of salinity produced by addition of NaCl and $CaCl_2$. He reported that increased salinity progressively retarded ammonification but did not suppress it completely. However, nitrification was completely suppressed by higher salinity.

McClung and Frankenberger (1985) studied effects of different salts viz., Na_2SO_4, NaCl and $CaCl_2$ on urea transformations. The different salts were applied in proportions which produced salinity levels ranging from 5 to 20 dSm^{-1}. They found no effect of salinity on ammonification of added urea irrespective of type of salinity. In contrary, inhibition of nitrification was quite high ranging from 8 to 83 per cent which varied among types of salinity or salts added. Generally, Na_2SO_4 was least inhibitory to nitrification than NaCl or $CaCl_2$. Kumar _et al_. (1988) studied the effect of salinity (produced by adding variable amounts of NaCl, $CaCl_2$ and $MgSO_4$) on nitrification. They reported that the amounts of NH_4^+-N and NO_2^--N increased at higher salinity levles. In contrast, the reverse trend was observed with NO_3^--N, which decreased with subsequent increase in salinity.

Suraj Bhan _et al_. (1990) studied the effects of types and levels of salinity on N-transformation of urea. They produced three types of salinity (100% Cl, 100% SO_4 and Cl^- : SO_4^{2-} mixture 50:50). They osberved that NH_4^+-N progressively increased from 24 to 42 days with increasing salinity levels, however, its accumulation was comparably more in chloride salinity than Cl^- + SO_4^{2-}mixture or sulphate-salinity and same was true with NO_2-N accumualtion. In contrary, NO_3^--N increased from 1 to 42 days of incubation periods. At every incubation day, NO_3^--N recovery was inhibited more by Cl^{-1} salinity than Cl^{-1} + SO_4^{2-}or SO_4^{2-}type salinity.

(iv) Effect of levels of sodicity

Aleem et al. (1957) observed that when urea was added to alkaline soils an appreciable amounts of NO_2^--N were detected. Broadbent et al. (1958) reported that there was a considerable accumulation of NO_2^--N in an alkaline soils when urea was added. Matula (1974) also reported that NO_2^--N accumulated in grey brown podzolic soil under alkaline conditions. This may have been due to the fact that microbial transformation of NO_2^-- to NO_3^- proceeds less rapidly than conversion of NH_4^+ to NO_2^- under alkaline soil conditions, presumably because nitrobacter is reported to be more vulnerable to alkalinity as compare to nitrosomonas spp.

Broadbent and Tyler (1965) reported that nitrogen immobilization increased with the icnrease in soil pH when ammonical form of N was added whereas reverse was true when the nitrate form of N was used. Wang et al. (1966) observed contradictory results among various types of soils ranging from silty clay to sandy loam indicating that nitrification was faster in sodic soil compared to non-sodic soil. Laura (1973) reported that CO_2 evolution or total carbon mineralization increased with increased ESP and the process of nitrification was inhibited between 70-92 ESP. Anthonisen et al. (1976) reported that high concentration of free ammonia associated with high pH in soil inhibited the activity of both nitrosomonas and nitrobacter spp. and consequently process of nitrification was inhibited. Beri and Brar (1978) indicated that NO_2^--N could accumulate in soils of high pH following application of urea.

Kumar et al. (1988) studied the effects of soil pH on transformation of added urea in soils. They observed that an increase in soil pH caused a delay in the hydrolysis of added urea. At soil pH 8.5 and 9.0 all the added urea was hydrolysed within 3 days, however, a pH 10.5 complete hydrolysis took 6 days. An increase in soil pH caused decrease in the concentration of NH_4^+-N in soil at day 1. However, at days 3 and 6 there was no significant effect of pH on NH_4^+-N concentration in soil. The initial decrease was presumably due to slow hydrolysis of urea at higher soil pH and later increase could have been due to slow nitrification. They further observed that the transformation of NO_2^- to No_3^--N proceeds less rapidly than the conversion of NH_4^+ to NO_2^- under alkaline soil conditions. Similar results have been reported by earlier workers (Mann, 1969 and Mann, 1979).

Sahrawat (1992) in a field study on transformations of surface applied urea in three soils varying in pH under optimal conditions of soil moisture and temperature found that 78 per cent of the applied urea-N was nitrified in vertisol (pH 8.35), 64 per cent in Alfisol (pH 6.20) and only 1 per cent of urea-N was nitrified in Alfisol 2 (pH 4.50) in first 10 days of incubation. Similarly, Focht and Verstracte (1977) and Sahrawat (1982) indicated that nitrification have been taking place at a slow rate in soils of pH less than 5.0.

2. Effect of different salinity and ESP levels on ammonia volatilization losses from soils

Ammonia volatilization has been termed as the process by which gaseous ammonia is released from soil system to the atmosphere. The extent of N losses from added urea to soils may be upto 50 per cent of applied N (Matocha, 1976). The studies on ammonia volatilization have recently received more attention primarily because of the high amounts of N are required to be added to different crops and also because such losses occurred immediately following application of urea. The magnitude of ammonia volatilization from applied urea has been reported to depend on several factors like temperature, organic matter, soil pH, salinity and water content in soils, etc. The effects of some of these factors have been discussed below:

(i) Effect of soil texture

The ammonium released in soil after hydrolysis of urea is partially subjected to gaseous losses of ammonia, which depends to a greater extent on soil texture, soil pH, soil organic matter and temperature, etc. The heavier textured soils having higher CEC volatilize less ammonia as compared to light textured soils.

Chao and Kroontje (1964) considered that soil texture is the key factor in determining volatilization losses in soils. He observed a higher NH_3 losses from a coarse textured soil as compare to heavy textured soil. Verma and Sarkar (1974) observed variation in ammonia volatilization in soils having different physico-chemical characteristics. They found that maximum losses were in soils having low CEC and the losses decreased in soils with the increase in its clay content. Basdeo and Gangwar (1976) studied ammonia volatilization losses under varying soil conditions. They reported higher losses in light textured soils and maximum losses occurred when urea was the source of N as compare to other N sources. Similar results were also reported by Gandhi and Paliwal (1976).

Reddy et al. (1986) studied ammonia volatilization from added urea in three soils of varying texture. Under identical experimental conditions the cumulative losses of applied N in 14 days were 15.9 per cent in sandy loam, 12.8 per cent in loam and 11.0 per cent in silty clay soil. They also reported that maximum losses occurred on 4th day following urea addition which concided with peak rise in the soil pH and no losses of NH_3 volatilization were observed after 14 days.

Preez and Burger (1988) observed that more NH_3 was lost from added urea in the clayey soil having CEC 28.0 me 100 g^{-1} soil compared with the sandy clay loam soil having CEC of 14.8 me 100 g^{-1} soil. Martens and Bremner (1989) studied the effects of various soil properties using different types of soils on ammonia volatilization. They incubated different soils for 8 days following addition of urea. They observed that losses of NH_3 were negatively correlated with CEC, silt content, clay content and were positively correlated with sand content. Whitehead and Raistrick (1990) made the measurements of NH_3 volatilization from added N through MAP, DAP, AS, and urea for a period of 8 days. Volatilization losses ranged from nil to 53 per cent of the applied nitrogen. The nature of the compound and soil type had large effects on NH_3 volatilization. Urea suffered maximum volatilization losses among all other fertilizers tested.

(ii) Effect of sodicity levels

Many workers have reported that NH_3 volatilization losses following the addition of nitrogenous compounds to soil increases with the increase in soil pH (Ernst and Massey, 1960 and Watkins et al., 1972). Significant amounts of NH_3 losses have also been observed even at pH 5.5 provided large amounts of ammonium producing nitrogenous fertilizers are applied to surface soil (Blasco and Cornfield, 1966). Avnimelech and Loher (1977) stated that the pH in the soil solution immediately surrounding a urea or NH_4^+ salt granule may be considerably more important in determining ammonia losses than the soil pH. Therefore, the original soil pH is of extreme importance in controlling the extent of volatilization only when the buffering capacity of the soil is high.

Shankaracharya and Mehta (1969) reported volatilization losses of 24.7 per cent in a soil of pH 4.9 and 75.8 per cent in soil of pH 9.9 following addition of nitrogen @ 220 kg/ha. Verma and Sarkar (1974) observed increased losses of NH_3 from the applied urea with the increase in soil pH. Basdeo and Gangwar (1976) studied the volatilization losses of NH_3 from added urea in soils of different pH. The per cent volatilization losses were as 17.6, 12.0 and 7.0 in soils of pH 9.4, 8.4 and 7.4, respectively.

Bhorania and Meisheri (1984) reported that losses of NH_3 from applied urea-N in soils at pH 8.3 and 9.4 were two and three times higher, respectively, than those at pH 7.0.

Reddy et al. (1986) reported that NH_3 losses following surface application of urea were closely related to the changes in the pH near the soil surface where urea is applied rather than initial pH of soil. Singh and Bajwa (1987) studied NH_3 volatilization losses from surface applied urea in soils at varying soil pH. They observed that the cumulative losses of NH_3 were largest in soils having higher pH. They further reported that the peak values of NH_3-volatilization were between 12 and 14 days following addition of urea, thereafter, the values declined and practically no losses could be detected after 16 days.

Preez and Burger (1988) studied NH_3 volatilization losses following addition of five N-containing fertilizers in alkaline soils. Although, they did not measure directly the volatilization losses. However, they presumed that the volatilization losses constitute the major proportion of N-losses. The soil

Sharma et al. (1992) studied the NH_3-volatilization losses at different exchangeable sodium percentage (ESP) levels viz., 9, 25, 50 and 75. They observed that the NH_3-losses increased with the increase in ESP levels. The magnitude of losses at 9 and 25 ESP levels were more upto 9 days following urea application and thereafter the losses were negligible. However, at 50 and 75 ESP levels the losses increased rapidly upto 15 days. The larger NH_3 volatilization losses observed at higher ESP may be due to the increase in Na content of soil which, in turn, increased soil pH. At 9, 25, 50, 75 ESP levels the pH were 8.11, 8.4, 9.5, 10.1, respectively.

(iii) Effect of salinity levels

Nitrogen has widely been reported to be the most limiting factor in salt-affected soils. Application of N-fertilizers has been found to increase the crop growth upto moderate levels of salinity. However, at higher salinity levels N-availability to plants has been reported less as compare to normal soils.

Blasco and Cornfield (1966) studied the effect of soil salinity on NH_3 votalization losses. They found that NH_3 volatilization losses increased with the increase in soil salinity. Gandhi and Paliwal (1976) studied gaseous losses of N following addition of urea and ammonium sulphate to three soils having different levels of salinity ranging from 1.1 to 50 dSm^{-1}. They found that gaseous losses of NH_3 increased with the increasing salinity. At the highest salinity level, the NH_3 volatilization was about 3-fold higher than the control soil samples following addition of fertilizers were left for air drying at room temperature for 3 days, which considered to be too short for microbial immobilization of added N. Nitrification was also ruled out, as they determined it in their preliminary experiments. Soil remained in an aerobic environment during drying period, so denitrification was also ruled out. Thus, they considered that the N lost from applied fertilizers to soil was presumed to be due to NH_3 volatilization. They further observed that urea suffered the largest losses among the five fertilizers they tested. They ranked them in decreasing order of NH_3 losses as: urea > DAP > $(NH_4)_2 SO_4$ > MAP < CAN.

Martens and Bremner (1989) reported that volatilization of NH_3 from added urea to soil was positively correlated with the altered soil pH which was increased due to addition of urea. However, they did not find any correlation between volatilization of NH_3 and initial soil pH or soil urease activity. Whitehead and Raistrick (1990) measured NH_3 volatilization from surface applied urea to five contrasting soils. The urea was applied as solid @ 100 kg N ha^{-1} to moist soils packed into columns and through which a stream of air was passed for a period of 8 days. They found that volatilization tended to icnrease, though not consistently with soil pH, this was probably due to the difference in CEC of soils. The maximum rate of volatilization occurred between days 2 and 4.

Sharma *et al*. (1992) studied the NH_3-volatilization losses at different exchangeable sodium percentage (ESP) levels viz., 9, 25, 50 and 75. They observed that the NH_3-losses increased with the increase in ESP levels. The magnitude of losses at 9 and 25 ESP levels were more upto 9 days following urea application and thereafter the losses were negligible. However, at 50 and 75 ESP levels the losses increased rapidly upto 15 days. The larger NH_3 volatilization losses observed at higher ESP may be due to the increase in Na content of soil which, in turn, increased soil pH. At 9, 25, 50, 75 ESP levels the pH were 8.11, 8.4, 9.5, 10.1, respectively.

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Rashid (1977) found considerably high volatilization of N from added urea in the coastal saline soils of Bangladesh. Sen and Bandyopadhay (1987) reported that with the increase in soil salinity from 3 to 8 dSm^{-1}, the volatilization losses increased from 17.8 to 37.3 per cent of the applied N as ammonium sulphate and from 12.0 to 23.4 per cent in case of lac-coated urea, respectively. Singh and Bajwa (1987) studied the NH_3 volatilization losses from salt-affected soils fertilized with urea under submerged conditions. They studied the volatilization losses in soils differing in salinity made artificially by treating with NaCl, Na_2SO_4 and $NaHCO_3$ salts. The treatment of the soil with $NaHCO_3$ and Na_2SO_4 increased NH_3-volatilization losses compared to NaCl treatment and untreated control soil.

3. Effect of salinity and N levels on yield, concentration and uptake of nutrients in wheat

The N is a universally deficient element in soils. When it is applied through different fertilizers to crops in salt affected soils, its availability is adversely affected.

The higher salt concentration in soils restrict the availability of several major and micronutrients to plants resulting in less yields. The information on salinity and N interactions on yield and uptake of some major and micronutrients is reviewed below:

(i) **Effect of N levels and salinity on yield, concentration and uptake in N, P and K**

Khalil et al. (1967) reported that increased salinity decreased dry matter yields of maize and cotton. They also observed that application of N and P fertilizers did not reduce the adverse effects of salinity. They further observed that increased salinity increased N concentration, decreased K concentration and had no effect on P concentration in shoots. Udovenko et al. (1971) reported that increased salinity inhibited N-metabolism and consequently decreased N uptake in wheat plants.

Nitant and Dargan (1974) studied the effect of N-levels on yield and N uptake of wheat in saline-sodic soil. They observed that straw yield and N uptake increased with increasing levels of N upto 180 kg ha^{-1}. Sharma and Lal (1975) conducted a pot experiment on wheat using two types of saline water having EC 2.55 and 6.30 dSm^{-1} and three N levels. They observed that both the yield and uptake of N, P, K decreased with the subsequent increase in the salinity of irrigation waters. They also observed that the increased application of N tended to counteract the adverse effects of salinity only upto medium dose of N application. In contrast, Ata et al. (1977) found higher straw and grain yields of wheat with increased levels of salinity in a pot experiment. The soil salinity were caused due to irrigation with saline waters of different salinity. However, Sameni et al. (1980) reported that high salinity caused severe burning of margins of older leaves of beans and growth was also stunted. They further reported that plant growth and N uptake generally decreased with increasing salinity of irrigation water at all N levels. Kumar and Singh (1980) observed a positive interaction between soil salinity levels and applied N levels. They also observed that wheat yield increased with increasing N levels upto soil salinity of 12 dSm^{-1}. Mahjan and Sonar (1980) reported that increasing salinity decreased dry matter yield, concentrations and uptake of N, P, K at flag leaf stage of wheat plants.

Hassan et al. (1980) reported that yield and nutrients uptake in wheat decreased with increasing salinity. They also reported that the deleterious effects of salinity were reduced by application of urea. Solaman et al. (1981) observed decreased wheat straw yield with increased levels of salinity. However, the yields were found to increase with increasing levels of N application. Selassie and Wagenet (1981) studied the interaction effects of 4 levels of soil salinity and 5 levels of N application. They found that the wheat yields decreased with the subsequent increase of salinity levels. At the highest salinity level (9.6 dSm^{-1}) the yields did not improve even with the application of N fertilizer. Garg et al. (1982) reported that the applciation of N fertilizer stimulated the plant growth and concentrations of N, P, K. Papadopovlos and Rendig (1983) studied the interaction effects of salinity and N levels with tomato as a test crop. They observed that plants responded positively to increasing N doses only at the lower levels of soil salinity. At higher soil salinity increasing N application did not ameliorate the adverse effects of soil salinity. Total N uptake was correlated with total water uptake which was suppressed by stunted growth associated with higher soil salinity levels irrespective of N concentrations varied with time.

Kang and Judel (1984) reported that there was no significant effect of increasing salinity levels on N, P and K concentrations in wheat shoots. They further reported that decreased yields were presumably due to excessive Na^+ and Cl^- concentrations in the shoots. Indulkar and More (1985) reported that dry matter yield and N, P, K concentrations in sorghum decreased with increasing salinity levels beyond 8.8 dSm^{-1}. They also observed that increasing N levels increased the dry matter yields and nutrients concentrations, presumably by subsidizing in part the adverse effects of salinity. Pessarakli and Tucker (1985) observed that concentration of N in cotton plants was significantly higher under moderate salinity stress than in the control. The adverse effects of salinity was more pronounced at vegetative than at reproductive stage of growth. They also observed that N concentration was greater in roots than shoots. Rabic et al. (1985) conducted a pot experiment where the levels of soil salinity were 0.18 (control), 0.3, 0.6 and 0.9 per cent salts on oven dry soil basis. They observed that dry matter yield, uptake of N, P, K and grain protein contents in wheat increased at 0.3 per cent and decreased at salt concentration of 0.9 per cent.

Pessarakli and Tucker (1988) conducted an absorption study in nutrient solution with seedlings of tomato to observe the effects of NaCl stress on ^{15}N uptake and distribution in plant roots and shoots. The nutrient solutions were salinized in the range of -0.3,-0.6 and -0.9 MPa osmotic potentials with NaCl before transferring of tomato seedlings. The cumulative N^{15} loss was considered to be absorbed by plants. They reported that lowering the osmotic potential of the culture solution decreased total N uptake at all salinity level, and N^{15} uptake of the plants at medium (-0.6 MPa) and high (-0.9 MPa) salinity levels. A low level of salinity (-0.3 MPa) did not affect N^{15} uptake compared with control (-0.3 MPa). They also observed N^{15} concentrations was slightly higher in roots than in shoots. Broadbent et al. (1988) in a field study measured the effect of salinity gradients on the uptake of labeled N fertilizer using wheat as the test crop. They observed that increase in salinity levels reduced both the dry matter yield and N uptake.

Lal and Lal (1990) studied the effects of application of different salinity waters on yield and nutrients uptake of wheat. They reported that uptake of N, P and K decreased with the subsequent increase in the salinity of irrigation water. However, the uptake of N, P and K was found to increase with the increased application of N, P and K fertilizers. Khandelwal and Lal (1991) conducted a pot experiment using irrigation water of varying salinities to evaluate their effects both on straw and grain yields of wheat. They observed that the straw and grain yields decreased significantly with the increase in salt contents of the irrigation water used. The decrease in yield was observed when the salinity increased from 4.22 to 7.31 dSm^{-1}. They attributed this due to the restricted water availability to the roots which were continuously exposed to saline environments.

Mozafar and Oertli (1992) studied the effects of root zone salinity (0, 30 and 60 mmol L^{-1} of NaCl), root zone temperature (10°, 15°, 20° and 25°C) and their interactions on the number of tillers, total dry matter yield and the concentration of nutrients in the roots and shoots of barley. The experiments were conducted in water culture conditions. They reported that salinity and root temperature affected all the parameters tested and concluded that the tolerance of barley plant to NaCl salinity of the rooting media appeared to be altered by the root temperature and was highest at the root temperature of 15 to 20°C.

(ii) Effects of N and salinity levels on concnetration and uptake of Zn, Cu, Mn and Fe

Olle Petterson (1976) studied heavy metal ion uptake by wheat plants. He observed that most of the metals, including Cu, Zn and Mn were in higher concentration in roots than in shoots. Bhatti and Sarwar (1976) studied the response of corn to Zn and Cu on a salinized soil in pots. They observed that salinity treatments, in general, increased Zn concentrations in shoots as well as in roots. At low Zn application, Zn concentrations in the shoots were higher than those in the roots. They also observed that salinity treatments also increased Cu concentrations to a slight extent in the shoots, which however, were much below those in the roots.

Dev and Shukla (1980) studied N-Zn relationship in corn plants using different levels of N and Zn. They found both N and Zn when applied together increased the yield as well as Zn concentration of shoots. They further stated that shoots N concentration decreased with the increase in N levels from 200 to 400 ppm when Zn was not applied but reverse was true in case of roots. Gajbhiye and Goswami (1981) reported that uptake of Cu, Zn and Fe increased with the increasing N levels in wheat straw.

Garg and Sachan (1986) studied the effects of applied N levels on the concentration and uptake of Zn, Mn and Fe in sorghum plants. They found that Zn, Mn and Fe concentrations and uptake increased with increasing fertilizer N doses. Sakal et al. (1988) reported that at optimum level of soil N the magnitude of Zn concentration in wheat straw was maximum. They also reproted that application of Zn significantly increased the Zn concentration both in straw and grain. Kumar (1990) studied the effect of N and Mn on yield and uptake by wheat plants. He observed that grain and straw yields of wheat were significantly increased by N and Mn application. The combined dose of 10 ppm Mn and 90 ppm N produced the highest yield. He further reported that the application of N significantly increased the mean N concentration in grain from 2.34 to 2.62 per cent whereas the Mn concentrations increased from 2.2 to

2.7 per cent. Similarly in straw, the application of N increased the Mn concentration in plants.

Kumar et al. (1990) conducted a pot experiment to study the effects of various levels of N and Cu on the dry matter yield and N and Cu contents of wheat. They reported that N application increased the dry matter yields of shoots and roots. The highest dry matter yields were obtained at the combined levels of 120 ppm N and 5 ppm Cu, however, no significant differences between 5, 10 and 20 ppm Cu treatments on shoot dry matter yields were observed, while the dry matter yield of roots decreased with the further addition of Cu beyond 5 ppm. They further added that N application increased the concentration of N in both the roots and shoots, whereas, the application of Cu decreased the concentration of N in both roots and shoots.

CHAPTER - 3

MATERIALS AND METHODS

The present study was undertaken to study, "Dynamics of nitrogen in normal, saline and sodic soils". Two experiments were conducted in the laboratory and one in the screen house. The details of the materials and techniques used in the present investigation are discussed in this chapter.

Soil description

For this study, four soils were used, viz., sandy loam, clay loam, silty loam and sandy soil were collected from Research Farm, Chaudhary Charan Singh Haryana Agricultural University, Hisar, Regional Research Station, Kaul (Kaithal), Morni hill area and village Balsamand, respectively. Bulk soil samples (0-15 cm) of all the four soils were collected, air dried, mixed well, crushed with wooden pestle and mortar and sieved through a 2 mm stainless steel sieve. The physico-chemical characteristics of these soils are as under:

Some main characteristics of soils used

Soil characteristics	Soils			
	Hisar	Kaul	Morni	Balsamand
Sand (%)	62.2	30.0	38.4	92.3
Silt (%)	18.5	22.6	44.4	1.5
Clay (%)	19.3	47.4	17.2	6.2
Texture	Sandy loam	Clay loam	Silty loam	Sandy
$CaCO_3$ (%)	0.28	Nil	Nil	Nil
pH (1:2)	8.2	7.8	6.5	8.6
ECe (dSm^{-1})	1.2	1.5	0.6	0.8
ESP (%)	7.0	8.0	3.0	3.6
O.C. (%)	0.32	0.60	0.93	0.06
CEC [$cmol(p^+)kg^{-1}$]	8.6	24.8	13.9	6.6
NH_4^+-N (ug g^{-1} soil)	12.0	27.0	36	11
NO_3^--N (ug g^{-1} soil)	10.0	17.0	31	4
NO_2^--N (ug g^{-1} soil)	Nil	Nil	Nil	Nil
Saturation (%)	35.0	44	27	22.8

Preparation of saline and sodic soils

(a) Saline soils

Two soils, one Hisar sandy loam and another Kaul clay loam were used to prepare artificially saline soils having ECe of (Cl^- : SO_4^{-2} ; 50:50) 4, 8, 12 and 16 dSm^{-1} were prepared by taking sub-samples of Hisar sandy loam and Kaul clay loam soils. The salinity was developed in the laboratory. For this, air dried and sieved soils (2 mm) were spread over polythene sheets and the requisite amounts of Na_2SO_4, $CaCl_2$ and $MgCl_2$ were dissolved in distilled water equivalent to saturation percentage of the soil was sprayed uniformly and left covered with another polythene sheet for three days. The soils were then thoroughly mixed, air dried and sieved (2 mm). The untreated soil was used as control in all experiments.

Salts added in (me/l) of the saturation extract

Ece (dSm^{-1}) Desired	Ece (dSm^{-1}) Observed	Na	Ca	Mg	Cl	SO_4
4	3.90	27	6.75	20.25	27	27
8	8.05	57	14.25	42.75	57	57
12	11.90	84	21.00	63.00	84	84
16	16.10	112	28.00	84.00	112	112

Saline soils of fixed ECe (8 dSm^{-1}) having different Cl: SO_4 ratios (10: 0; 75:25; 50:50; 25:75 and 0:10) were also prepared separately from both the soils (Hisar and Kaul soils). Amounts of salts added (me/l) at the saturation extract are given below:

Amounts of salts added (me/l) of the saturation extract

TDS	Na	Ca	Mg	Cl	SO_4
84	42	10.63	31.87	84	0
105	52.5	13.13	37.39	63.75	21.25
114	57	14.25	42.75	57	57
125	62.5	15.63	46.89	31.25	93.75
130	65	16.25	48.75	0	130

TDS - Total dissolved salts.

In the similar way, same two soils, one Hisar sandy loam and another Kaul clay loam were used to prepare artificially sodic soils having different ESP levels. From each of the bulk soils, four soils of 15, 30, 60 and 90 ESP were prepared in the laboratory by dissolving the requisite amounts of $NaHCO_3$ in distilled water equivalent to saturation percentage of the soil was sprayed uniformly and left covered with another polythene sheet for three days. The soils were then thoroughly mixed, air dried and sieved (2 mm). The untreated soil was used as control in all experiments.

EXPERIMENT I: KINETICS OF UREA TRANSFORMATION IN NORMAL, SALINE AND SODIC SOILS

This experiment was conducted in laboratory in four parts as per experimental procedures discussed below:

EXPERIMENT 1a: Effect of soil type and moisture regimes on hydrolysis and nitrification of applied urea

Treatments

Soils	:	I	Hisar soil
		II	Kaul soil
		III	Morni soil
		IV	Balsamand soil
Moisture	:	i	Field capacity (F.C.)
		ii	Flooding (2 cm standing water)
N level	:		100 ug N g^{-1} soil as urea
Replications:			3
Sampling time:			0, 3, 6, 9, 12 and 24 hours for hydrolysis of urea and 7, 14, 21 and 28 days for nitrification of urea after incubation

Incubation temperature: 25°C $\pm$ 1°C

The experimental procedure involved 20 g soil in 120 ml wide mouth polythene bottles to which 100 ug g^{-1} soil N as urea was mixed thoroughly. Sufficient number of bottles for each treatment and time were thus prepared separately and incubated. At the end of each incubation period, soils were extracted for 1 hour with 40 ml 2 M KCl containing 5 ppm phenyl mercuric acetate (PMA) solution and analysed for urea-N, NH_4^+-N, NO_3^--N and NO_2^--N.

EXPERIMENT 1 b: Effect of soil types and salinity levels on hydrolysis and nitrification of applied urea

Treatments

Soils	:	I Hisar soil
		II Kaul soil
Salinity levels	:	Control, 4, 8, 12 and 16 dSm^{-1}
Moisture regime	:	F.C.
N applied @	:	100 ug N g^{-1} soil as urea
Replication	:	3
Sampling time	:	0, 3, 6, 9, 12 and 24 hours for hydrolysis and 7, 14, 21 and 28 days for nitrification of urea after incubation
Incubation temperature	:	25°C $\pm$ 1°C

The experimental procedure was similar as discussed above in experiment 1a.

EXPERIMENT 1c: Effect of soil type and types of salinity on hydrolysis and nitrification of urea

Treatments

Soils	:	I Hisar soil
		II Kaul soil
Type of salinity ($8\ dSm^{-1}$)	:	100% Cl^-, 100% SO_4^{2-}; Cl^-; SO_4^{2-}; 75 : 25; Cl^-; SO_4^{2-}; 50: 50, Cl^- : SO_4^{2-}; 25 : 75.
Moisture regime	:	F.C.
N level	:	100 ug N g^{-1} soil as urea
Replication	:	3
Sampling time	:	0, 3, 6, 9, 12 and 24 hours for hydrolysis and 7, 14, 21 and 28 days for nitrification of urea following incubation
Incubation temperature	:	25°C $\pm$ 1°C

The experimental procedure was similar as discussed in experiment 1a.

EXPERIMENT 1d: Effect of soil type and ESP levels on hydrolysis and nitrification of urea

Treatments

Soils	:	I Hisar soil
		II Kaul soil
ESP	:	Control, 15, 30, 60 and 90 ESP
Moisture regime	:	F.C.
N applied @	:	100 ug N g^{-1} soil as urea
Replication	:	3

Sampling time	:	0, 3, 6, 9, 12 and 24 hours for hydrolysis and 7, 14, 21 and 28 days for nitrification of urea after incubation
Incubation temperature	:	25°C ± 1°C

The experimental procedure was similar as discussed in experiment 1a.

EXPERIMENT 2: EFFECT OF DIFFERENT SALINITY AND ALKALINITY LEVELS ON VOLATILIZATION LOSSES OF UREA NITROGEN IN SOILS

This experiment was conducted in two parts:

EXPERIMENT 2a: Effect of salinity levels on NH_3 volatilization losses

Treatments

Salinity levels	:	Controls, 4, 8 and 16 dSm^{-1}
Soils	:	I Hisar soil
		II Kaul soil
Moisture regime	:	F.C.
N level	:	200 ug N g^{-1} soil as urea
Time of measurements	:	1 to 9 days daily then at 12, 15, 18 and 21 day following urea-N application
Replication	:	2

Experimental Procedure

For measuring NH_3 volatilization losses, the device given by Fenn and Kissel (1973) was used. Flexy glass columns, 5 cm in diameter and 20 cm in length, were used. One side of the column was closed with the help of a plastic disc (10 cm in diameter) using araldite as a fixing material. This disc served the purpose of platform also. The column was filled with the soil upto 10 cm height and remaining space was left for gas exchange. The soil was packed in the column to obtain a uniform bulk density of 1.4 g cm^{-3}. After surface application of urea the column was immediately closed at the top with the help of a rubber cork having two holes in it. Glass tubes were fitted in both the holes in such a way that gas can be expelled from the gas exchange chamber by blowing N-free air through one tube with the help of a commercial air compressor. Volatilized NH_3 was collected in 25 ml of 1% boric acid The acid was titrated against 0.01 N H_2SO_4 using mixed indicator. It was ensured that the device was completely air tight and leak proof.

EXPERIMENT 2b: Effect of ESP levels on NH_3 volatilization losses

The NH_3 volatilization losses were measured in the similar way as explained in 2a.

Treatments

ESP levels	:	Control, 30, 60 and 90 ESP
Soils	:	I Hisar soil
		II Kaul soil
N levels	:	200 ug N g^{-1} soil as urea
Moisture regime	:	F.C.
Time of measurements	:	1 to 9 days daily then at 12, 15, 18 and 21 day following urea application
Replication	:	2

Screen house studies

EXPERIMENT 3: EFFECT OF SALINITY AND NITROGEN LEVELS ON YIELD AND UPTAKE OF NUTRIENTS IN WHEAT

Experimental Procedure

For this study, Hisar soil was used. Four kg soil was taken in earthen pots lined with polythene sheets. To develop salinity levels of 4, 8 and 12 dSm^{-1} (Cl^-: SO_4^{2-}; 50 : 50) salts dissolved in distilled water were added directly to the soils in the pots. Before sowing of the crop, the soils were mixed thoroughly and were tested for the actual salinity levels developed. Four levels of N viz., 0, 60, 120 and 150 ug g^{-1} soil as urea were applied separately at each salinity levels. A basal dose of P and K @ 60 and 75 ug g^{-1} soil was applied in the form of Ca (H_2PO_4) and KCl, respectively. The basal dose of Zn, Cu, Mn and Fe was also given @ 5 ug g^{-1} soil each, through their respective sulphate salts. Half of the N was added at sowing and another half after 3 weeks of sowing. Wheat (WH-291) was grown as test crop.

Ten seeds of wheat were sown in each pot. After complete emergence of seedlings, only four uniform plants at nearly equal distance from each other were kept in each pot and rest were uprooted. The pots were irrigated with deionized water as and when required. The plants were harvested after 70 days of sowing. Plant tops (shoots) were cut at the soil surface. Roots were separated from the soil by a gentle spray of water. Both shoots and roots were thoroughly washed with tap water, acidified deionised water, distilled water and finally with double distilled water. They were then dried at 70°C for 48 hrs in an oven, weighed and ground using stainless steel sieve. The plants were then analysed for different N, P, K, Zn, Cu, Mn and Fe.

Post harvest soil samples were also analysed for mineral N.

Methods of analysis

Mechanical analysis was done according to International Pipette Method (Piper, 1950).

The electrical conductivity of soil water suspension (1:2) was estimated with the help of a conductivity meter (USDA Handbook No. 60, 1954).

Organic carbon of soil determined by the rapid titration method of Walkly and Black (1934).

pH was determined in soil water suspension (1:2) by using glass electrode pH meter (Jackson, 1958).

Saturation percentage of soils was determined gravimetrically (USDA Handbook No. 60, 1954).

Cation exchange capacity of soil was determined by leaching soil with 1 N sodium acetate followed by washing with 1 N ammonium acetate (USDA Handbook No. 60, 1954).

Calcium carbonate of soil was estimated by Puri's method (1949).

Total soil nitrogen was determined by digesting the soil with sulphuric and Salicyclic acid (Jackson, 1958).

Urea-N, NH_4^+-N, NO_2^--N and NO_3^--N were determined by Onken and Sunderman (1977) method.

The nitrogen in plants was determined colorimetrically as outlined by Lindner (1944).

The phosphorus in plant samples was determined calorimetrically using Vanado-molybdate yellow colour method (Koeing and Johnson, 1942).

The K in plant samples was determined using flame photometer (USDA Handbook No. 60, 1954).

Zn, Cu, Mn and Fe of plant samples were determined by atomic absorption spectrophotometer.

The data was statistically analysed using the standard procedure as described by Panse and Sukhtme (1978).

CHAPTER - 4

RESULTS AND DISCUSSION

In order to study the N dynamics in normal, saline and sodic soils, three experiments were conducted; two in the laboratory and one in the screen house. The results of these experiments are discussed below:

EXPERIMENT 1: Kinetics of urea transformation in normal, saline and sodic soils

1(a) Effect of soil type and moisture regimes on hyrolysis of urea

The hydrolysis of urea was fast in Morni and Kaul soils as compare to Hisar and Balsamand soils (Table 1). At F.C. 91, 87, 83 and 93 per cent and at flooding 92, 88, 92 and 94 per cent of added urea N remained unhydrolysed in Hisar, Kaul, Morni and Balsamand soils, respectively at 3 h following incubation. Upon further incubation the hydrolysis of urea proceeded positively and at 24 h almost all of the added urea in Morni or Kaul soil was hydrolyzed at F.C. Whereas at this stage about one-fourth and one-third of the added urea-N remained unhydrolyzed in Balsamand and Hisar soils, respectively.

Table 1. Effect of soil type and water regime on hydrolysis of added urea in soils

Soils	Incubation time (h)									
	3		6		9		12		24	
	Moisture regimes									
	F.C.	F	F.C.	F	F.C.	F	F.C.	F	F.C.	F
	Urea-N (ug g^{-1}soil)									
Hisar soil	91	92	80	82	71	73	62	69	25	45
Kaul soil	87	88	75	77	62	64	49	56	7	25
Morni soil	83	82	68	69	52	53	38	46	0	10
Balsamand soil	93	94	85	86	77	78	70	78	35	50
LSD (P=0.05)										
Soil	2.51		2.63		2.11		1.90		1.86	
Moisture level	2.60		2.55		2.43		2.00		1.80	
Soil x Moisture	3.90		4.01		3.70		3.49		2.19	

F.C. = Field capacity; F = Flooding

Table 2. Effect of soil type and moisture regimes on first order rate constant (k, h^{-1}) and $t_{1/2}$ values of urea hydrolysis

Soils	Moisture regimes			
	F.C.	F	F.C.	F
	k h^{-1}		$t_{1/2}$, h	
Hisar soil	0.0406	0.0322	17.06	21.52
Kaul soil	0.0583	0.0475	11.88	14.59
Morni soil	0.0798	0.0611	8.68	11.34
Balsamand soil	0.0291	0.0245	23.81	28.28

The higher rates of urea hydrolysis in Morni or Kaul soils could be ascribed due to their higher organic matter and clay contents compared to Hisar or Balsamand soils. These results are in line with those reported earlier (Singh et al., 1991) who found that organic matter and CEC accounted for more than 93 per cent variation in urease activity in Haryana soils. The positive relationship between urease activity and organic matter or clay contents have also been reported by Dash et al. (1981), Rachhpal Singh and Nye (1984) and Reynolds et al. (1985).

In general, the rate of urea hydrolysis was fast at F.C. than at flooding irrespective of soil types (Table 1). Such effects were more pronounced after 9 h of incubation in all the soils studied. The observed smaller rates of urea hydrolysis at flooding than at F.C. could have been due to depletion of O_2 under flooding. In the initial stages (upto 9 h) the effects were not very clear, but after 9 h, the hydrolysis of urea was significantly retarded at flooding which may be due to consumption of O_2 by aerobic microorganisms. The depletion of O_2 resulted in slow hydrolysis of added urea (Savant et al., 1985). The reduced rates of urea hydrolysis in waterlogged conditions have also been reported by Delaune and Patrick (1970) and Yadav et al. (1987). On the contrary, Bremner and Mulvaney (1978) showed a non-significant effects of water levels upto 1 ml/g soil on urea hydrolysis.

The values of first order rate constant (k) were calculated for different soils and moisture levels (Table 2).

The K values ranged from 0.0291 to 0.0798 h^{-1} at F.C. and 0.0245 to 0.0611 h^{-1} at flooding in Balsamand and Morni soils, respectively, showing the lowest and highest rates of urea hydrolysis in this study (Table 2).

The time required to hydrolyse half the amounts of added urea-N ($t_{1/2}$) was maximum in Balsamand soil and minimum in Morni soil, at both the moisture levels (Table 2). These results, therefore, indicate a negative correlation between K values and $t_{1/2}$ in all the four soils studied here.

1(b) Effect of soil type and salinity levels on hydrolysis of urea

The increasing levels of salinity decreased the rate of urea hydrolysis in both the soils (Table 3). The reduction in urea hydrolysis at soil salinity of 16 dSm^{-1} over control were 5 and 8 per cent at 3 h, and 9 and 11 per cent at 24 h in Hisar and Kaul soils, respectively. However, at 3 h there was no significant difference in urea hydrolysis between the soils but, from 6 to 24 h the hydrolysis was more in Kaul soil than Hisar soil. At 24 h, about 25 and 8 per cent of applied urea remained unhydrolyzed in control soils whereas in soils of 16 dSm^{-1} salinity 34 and 19 per cent of added urea remained unhydrolyzed in Hisar and Kaul soils, respectively.

The reduced rates of urea hydrolysis in saline conditions may be due to decrease in urease activity associated with the decrease in osmotic potential of the soil water which could possibly be due to the fact that the enzyme proteins were subjected to a "salting out" effect. The addition of salts to a

Table 3. Effect of soil type and salinity levels on hydrolysis of added urea in soils

Salinity levels (dSm^{-1})	Incubation time (h)									
	3		6		9		12		24	
	Hisar soil	Kaul soil	Hisar soil	Kaul soil	Hisar soil	Kaul soil	Hisar soil	Kaul soil	Hisar soil	Kaul soil
	Urea-N (ug g^{-1}soil)									
Control	91	87	80	75	71	62	62	49	25	8
4	90	89	81	77	72	64	63	51	26	10
8	92	90	83	79	74	66	65	53	28	11
12	94	92	86	82	76	69	67	56	30	14
16	96	95	89	85	79	72	70	58	34	19
LSD (P=0.05)										
Soil	2.65		2.61		2.54		2.33		1.18	
Salinity	2.51		2.43		2.39		2.18		1.19	
Soil x Salinity	3.78		3.60		3.45		3.40		1.96	

Original ECe of Hisar soil = 1.2 dSm^{-1}.
Original ECe of Kaul soil = 1.5 dSm^{-1}.

Table 4. Effect of soil type and salinity levels on first order rate constant (k, h^{-1}) and $t_{½}$ values of urea hydrolysis

Salinity levels (dSm^{-1})	Soil type			
	Hisar	Kaul	Hisar	Kaul
	k h^{-1}		$t_{½}$, h	
Control	0.0406	0.0591	17.06	11.72
4	0.0376	0.0552	18.43	12.55
8	0.0368	0.0529	18.83	13.10
12	0.0330	0.0475	21.00	14.59
16	0.0291	0.0460	23.81	15.05

protein solution can decrease the solubility of the protein by dehydration, subsequently altering the active conformation of the enzyme protein (Frankenberger and Bingham, 1982). The addition of salts to soils have been reported to decrease the urease activity in soils by several other wokers (Agarwal et al., 1971; Ryan and Sims, 1974). Mann (1979) reported that urea hydrolysis rates decreased with increasing salinity levels. Kumar et al. (1988) observed that increasing salinity decreased the rate of hydrolysis of urea in a sandy loam soil.

The K values for Hisar soil ranged from 0.0291 to 0.0406 h^{-1} and in Kaul soil from 0.0460 to 0.0591 h^{-1} in 16 dSm^{-1} and control trreatments of salinity, respectively (Table 4). Similarly t½ in control for Hisar soil was 17.06 h and for Kaul soil 11.72 h. The increasing levels of salinity increased the t½ values in both the soils (Table 4).

1(c) Effect of soil type and type of salinity on hyrolysis urea

The hydrolysis of urea was generally more in SO_4^{-2}domi-nated salinity as compare to Cl^--dominated salinity in both the soils (Table 5). At 12 h; 62 and 67 per cent of added urea remained unhydrolyzed in Hisar soil at 100% SO_4^{2-} and 100% Cl^- salinity treatments whereas in Kaul soil the corresponding values in the above treatments were 50 and 56 per cent, respectively. In 100% SO_4^{2-}-dominated treatment, only 26 and 10 per cent of added urea remained unhydrolyzed at 24 h in Hisar and Kaul soils, respectively. Meaned over all incubation periods and salinity treatments the rate of urea hydrolysis was

Table 5. Effect of soil type and types of salinity on hydrolysis of added urea in soils

Type of salinity (8 dSm^{-1})	Incubation time (h)									
	3		6		9		12		24	
	Hisar soil	Kaul soil	Hisar soil	Kaul soil	Hisar soil	Kaul soil	Hisar soil	Kaul soil	Hisar soil	Kaul soil
Cl^- : SO_4^{2-}	Urea-N (ug g^{-1} soil)									
Cl 100%	94	92	85	81	76	68	67	56	31	13
75 : 25	93	92	84	80	75	66	67	54	30	12
50 : 50	92	90	83	79	74	66	65	53	28	11
25 : 75	91	89	82	79	73	65	64	53	28	10
100% SO_4	89	87	80	77	71	63	62	50	26	10
LSD (P=0.05)										
Soil	2.43		2.49		2.41		2.56		2.01	
Type of salinity	3.55		3.36		3.06		3.13		1.99	
Soil x Type of salinity	4.49		4.31		4.02		3.93		3.26	

Table 6. Effect of soil type and types of salinity on first order rate constant (k, h^{-1}) and $t_{½}$ values of urea hydrolysis

Types of salinity (8 dSm^{-1})	Soils			
	Hisar	Kaul	Hisar	Kaul
	k h^{-1}		$t_{½}$, h	
Cl : SO_4				
100% Cl	0.0330	0.0483	21.00	14.34
75 : 25	0.0340	0.0522	20.30	13.27
50 : 50	0.0360	0.0529	19.25	13.10
25 : 75	0.0368	0.0537	18.83	12.90
100% SO_4	0.0375	0.0568	18.48	12.20

fast in Kaul soil than Hisar soil. These results indicate that Cl^- have more deleterious effects on hydrolysis of urea. Various workers have reported the adverse effects of salinity on microbial activities and consequently on hydrolysis of urea. For example, Frankenberger and Bingham (1982) reported that soil enzyme activities decreased with increasing salinity, however, the degree of inhibition varied with the nature and amounts of salts added to produce various levels of salinity. They observed that, generally, the inhibition of soil enzyme activities by the addition of salts decreased in the following order when compared at the same ECe level; NaCl > $CaCl_2$ > $NaSO_4$. The reduced enzyme activities in saline soils could be due to the osmotic desiccation of microbial cells. And specific ion toxicities causing nutritional imbalances for microbial growth and subsequent enzyme synthesis. Some other workers also reported that specific ion-toxicities may have a significant influence on microbial growth in saline soil which are considered to be responsible for hydrolysis of urea (Johnson and Guenzi, 1963; Agarwal et al., 1971 and Heliman, 1975).

The K values ranged from 0.0330 to 0.0375 h^{-1} in Hisar and 0.0483 to 0568 h^{-1} in Kaul soils (Table 6). The $t_{1/2}$ values ranged from 18.48 to 21.00 h in Hisar and 12.20 to 14.34 h for Kaul at 100% SO_4^{2-} and 100% Cl^--dominated salinity treatments, respectively (Table 6). These results indicate that chlorides have more deleterious effects than sulphates on hydrolysis of urea.

1(d) Effect of ESP levels on hydrolysis of urea

In general, increasing levels of ESP decreased the rate of urea hydrolysis in both the soils (Table 7). However, the effects of ESP on rates of urea hydrolysis were more pronounced at 12 and 24 h only. Meaned over all incubation period and ESP levels, the hydrolysis of urea was fast in Kaul soil than Hisar soil. This again can be attributed due to higher organic matter and clay contents of Kaul soil compared to Hisar soil.

Soil pH values between 7 and 8 have been reported to be optimum for highest urease activity (e.g. Roberge and Knowles, 1968). It is known that increasing ESP levels, in turn, increased soil pH. Therefore, the decreased rates of urea hydrolysis at higher ESP levels in this work, could be attributed due to decreased urease activity at higher soil pH. Several other workers also reported similar results (Beri and Brar, 1978; Kumar et al., 1988). They reported that an increase in soil pH delayed the hydrolysis of urea. Similarly, Singh et al. (1991) reported that urease activity was found to have negative correlation with soil pH.

The K values for Hisar soil ranged from 0.0276 to 0.0406 h^{-1} and in Kaul soil from 0.0452 to 0.0591 h^{-1} at 90 ESP and control treatment, respectively (Tahle 8). Similarly, the t½ in control treatments were 17.06 and 11.72 h in Hisar and Kaul soils, respectively (Table 8).

1.2 Transformation of added urea-N in normal, saline and sodic soils

In this section, the results of the laboratory experiments

Table 7. Effect of soil type and ESP levels on hydrolysis of added urea in soils

ESP levels	Incubation time (h)									
	3		6		9		12		24	
	Hisar soil	Kaul soil	Hisar soil	Kaul soil	Hisar soil	Kaul soil	Hisar soil	Kaul soil	Hisar soil	Kaul soil
Control	91	87	80	75	71	62	62	49	25	8
15	92	89	81	76	72	64	63	50	25	9
30	94	90	83	78	74	66	64	52	27	12
60	95	92	85	81	77	68	67	53	31	16
90	97	94	88	83	81	73	73	58	37	24
LSD (P=0.05)										
Soil	2.55		2.68		2.36		2.40		1.91	
ESP	3.19		3.01		2.98		2.69		2.02	
Soil x ESP	4.21		4.03		3.62		3.28		3.11	

Original ESP of Hisar soil = 7.0.
Original ESP of Kaul soil = 8.0.

Table 8. Effect of soil type and ESP levels on first order rate constant (k, h^{-1}) and $t_{½}$ values of urea hydrolysis

ESP levels	Soil type			
	Hisar	Kaul	Hisar	Kaul
	k h^{-1}		$t_{½}$, h	
Control	0.0406	0.0591	17.06	11.72
15	0.0383	0.0568	18.09	12.20
30	0.0368	0.0529	18.83	13.10
60	0.0330	0.0480	21.00	14.20
90	0.0276	0.0442	25.10	15.63

conducted to study the effect of different factors on transformation of added urea-N in soils are discussed. The amounts of NH_4^+, NO_2^- and NO_3^--N shown in tables 9 to 12 are the amended values obtained after substraction of the amounts of the control treatments.

1.2(a) Effects of soil type and moisture regimes on nitrification of added urea

At day 7 of incubation the contents of NH_4^+-N were lowest in the Balsamand soil and highest in Morni soil at both the moisture levels (Table 9). However, as the incubation proceeds, the reverse trend was observed at both the moisture regimes. At 28 days 16, 11, 9 and 32 per cent of added urea was in the form of NH_4^+-N at F.C. in Hisar, Kaul, Morni and Balsamand soils, respectively. The corresponding values at flooding were 37, 34, 30 and 55 per cent, respectively. These results, therefore, clearly indicate that moisture levels had significant effects on the NH_4^+-N contents of the soils amended with urea. The higher NH_4^+-N contents at flooding compared to at F.C. in all the soils may be due to slow rate of nitrification at flooding. These results support the findings of Sahrawat (1980), who reported that nitrification rates were slow in soils having moisture content higher than F.C. Similar, results were also reported by Yadav _et al_. (1987) and Sarkar _et al_. (1991).

The NO_2^--N contents increased upto 14 days at F.C. in all the soils and then decreased with further incubation. At 28 days negligible amounts of NO_2^--N were recovered in all the soils indicating that most of the added urea was nitrified

Table 9. Effect of Soil type and moisture regimes on nitrification of added urea in soils

Soil type	Incubation time (days)							
	7		14		21		28	
	F.C.	F	F.C.	F	F.C.	F	F.C.	F
	NH_4^+-N (ug g^{-1} soil)							
Hisar	72	74	50	65	29	51	16	35
Kaul	73	75	46	63	25	55	11	34
Morni	74	76	41	61	21	49	9	30
Balsamand	69	72	56	68	45	67	32	56
LSD (P=0.05)								
Soil	2.16		2.04		1.97		1.67	
Moisture	2.43		2.17		2.06		1.93	
Soil x Moisture	3.52		3.19		3.11		2.69	
	NO_2^--N (ug g^{-1} soil)							
Hisar	4.6	1.3	8.3	4.0	3.5	7.1	0.3	5.1
Kaul	5.1	1.6	8.8	3.8	3.7	7.4	0.3	3.9
Morni	5.3	1.8	8.7	3.9	3.9	8.1	0.2	5.5
Balsamand	4.4	1.2	7.9	3.1	2.7	3.1	0.4	2.1
LSD (P=0.05)								
Soil	0.10		0.10		0.11		0.07	
Moisture	0.12		0.11		0.12		0.09	
Soil x Moisture	0.20		0.19		0.21		0.14	
	NO_3^--N (ug g^{-1} soil)							
Hisar	9.1	4.8	31.5	20.4	56.0	29.2	72.0	42.8
Kaul	12.5	5.1	38.0	23.8	64.0	31.9	79.0	48.1
Morni	13.7	5.9	43.0	25.8	68.0	34.2	82.0	52.4
Balsamand	7.8	2.6	18.0	10.7	35.7	12.7	48.5	26.2
LSD (P=0.05)								
Soil	1.10		1.21		1.29		1.39	
Moisture	1.21		1.26		1.33		1.45	
Soil x Moisture	1.90		1.83		1.89		2.07	

until then. However, at flooding a slightly different trend was observed where NO_2^--N increased upto 21 days and then decreased between 21 and 28 days. The contents of NO_2^--N were significantly higher at flooding than at F.C. These results are in accordance with those of Sahrawat (1980), who reported that the nitrification of added urea-N was fast at F.C. than at higher moisture regimes (100% and 200% of WHC) where the added urea-N was found mainly as NH_4^+-N and, therefore, the NO_2^--N accumulation was mainly associated with higher concentrations of NH_4^+-N. Similarly, Yadav et al. (1987) in an incubation experiment studied the effects of five moisture levels on nitrification (20%, 40%, 80%, 100% F.C. and Flooding) and reported that nitrification rates were fast only at 80 and 100% F.C. whereas at other (both lower and higher than F.C.) moisture regimes nitrification rates were comparatively low.

The amounts of NO_3^--N increased in all the soils with increasing incubation period upto 28 days at both moisture levels. The contents of NO_3^--N were, however, higher at F.C. than at flooding in all the soils at all incubation periods. At 28 days; 72, 79, 82 and 48 per cent of added urea-N was nitrified at F.C. in Hisar, Kaul, Morni and Balsamand soils, respectively. The corresponding values at flooding were 43, 48, 52 and 26, respectively. The slower rates of nitrification in Balsamand soil compared to other soils studied at both the moisture levels could be due to low organic matter and clay contents of this soil which influence the rate of nitrification.

These results support the findings of Singh and Yadav (1980), who observed that nitrification was slow in sandy soil than that in sandy loam soil.

At 28 day recovery (NH_4^+ + NO_3^- + NO_2^--N) of added urea-N was 81 and 91 per cent at F.C. and about 78 and 88 per cent at flooding in Balsamand and Morni soils, respectively. The smaller recovery of added urea-N observed in Balsamand soil may be due to higher NH_3 volatilization losses due to its higher pH and low organic matter content.

1.2(b) Effects of soil type and salinity levels on nitrification of added urea

Increasing salinity levels decreased the contents of NH_4^+-N significantly upto 14 days of incubation in both the soils (Table 10). This decrease in NH_4^+-N contents during initial incubation period may be due to higher NH_3-volatilization losses at higher salinity levels. McClung and Frankenberger (1985) reported that increasing salinity levels promoted NH_3 volatilization of applied urea-N. The increase in NH_4^+-N contents at 21 and 28 days of incubation with increasing salinity was due to poor nitrification at higher salinity levels.

The contents of NO_2^--N increased upto 14 days and then decreased until 28 days of incubation in all treatments. However, the amounts of NO_2^--N were higher in soils at higher salinity at all incubation periods indicating that 2nd step of nitrification i.e., conversion of NO_2^--N to NO_3^--N was more

Table 10. Effect of salinity levels on nitrification of added urea in soils

Salinity levels (dSm^{-1})	Incubation time (days)							
	7		14		21		28	
	Hisar	Kaul	Hisar	Kaul	Hisar	Kaul	Hisar	Kaul
	NH_4^+-N (ug g^{-1} soil)							
Control	76	74	50	46	29	25	17	11
4	73	73	48	44	28	24	18	13
8	69	70	46	42	29	25	19	14
12	65	66	44	43	30	26	20	15
16	60	62	42	41	31	27	21	17
LSD (P=0.05)								
Soil	1.85		1.73		1.25		1.19	
Salinity	2.11		1.92		1.70		1.55	
Soil x Salinity	3.09		2.98		2.85		2.60	
	NO_2^--N (ug g^{-1} soil)							
Control	4.6	5.1	8.3	8.8	3.5	3.7	0.6	0.4
4	5.4	5.5	9.5	9.7	4.1	4.3	1.7	1.4
8	5.6	5.8	11.7	11.3	6.8	5.6	3.5	2.6
12	6.3	6.1	12.8	12.8	7.3	6.4	4.4	3.1
16	7.9	7.3	14.1	12.4	9.9	7.8	4.8	3.9
LSD (P=0.05)								
Soil	0.53		0.59		0.26		0.29	
Salinity	0.69		0.64		0.29		0.34	
Soil x Salinity	0.70		0.79		0.51		0.50	
	NO_3^--N (ug g^{-1} soil)							
Control	9.1	12.5	31.5	38.1	56.0	64.0	72.0	79.0
4	7.8	11.6	28.4	35.0	53.5	59.7	65.2	75.0
8	7.5	9.8	23.2	31.5	44.7	54.6	59.1	69.1
12	7.2	9.4	21.7	28.2	40.8	49.8	54.5	63.8
16	6.1	8.7	17.9	24.2	33.6	44.2	50.3	58.4
LSD (P=0.05)								
Soil	0.47		1.21		2.16		2.41	
Salinity	0.49		1.26		2.31		2.54	
Soil x Salinity	0.73		1.93		3.15		3.81	

adversely affected compared to first step at higher soil salinity. Thus, from these results it seems most likely that the activities of Nitrobacter, which is responsible for the conversion of NO_2^- to NO_3^- are hampered in the presence of higher salt concentration in soils. These results support the work of Gupta and Bajpai (1974), who found a higher proportion of Nitrosomonas to Nitrobacter in salt affected soils. Similarly, McClung and Frankenberger (1985) also found that with increasing salinity levels there was accumulation of NO_2^--N

In contrast, the amounts of NO_3^--N continuously increased from the beginning till the end of incubation in all the treatments. Taken at face value, these results suggest that nitrification is a continuous process and the increase in NO_3^--N contents was coupled with decrease in NH_4^+-N in soils. However, the amounts of NO_3^--N were smaller in soils of higher salinity which indicate that nitrification process is retarded in the presence of higher salt concentration in soils. Another, most likely explanation could be that less of NH_4^+-N was available for conversion into NO_3^--N as some of the NH_4^+-N might have been volatilized in highly saline soils. Several other workers also made similar observations, e.g., Gandhi and Paliwal (1976) and Suraj Bhan et al. (1990).

The recovery of applied urea-N at 28 day was about 90 per cent in control treatment and about 77 per cent in 16 dSm^{-1} salinity treatment of both the Hisar or Kaul soils. The most likely reason for less recovery of applied N at higher salinity levels could presumably be due to occurrence of more NH_3 volatilization losses. Gandhi and Paliwal (1976) also reported higher volatilization losses of N from added urea-N in saline soils. Similar, observations were also made by McClung and Frankenberger (1985).

1.2(c) Effects of soil type and types of sainity on nitrification of added urea

The contents of NH_4^+-N decreased with increasing incubation period in all treatments of both Hisar and Kaul soils (Table 11). The decrease in NH_4^+-N contents with the advancement of incubation period was coupled with the subsequent increase in NO_3^--N contents. The contents of NH_4^+-N at day 7 were 71 and 66 per cent in Hisar soil and 73 and 68 per cent in Kaul soil in 100% Cl^--dominated and 100% SO_4^{2-}-dominated salinity treatments, respectively. However, the corresponding values at 28 days were 20 and 18 per cent in Hisar soil, and 15 and 11 per cent in Kaul soil. Thus, these results indicate that there were no apparent effects of salinity and/or type of salinity on ammonification of urea in either the soil studied. These findings resemble with the work of Singh _et al_. (1969), Broadbent and Nakasha (1971) and Westerman and Tucker (1974), who found that ammonfication was less sensitive to salinity than nitrification.

The contents of NO_2^--N increased upto 14 days in all treatments and then decreased until the end of incubation in both the soil (Table 11). Upto 14 days, however, there was no significant difference in the contents of NO_2^--N with respect to

Table 11. Effect of type of salinity on nitrification of added urea in soils

Type of salinity (8 dSm^{-1})	Incubation time (days)							
	7		14		21		28	
	Hisar	Kaul	Hisar	Kaul	Hisar	Kaul	Hisar	Kaul
Cl^-: SO_4^{2-}	NH_4^+-N (ug g^{-1} soil)							
100% Cl^-	71	73	49	43	31	27	20	15
75 : 25	70	72	48	42	30	26	19	14
50 : 50	69	70	46	42	29	25	19	13
25 : 75	69	69	45	42	29	24	18	12
100% SO_4	66	68	44	41	28	23	18	11
LSD (P=0.05)								
Soil	NS		1.76		1.68		1.36	
Salinity	NS		NS		NS		NS	
Soil x Salinity	NS		NS		NS		NS	
Cl^-: SO_4^{2-}	NO_2^--N (ug g^{-1} soil)							
100% Cl^-	6.0	7.2	12.2	11.9	7.4	6.4	4.4	2.9
75 : 25	5.9	6.4	11.8	11.5	7.1	5.9	3.8	2.7
50 : 50	5.6	5.8	11.7	11.3	6.8	5.6	3.5	2.6
25 : 75	5.6	5.6	11.7	11.1	6.6	5.4	3.3	2.3
100% SO_4^{2-}	5.4	5.5	11.4	10.8	6.2	5.1	3.1	2.0
LSD (P=0.05)								
Soil	NS		NS		0.41		0.15	
Salinity	NS		NS		NS		NS	
Soil x Salinity	NS		NS		NS		NS	
Cl^-: SO_4^{2-}	NO_3^--N (ug g^{-1} soil)							
100% Cl^-	5.2	6.3	20.5	29.7	41.7	51.9	56.2	66.8
75 : 25	5.7	7.8	22.1	30.6	42.2	52.6	57.7	67.5
50 : 50	7.5	9.8	23.2	31.5	44.5	54.6	59.4	69.1
25 : 75	7.7	11.5	23.8	31.8	44.0	55.1	59.7	70.3
100% SO_4^{2-}	8.8	12.4	24.6	32.8	45.2	55.4	60.5	71.2
LSD (P=0.05)								
Soil	0.91		1.83		2.43		2.63	
Salinity	0.70		0.82		1.16		1.19	
Soil x Salinity	1.39		2.18		2.61		2.84	

type of salinity. The increase in NO_2^--N with increasing incubation period upto 14 days again indicates that the second step of nitrification (i.e. conversion of NO_2 to NO_3) was inhibited more adversely than the first step (i.e. conversion of NH_4-N to NO_2^--N). McClung and Frankenberger (1985) also found appreciable amounts of NO_2^--N accumulation in saline soils, particularly when urea was applied as a source of N. Similar, results were also reported by Kumar et al. (1988) and Suraj Bhan et al. (1990).

The amounts of NO_3^--N continuously increased from the beginning till the end of incubation in all the treatments. However, the amounts of NO_3^--N were significantly smaller in 100% Cl^- treatments than that of 100% SO_4^{2-}-treatment in both the soils. Thus, these results indicate that Cl^- salts were more inhibitory to nitrification than SO_4-salts. These results support the work of Sindhu and Cornfield (1967), Agarwal et al. (1971), Heilman (1975) and McClung and Frankenberger (1985). It is, however, not well understood why chlorides have more inhibitory effects than sulphates on nitrification but several workers agree that sulphates are less inhibitory than chlorides to microbial activities and soil enzymes which are responsible for N mineralization in soil (McCormick and Wolf, 1980 and Frankenberger and Bingham, 1982).

1.2(d) Effect of soil type and ESP levels on nitrification of added urea

Generally, increasing ESP markedly decreased the contents of NH_4^+-N with the advancement of incubation period in both the soils (Table 12). However, the decline in contents of NH_4^+-N in 60 or 90 ESP treatments was relatively faster than in the control or 30 ESP treatment. This sharp decrease in NH_4^+-N in higher ESP treatments particularly upto 14 days of incubation was probably associated with increased NH_3-volatilization losses. The higher NH_3-volatilization losses observed in higher ESP treatments may be due to increased Na contents of these soils which, in turn, caused increased soil pH. As the observed soil pH were 8.2, 8.4, 9.6 and 10.4 in the control, 30, 60 and 90 ESP treatments, respectively. Volk (1959) reported that high soil pH decreased the NH_3 adsorption potential of soil which resulted in greater NH_3 volatilization from applied urea. These results also confirm the work of Rao and Batra (1983) who reported that NH_3 volatilization losses from applied urea-N were largely governed by the pH of the soil solution.

In general, the contents of NO_2^--N increased upto 14 days and then decreased with further incubation period in both the soils. However, there was no significant difference in NO_2^--N accumualtion within the different ESP levels. These results are in line with those reported by Broadbent <u>et</u> <u>al</u>. (1958), Matula (1974) and Kumar <u>et</u> <u>al</u>. (1988) found that when urea was applied to alkaline soils an appreciable amounts of NO_2^--N were detected They further observed that this may have been due to the fact that microbial transformation of NO_2^- to NO_3^- proceeds less rapidly than conversion of NH_4^+ to NO_2^- under alkaline soil conditions, presumably because nitrobacter may be more susceptible to alkalinity compared to nitrosomonas species.

Table 12. Effect of ESP levels on nitrification of added urea in Kaul and Hisar soils

ESP levels	Incubation time (days)							
	7		14		21		28	
	Hisar	Kaul	Hisar	Kaul	Hisar	Kaul	Hisar	Kaul
	NH_4^+-N (ug g^{-1} soil)							
Control	76	74	50	46	29	25	17	11
15	72	71	46	43	30	23	19	11
30	65	67	42	39	29	24	19	12
60	51	55	36	35	23	20	15	10
90	33	45	25	30	18	18	13	8
LSD (P=0.05)								
Soil	2.14		1.53		1.21		1.02	
ESP	2.43		1.64		1.26		1.11	
Soil x ESP	3.68		2.16		1.62		1.42	
	NO_2^--N (ug g^{-1} soil)							
Control	4.6	5.1	8.3	8.8	3.5	3.7	0.6	0.4
15	6.0	6.4	10.2	11.2	4.3	4.8	1.3	1.0
30	7.2	8.1	12.7	12.0	5.2	5.6	2.5	1.6
60	6.8	7.3	9.8	10.2	5.8	6.3	2.6	1.8
90	5.7	6.6	8.5	10.1	5.7	6.1	2.1	1.6
LSD (P=0.05)								
Soil	0.46		0.53		0.33		NS	
ESP	NS		NS		NS		NS	
Soil x ESP	NS		NS		NS		NS	
	NO_3^--N (ug g^{-1} soil)							
Control	9.1	12.5	31.5	38.1	56.0	64.0	72.0	79.0
15	7.2	11.2	28.6	33.6	50.5	57.5	64.2	73.1
30	6.6	8.1	21.4	28.9	43.2	51.2	54.8	66.2
60	6.5	7.2	17.1	22.1	37.1	41.0	46.5	54.5
90	5.6	6.8	13.7	17.5	23.5	31.5	33.7	44.0
LSD (P=0.05)								
Soil	0.93		2.14		2.36		2.71	
ESP	0.98		2.20		2.43		2.79	
Soil x ESP	1.55		3.46		3.69		4.06	

Generally, the increased ESP levels decreased NO_3^--N drastically in both the soils at all incubation periods. At 28 days, the contents of NO_3^--N decreased from 72 to 34 per cent in Hisar soil and 79 to 44 per cent in Kaul soil when the ESP of the control soil increased to 90. The smaller amounts of NO_3^--N detected in soils of higher ESP could be either due to retarded nitrification process or enhanced volatilization losses or both operating simultaneously. These results are in line with those of Anthonisen et al. (1976), who reported that high concentration of free NH_3 associated with high pH in soil inhibited the activity of both Nitrosomonas and Nitrobacter species and consequently the process of nitrification was inhibited. Similarly, Kumar et al. (1988) reported that higher soil pH decreased the rate of nitrification process. In contrast, Wang et al. (1966) reported that nitrification was faster in sodic soils as compare to non-sodic soils.

The recoveries of applied urea-N at 28 days were about 90 per cent in control treatments and about 50 per cent in 90 ESP treatments in both the soils. It indicates that at higher ESP levels, a substantial amount of added N was lost mainly due to NH_3 volatilization losses. Sharma et al. (1992) reported that larger volatilization losses occurred at higher ESP levels.

EXPERIMENT 2. Studies on ammonia volatilization losses in saline and sodic soils

2.1 Effects of different ESP levels on ammonia volatilization losses

The losses of NH_3 volatilization were more in Hisar soil than Kaul soil during 21 days of incubation at all ESP levels

(Table 13). Losses in both the soils started on the first day and continued upto 21 days. However, the mangitude of the NH_3 losses increased upto 3rd day and then losses decreased in both the soils. About 90 per cent of NH_3 volatilization losses occurred during the first 5 days and in subsequent days losses were about 10 per cent of added N at all ESP levels in both the soils. In control, the cumulative losses of NH_3 were 35.3 and 28.0 per cent in Hisar and Kaul soils, respectively. The ESP of the soils increased the losses. The highest losses were found 55.8 per cent in Hisar soil and 44.7 per cent in Kaul soil at 90 ESP level. The larger amounts of NH_3 losses were at higher ESP levels could be due to several reasons. Firstly, at the higher ESP levels soils contained higher Na content, which consequently increased soil pH. It is believed that high soil pH decreased cation adsorption potential of soils which resulted in higher NH_3 volatilization from applied urea (Volk, 1959).

Secondly, it has also been often reported that NH_4^+ ions from the exchange sites of soils may come into the soil solution in high ESP soils and when urea or NH_4^+ containing fertilizers were added to such high ESP soils, more NH_4^+ ions were volatilized to the atmosphere as NH_3. Whereas at relatively lower ESP levels added NH_4^- ions may be partly or wholly adsorbed at exchange sites and may not be lost as NH_3. Third, possible reason may be that the excessive dispersion of soil particles at higher ESP results in reduced O_2 content of soil which, in turn, may reduce the process of nitrification

Table 13. Effect of ESP levels on ammonia volatilization losses of added urea from Hisar and Kaul soils

Days after N-application	Hisar soil				Kaul soil				LSD (5%)		
	ESP levels				ESP levels						
	Control (7.0)	30	60	90	Control (8.0)	30	60	90	ESP	Soil	Soil x ESP
	% of applied N volatilized				% of applied urea volatilized						
0-1	2.3	2.5	2.9	2.7	1.6	1.8	2.5	2.7	0.17	0.12	0.22
1-2	7.6	7.9	5.1	3.6	6.6	7.0	8.5	8.1	0.19	0.14	0.25
2-3	9.0	9.9	9.6	10.2	7.3	7.8	8.9	9.6	0.23	0.19	0.36
3-4	7.7	8.4	10.7	12.3	5.7	6.0	7.0	9.7	0.22	0.17	0.33
4-5	3.5	3.7	10.4	14.9	2.9	3.1	3.6	4.9	0.19	0.15	0.26
5-6	1.9	2.1	2.5	6.2	1.1	1.5	3.1	3.7	0.11	0.09	0.15
6-7	1.0	1.4	1.4	1.6	0.8	1.2	1.7	1.9	NS	NS	NS
7-8	0.6	1.1	0.9	1.1	0.6	1.1	1.0	1.1	NS	NS	NS
8-9	0.4	0.8	0.9	1.0	0.3	0.8	0.9	0.9	NS	NS	NS
9-10	0.5	0.5	0.5	0.6	0.5	0.4	0.6	0.7	NS	NS	NS
12-15	0.3	0.4	0.5	0.6	0.2	0.7	0.6	0.5	NS	NS	NS
15-18	0.3	0.3	0.4	0.5	0.2	0.3	0.3	0.4	NS	NS	NS
18-21	0.2	0.3	0.4	0.5	0.2	0.3	0.3	0.4	NS	NS	NS
Cumulative	35.3	39.3	46.2	55.8	28.0	32.7	39.2	44.7			

and hence less NH_4^+ ions got nitrified, which creates a condition ideally suited for NH_3 volatilization. Kumar et al. (1988) reported that accumulation of NH_4^+ ions for longer period in high ESP soils.

Justic and Smith (1962) also reported that process of nitrification decreased with decreasing amounts of O_2. There appears to be limited reports available in the literature, which have studied directly the effect of ESP on the volatilization losses of N. However, the effects of pH have widely been reported by several workers. For example, Bhorania and Meisheri (1984) observed that losses of NH_3 from applied urea in soils of pH 8.3 and 9.4 were two to three-fold higher than those at pH 7. Similarly, Sharma et al. (1992) studied the NH_3 volatilization losses following application of urea at different ESP levels and found that the magnitude of NH_3 losses increased with increasing ESP levels. However, Laher (1977) has shown that the pH of soil solution immediately surrounding a urea or NH_4^+ containing fertilizer granule may be considerably more important than of the whole soil.

The cumulative losses of N over the 21 days incubation in all the treatments were more in Hisar than Kaul soil. The obvious reason for smaller volatilization losses in Kaul soil may be due to its higher CEC, organic matter and clay; which tend to reduce these losses. These results are in line with the work of Martens and Bremner (1989), Whitehead and Raistrick (1990), who reported that gaseous losses of NH_3 were negatively correlated with soils CEC and clay contents. Verma and Sarkar (1974); Basdeo and Gangwar (1976) and Reddy et al. (1986) have also made similar observations.

The maximum volatilization losses occurred between day 2 and 5 of incubation. Thus, these results indicate that few days period is necessary for urease activity to develop in response to the addition of urea (Black et al., 1985). These findings also support the work of Singh and Bajwa (1987), who studied NH_3 volatilization losses at varying pH and observed that the cumulative losses of NH_3 were largest in soils having higher pH. They further reported that the maximum NH_3 losses occurred during first week of incubation which declined sharply upon further incubation and practically no apparent losses could be detected after 21 days. These results confirm the work of Whitehead and Raistrick (1990) and Kumar and Menon (1992), who reported that more than 85 per cent of the volatilization losses occurred during the first week of N fertilizer application. Similar results were reported in different ESP soils by Sharma et al. (1992).

2.2 Effects of soil type and salinity levels on ammonia volatilization losses

The gaseous losses of NH_3 increased with the increasing salinity levels in both Hisar and Kaul soils (Table 14). Thus, the cumulative losses of N over the 21 days of incubation were lower (about 35 and 28% of the added urea-N) in the control treatments and higher (about 44 and 35%) in the highest salinity treatment of Hisar and Kaul soils, respectively. These

Table 14. Effect of salinity levels on ammonia volatilization losses of applied urea from Hisar and Kaul soils

Days after N-application	Hisar soil				Kaul soil				LSD (5%)		
	Salinity levels dSm^{-1}				Salinity levels dSm^{-1}						
	Control (1.2)	4	8	16	Control (1.5)	4	8	16	Soil	Sali-nity	Soil x salinity
	% of applied N volatilized				% of applied N volatilized						
0-1	2.3	2.4	2.5	2.7	1.6	1.7	1.8	2.1	0.16	0.12	0.21
1-2	7.6	7.8	8.1	8.9	6.5	6.6	6.8	7.5	0.22	0.16	0.32
2-3	9.0	9.2	9.5	9.7	7.2	7.4	7.7	8.0	0.23	0.18	0.34
3-4	7.7	7.9	7.9	8.8	5.9	6.1	6.4	7.1	0.22	0.17	0.32
4-5	3.5	3.7	3.9	4.5	2.9	3.0	3.2	3.9	0.17	0.12	0.22
5-6	1.9	2.1	2.4	2.5	1.1	1.1	1.3	1.5	1.13	0.11	0.18
6-7	1.0	1.2	1.5	2.3	0.8	0.9	1.0	1.3	0.11	0.09	0.15
7-8	0.6	0.8	1.0	1.3	0.6	0.7	0.9	1.1	NS	NS	NS
8-9	0.4	0.5	0.6	0.9	0.3	0.4	0.5	0.7	NS	NS	NS
9-12	0.5	0.5	0.6	0.8	0.5	0.5	0.7	0.9	NS	NS	NS
12-15	0.3	0.3	0.4	0.6	0.2	0.3	0.4	0.5	NS	NS	NS
15-18	0.3	0.2	0.3	0.5	0.2	0.2	0.4	0.4	NS	NS	NS
18-21	0.2	0.2	0.2	0.3	0.2	0.2	0.2	0.3	NS	NS	NS
Cumulative	35.3	36.8	38.9	43.8	28.0	29.1	31.4	35.4			

results are comparable to those of Blasco and Cornfield (1966), Gandhi and Paliwal (1976). Singh and Bajwa (1987) also observed increased volatilization losses at higher salinity levels. The increase in volatilization losses of applied urea with increasing soil salinity in this study may be attributed to the decreased nitrification rates at higher salinity (McClung and Frankenberger, 1985). Several other workers (Singh et al., 1969; Broadbent and Nakasha, 1971 and Laura, 1974) also reported that ammonification was less sensitive to salinity than nitrification.

Meaned over all incubation period and salinity levels, the amounts of N volatilized were significantly higher in Hisar than Kaul soil. This was most likely due to lower clay and organic matter contents in Hisar than Kaul soil. These results support the work of Martens and Bremner (1989), who reported that volatilization losses of N were negatively correlated with CEC, silt content, clay content and were positively with sand content. Similar observations were also made by Whitehead and Raistrick (1990).

The peak values of volatilization losses of N occurred between day 2 and 5 which after 7 days, declined drastically, thus very little losses were observed between days 7 and 21. Similar results were also reported by Whitehead and Rastrick (1990) and Kumar and Menon (1992). They found that more than 85 per cent of the total losses occurred during the very first week of the fertilizer N application. The apparent losses of

NH_3 volatilization were significantly smaller during first day of incubation in all the treatments of both soils. This may be attributed to delayed urea hydrolysis, since urease loses its activity, due to salinity being above the critical level, permitting less hydrolysis and therefore, less volatilization losses. However, after first day of incubation there were substantial NH_3 losses as explained above in both the soils indicating that the enzymic conversion of added urea to ammonium carbonate was enough by the time supporting the fact that $(NH_4)_2CO_3$ caused a substantial, though localized, increase in soil pH. These results support the findings of Fenn and Richards (1986), who reported that NH_3 volatilization could occur from both acid as well as alkaline soils due to high pH caused by NH_4^+ ions concentrations in the microsite where urea granules got dissolved and hydrolyzed. Similar results were also observed by Fann and Mackenzie (1993), who found that in Rosalie soil, addition of urea increased soil pH from 5.2 to 7.0 at the site of its placement on the second day of incubation. The effect of urea hydrolysis on soil pH extended to 15 mm from the site of placement. They further observed that soil pH increased upto 7.8 to 10 mm distance from the fertilizer site in 4 days, the increased pH subsequently decreased with time.

EXPERIMENT 3. Effect of salinity and nitrogen on yield and uptake of nutrients in wheat

3.1 Dry matter yield

There was drastic decrease in mean dry matter yields of both roots and shoots with increased levels of soil salinity (Table 15). The mean per cent decrease in root and shoot dry matter yields at highest salinity level (12 dSm^{-1}) over control was 37 and 53, respectively. Reduction in dry matter yields due to salt stress has been reported by many investigators (Khalil et al., 1967; Rabic et al., 1985; Broadbent et al., 1988). However, there was significant increase in dry matter yields with the increasing levels of N from 0 to 150 ug g^{-1} soil. Though, the magnitude of increase was remarkably high in the treatment receiving 60 ug N g^{-1} soil compared to other N levels. However, a decrease in dry matter yields was recorded at higher salinity levels when N level increased from 120 to 150 ug g^{-1} soil. These results support the hypothesis that the suppressing effects of moderate salinity on dry matter yield can be alleviated to some extent with N fertilization. These results further indicate that higher N application rates were ineffective to counteract the adverse effects of the highest salinity levels (12 dSm^{-1}). These results corroborate with the findings of Papadopoulos and Rending (1983), who also reported that plants responded positively to increasing N doses only at the lower levels of soil salinity. They further reported that at higher soil salinity, increasing N application did not mitigate the adverse effects of soil salinity on dry matter yields. Similar, observations were also made by Khandelwal and Lal (1991) and Mozafar and Oertli (1992).

Table 15. Effect of different levels of N and salinity on dry matter (g pot^{-1}) yield of wheat

N levels ($ug\ g^{-1}$ soil)	Salinity levels (dSm^{-1})				
	Control (1.2)	4	8	12	Mean
		Root dry matter			
0	3.64	3.38	3.25	2.72	3.25
60	5.68	5.56	5.35	4.40	5.20
120	7.64	6.33	5.30	4.60	5.95
150	7.71	6.48	3.80	3.75	5.42
Mean	6.17	5.42	4.43	3.87	
LSD (P=0.05)	N levels = 0.21				
	Salinity levels = 0.30				
	N x Salinity = 0.42				
		Shoot dry matter			
0	10.4	9.6	8.2	6.8	8.50
60	15.8	15.4	11.9	8.2	12.60
120	19.1	17.6	12.2	8.4	14.30
150	19.4	17.9	9.5	7.2	13.50
Mean	16.20	15.10	10.45	7.65	
LSD (P=0.05)	N levels = 0.35				
	Salinity levels = 0.49				
	N x Salinity = 0.63				

3.2 Nitrogen, phosphorus and potassium concentrations and uptake

3.2.1 Nitrogen: Nitrogen concentration in wheat roots increased significantly with increasing levels of N application (Table 16). Similarly, the N concentration increased significantly with the increasing levels of salinity. These results are comparable to those of Pessarakli and Tucker (1985), who found that N concentrations significantly increased under saline conditions. Similarly, the N concentration in wheat shoots increased substantially with the increase in N levels from 0 to 150 ug g^{-1} soil (Table 16). The mean per cent increase in N concentration with the application of 60 and 150 ug N g^{-1} soil compared to control were about 23 and 78, respectively. Likewise, the mean N concentration in wheat shoots increased with increasing salinity levels. The N concentrations were increased with increased application of N in wheat shoots from 0 to 150 ug g^{-1} soil at all salinity levels. These results are in line with those of Khalil et al. (1967), who found that N concentrations in shoots increased with N application, as well as with salinity levels.

The N uptake by wheat roots significantly increased with the increase in N levels from 0 to 150 ug g^{-1} soil (Table 17). The mean per cent increase in N uptake with the application of 60 and 150 ug N g^{-1} soil over no N treatment were about 111 and 183, respectively. On the contrary, there was a significant decrease in N uptake with the increase in soil salinity levels. The mean per cent decrease in N uptake at salinity levels of 4,

Table 16. Effect of different levels of N and salinity on N concentration (%) in wheat roots and shoots

N levels ($\mu g\ g^{-1}$ soil)	Salinity levels (dSm^{-1})				
	Control (1.2)	4	8	12	Mean
			Roots		
0	0.46	0.48	0.66	0.70	0.57
60	0.66	0.72	0.77	0.82	0.74
120	0.78	0.86	0.95	1.05	0.91
150	0.86	0.92	1.04	1.14	0.99
Mean	0.69	0.74	0.85	0.93	
LSD (P=0.05)	N levels = 0.06				
	Salinity levels = 0.07				
	N x Salinity = 0.09				
			Shoots		
0	0.83	1.02	1.14	1.35	1.08
60	1.18	1.23	1.36	1.57	1.33
120	1.52	1.68	1.80	1.96	1.74
150	1.75	1.79	2.01	2.12	1.92
Mean	1.32	1.43	1.58	1.75	
LSD (P=0.05)	N levels = 0.11				
	Salinity levels = 0.14				
	N x Salinity = 0.19				

8 and 12 dSm^{-1} over control were about 5, 16 and 19, respectively. Similarly, the N uptake by wheat shoots decreased as the salinity levels increased from 1.2 (Control) to 12 dSm^{-1} (Table 17). Greater reduction in N uptake, were probably due to reduced dry matter yields, as dry matter production decreased at higher salinity levels. However, plants continued to accumulate N under saline conditions in spite of the reduction in dry matter production (Pessarakli and Tucker, 1988).

Although, most of the work conducted to study the effects of salt stress on plants indicated a reduction in the uptake of N. However, the contradictory results which have demonstrated either an increase or no effect of N uptake by plants make the generalization difficult. Such effects can probably occur due to varying dilution effects, as reported by Frota and Tucker (1978) and Saad (1979). Thus, these results clearly indicate that plant growth was more sensitive to salt stress which causes increased concentrations of N in different plant parts.

3.2.2 Phosphorus: The mean P concentrations in wheat roots increased significantly with N application rates from 0 to 120 ug g^{-1} soil (Table 18). However, subsequent increase in N levels beyond 120 ug g^{-1} soil did not influence P concentration markedly. Conversely, there was significant decrease in P concentrations with the increase in soil salinity 1.2 (control) to 12 dSm^{-1}. The mean per cent decrease in P concentration at highest soil salinity (12 dSm^{-1}) compared to control was about 28 per cent. The reverse trends of P concentration with

Table 17. Effect of different levels of N and salinity on N uptake (mg pot^{-1}) in wheat roots and shoots

N levels ($\mu g\ g^{-1}$ soil)	Salinity levels (dSm^{-1})				
	Control (1.2)	4	8	12	Mean
			Roots		
0	16.74	16.22	21.45	19.04	18.36
60	37.48	40.03	41.20	36.08	38.70
120	59.60	54.43	50.82	48.32	53.29
150	66.30	59.61	39.52	47.75	52.04
Mean	45.03	42.57	38.24	36.54	
LSD (P=0.05	N levels = 3.16				
	Salinity levels = 3.72				
	N x Salinity = 5.44				
			Shoots		
0	86.32	96.19	93.48	91.80	91.94
60	168.84	189.42	161.84	128.74	162.21
120	200.90	295.68	219.60	164.64	220.20
150	208.55	320.41	190.95	152.60	218.15
Mean	166.16	225.42	166.46	134.45	
LSD (P=0.05)	N levels = 8.18				
	Salinity levels= 8.62				
	N x Salinity = 13.29				

Table 18. Effect of different levels of N and salinity on P concentrations (%) in wheat roots and shoots

N levels ($\mu g\ g^{-1}$ soil)	Salinity levels (dSm^{-1})				
	Control (1.2)	4	8	12	Mean
			Roots		
0	0.16	0.15	0.14	0.12	0.14
60	0.18	0.17	0.16	0.13	0.16
120	0.19	0.18	0.17	0.14	0.18
150	0.19	0.18	0.17	0.14	0.18
Mean	0.18	0.17	0.16	0.13	
LSD (P=0.05)	N levels = 0.006				
	Salinity levels= 0.008				
	N x Salinity = 0.010				
			Shoots		
0	0.22	0.21	0.18	0.16	0.19
60	0.25	0.23	0.20	0.18	0.21
120	0.27	0.24	0.22	0.19	0.23
150	0.28	0.25	0.23	0.19	0.24
Mean	0.25	0.23	0.20	0.18	
LSD (P=0.05)	N levels = 2.09				
	Salinity levels= 2.43				
	N x Salinity = 3.17				

increasing levels of salinity were probably due to competition between Cl and P in soil solution (Papadopoulos and Rending, 1983). In fact, divergent views do exist in the literature; Bernstein et al. (1974) suggested that high Ca concentrations in the saline soils would probably cause P precipitation and consequently reduction in P availability to the plants. On the other hand, Khalil et al. (1967) reported that the restriction in root by salinity may decrease the recovery of P by the roots. In the present study, one or more of these mechanisms could have been involved.

The application of N upto 120 ug g^{-1} soil significantly increased the P content in wheat shoots at all salinity levels (Table 18). These results are in agreement with those reported by Indulkar and More (1985). However, there was a significant decrease in P contents in wheat shoots with increasing salinity from 1.2 (control) to 12 dSm^{-1}. The decrease in P concentration at 12 dSm^{-1} salinity compared to control was 28 per cent. These results are in accordance with the observations made by Mahajan and Sonar (1980), who found that increasing soil salinity caused decreased P content in shoots.

There was significant decrease in mean P uptake by wheat roots with the increasing level of soil salinity (Table 19). Mean per cent decrease of P uptake was about 54 at highest salinity (12 dSm^{-1}) over control. However, there was significant increase in P uptake with the increase of applied N. The mean per cent increase in P uptake by wheat at N levels

Table 19. Effect of different levels of N and salinity on P uptake (mg pot^{-1}) in wheat roots and shoots

N levels ($ug\ g^{-1}$ soil)	Salinity levels (dSm^{-1})				
	Control (1.2)	4	8	12	Mean
			Roots		
0	5.82	5.07	4.55	3.26	4.67
60	10.22	9.45	8.02	5.72	8.35
120	14.51	11.39	8.48	6.44	10.20
150	15.40	12.31	6.84	5.62	10.04
Mean	11.49	9.55	6.97	5.26	
LSD (P=0.05)	N levels = 0.93				
	Salinity levels = 1.04				
	N x Salinity = 1.39				
			Shoots		
0	22.88	20.16	14.76	10.88	17.17
60	39.50	33.88	23.80	14.76	27.98
120	51.57	42.24	25.62	15.96	33.84
150	54.32	44.75	21.85	14.40	33.33
Mean	42.06	35.26	21.51	14.00	
LSD (P=0.05)	N levels = 2.09				
	Salinity levels= 2.43				
	N x Salinity = 3.17				

of 60 and 150 ug g^{-1} soil compared to no N treatment were 79 and 115, respectively.

Similarly, the data on P uptake by wheat shoots showed a significant increase in P uptake with the increasing N levels from 0 to 150 ug g^{-1} soil only at lower salinity levels (Table 19). However, in the treatments containing 150 ug N g^{-1} soil and salinity levels of 8 and 12 dSm^{-1}, the P uptake decreased slightly, which may be ascribed to poor plant growth. On the other hand, there was substantial decrease in P uptake with the increasing levels of salinity. The decrease in P uptake at the highest salinity level (12 dSm^{-1}) compared to control was 67 percent. Similar, results were also reported by Mahajan and Sonar (1980) and Rabic (1985).

3.2.3 **Potassium:** The concentration of K in wheat roots increased with the increase in N application rates (Table 20). On the other hand, with the increasing levels of salinity from 1.2 (control) to 8 dSm^{-1}, there was significant increase in K concentration. However, at highest salinity (12 dSm^{-1}), there was a slight reduction in K contents in wheat roots. These results are in line with those reported by Rush and Esptein (1976). While, the K concentration in wheat shoots increased significantly with N application from 0 to 60 ug g^{-1} soil and then, it decreased with the further increase in N levels at all salinity levels. Conversely, Indulkar and More (1985) reported that K concentrations in wheat shoots did not decrease with increasing N levels (0 to 90 ug N g^{-1} soil) at all the salinity

Table 20. Effect of different levels of N and salinity on K concentrations (%) in wheat roots and shoots

N levels ($\mu g\ g^{-1}$ soil)	Salinity levels (dSm^{-1}) Control (1.2)	4	8	12	Mean
	Roots				
0	1.68	1.94	1.80	1.73	1.79
60	2.15	2.27	2.20	2.08	2.18
120	2.07	2.19	2.05	1.93	2.06
150	2.01	2.09	2.03	1.90	2.00
Mean	1.98	2.12	2.02	1.91	
LSD (P=0.05)	N levels = 0.09				
	Salinity levels = 0.11				
	N x Salinity = 0.13				
	Shoots				
0	1.82	1.90	1.96	1.98	1.91
60	2.17	2.40	2.53	2.58	2.42
120	2.25	2.31	2.37	2.40	2.33
150	2.26	2.20	2.20	2.22	2.22
Mean	2.13	2.20	2.26	2.29	
LSD (P=0.05)	N levels = 0.08				
	Salinity levels = 0.09				
	N x Salinity = 0.12				

Table 21. Effect of different levels of N and salinity on K uptake (mg pot^{-1}) in wheat roots and shoots

N levels ($ug\ g^{-1}$ soil)	Salinity levels (dSm^{-1})				
	Control (1.2)	4	8	12	mean
			Roots		
0	61.15	65.57	58.50	47.05	58.06
60	122.12	126.21	96.80	91.52	109.16
120	158.14	138.62	108.65	88.78	123.55
150	154.97	135.43	77.14	71.25	109.69
Mean	124.10	116.46	85.27	74.65	
LSD (P=0.05)	N levels = 4.21				
	Salinity levels = 4.63				
	N x Salinity = 6.39				
			Shoots		
0	189.28	194.88	160.72	129.20	168.52
60	342.86	396.60	301.07	195.16	308.92
120	429.75	406.56	276.94	184.80	324.51
150	444.26	393.80	209.80	151.20	299.56
Mean	351.53	347.96	236.90	165.09	
LSD (P=0.05)	N levels = 12.14				
	Salinity levels = 13.48				
	N x Salinity = 21.26				

levels tested. Similarly, the concentration of K increased with increasing soil salinity. The higher K concentrations with increasing salinity were probably due to the stunted growth of wheat plants, therefore, plants under saline soil environment may accumulate more nutrients per unit of dry matter produced.

The results on K uptake by wheat roots (Table 21) indicated that there was significant increase in K uptake with the application of N from 0 to 120 ug g^{-1} soil. However, there was a decrease in K uptake with increased soil salinity. The lower K uptake with increased salinity may be due to decreased dry matter production. Similarly, there was significant increase in K uptake by wheat shoots with N application from 0 to 120 ug g^{-1} soil (Table 21). However, in treatments containing 120 ug N^{-1} soil and salinity levels of 8 and 12 dSm^{-1}, the K uptake decreased. There was a significant decrease in K uptake with the subsequent increase in salinity levels from 1.2 to 12 dSm^{-1}. These results are in good agreement with the observations made by Mahajan and Sonar (1980) and Rabic (1985), who also reported decreased K uptake with increased soil salinity.

Concentration and uptake of zinc

Application of N decreased the concentration of Zn both in roots and shoots of wheat (Table 22). However, the significant reduction was found in the treatments receiving N level at the rate of 120 ug g^{-1} soil at all salinity levels in both the roots and shoots. There was no significant difference in Zn

Table 22. Effect of different levels of N and salinity on Zn concentrations (ug g^{-1} dry weight) in wheat roots and shoots

N levels (ug g^{-1} soil)	Salinity levels (dSm^{-1}) Control (1.2)	4	8	12	Mean
	Roots				
0	27.95	23.92	17.81	10.19	19.96
60	27.40	22.78	16.77	9.85	19.20
120	23.62	21.40	13.93	7.87	16.70
150	23.10	20.47	12.82	7.41	15.95
Mean	25.52	22.14	15.33	8.83	
LSD (P=0.05)	N levels = 1.13				
	Salinity levels = 1.35				
	N x Salinity = 1.88				
	Shoots				
0	21.50	18.40	13.70	7.90	15.37
60	20.80	17.80	12.90	7.70	14.80
120	18.90	16.30	10.80	6.10	13.02
150	18.10	15.75	10.10	5.70	12.41
Mean	19.82	17.06	11.87	6.85	
LSD (P=0.05)	N levels = 1.19				
	Salinity levels = 1.36				
	N x Salinity = 1.82				

concentrations of roots and shoots at N level of 150 over 120 ug g^{-1} soil at all salinity levels. The reductions in Zn concentration at N levels of 150 ug g^{-1} over no N treatment were about 17, 14, 29 and 27 per cent in roots in 1.2 (control) 4, 8 and 12 dSm^{-1} salinity levels. The concentrations of Zn in roots were, generally, more than in shoots. Similarly, increasing salinity levels also decreased the concentrations of Zn in shoots as well as in roots. The reductions in Zn concentration at 8 and 12 dSm^{-1} salinity levels were more than at 4 dSm^{-1} salinity level over control (1.2 dSm^{-1}) at all N levels. The lowest Zn concentration was found in the treatments having N levels 150 ug g^{-1} soil and salintiy of 12 dSm^{-1} and highest in control treatment. The decrease in Zn concentrations both in root and shoot with increasing N application may have been due to dilution effect, as N application increased the dry matter yield, which might have resulted in the dilution of Zn per unit of the dry matter produced (Kumar _et al_., 1985). Dev and Shukla (1980) found antagonistic effect of N applications in maize (_Zea mays_ L.) at higher N application rates. Ozanne (1955) observed severe Zn deficiency in subterranean clover as the N application was increased. The N induced Zn deficiency and antagonistic effects of N application in different crops have also been reproted by Reuther and Smith (1950), Shukla and Morris (1967) and Kumar _et al_. (1985). The antagonistic effects of salinity on Zn concentration may be due to salt effects in saline soils, as Ca^{++}, Mg^{++} present in excess in saline soils may block the

Table 23. Effect of different levels of N and salinity on uptake (ug pot^{-1}) of Zn in wheat roots and shoots

N levels (ug g^{-1} soil)	Salinity levels (dSm^{-1}) Control (1.2)	4	8	12	Mean
	Roots				
0	102	81	58	28	67
60	156	127	90	43	104
120	180	135	74	36	106
150	178	133	49	28	97
Mean	154	119	68	34	
LSD (P=0.05)	N levels = 3.11				
	Salinity levels = 3.42				
	N x Salinity = 5.20				
	Shoots				
0	224	177	112	54	142
60	329	274	153	63	205
120	361	287	132	51	208
150	351	282	96	41	192
Mean	316	255	123	52	
LSD (P=0.05)	N levels = 4.22				
	Salinity levels = 4.38				
	N x Salinity = 6.17				

entry of Zn in plants. The antagonistic effects of Mg application on Zn concentrations of wheat shoots have also been reported by Kumar et al. (1981).

The uptake of Zn increased with increasing the N levels upto 120 ug g^{-1} in control and 4 dSm^{-1} soil salinity treatments both in roots and shoots (Table 23). However, at higher soil salinity the increase in Zn uptake was found only upto N levels of 60 ug g^{-1}. At higher N levels, the uptake decreased both in roots and shoots. In general, the mean uptake of Zn was more in shoots than in roots, which was probably due to higher dry matter yield of shoots than roots. These results are in line with those reported by Shukla and Morris (1967) and Kumar et al. (1985).

Concentration and uptake of copper

Application of N decreased the concentration of Cu both in roots and shoots of wheat (Table 24). The decrease in concentrations of Cu in roots at N levels of 150 ug g^{-1} soil were about 8, 24 and 30 per cent at 4, 8 and 12 dSm^{-1} salinity levels, respectively. The decrease in Cu concentrations at lower levels of N were relatively small as compare to at higher N levels. The increasing levels of soil salinity also decreased the Cu concentrations in roots and shoots. The Cu concentrations at 12 dSm^{-1} salinity level over control (1.2 dSm^{-1}) decreased by about 32, 34, 28 and 46 per cent in roots, whereas the decrease in case of shoots was 26, 30, 24 and 27 per cent at N levels 0, 60, 120 and 150 ug g^{-1} soil, respectively. The

Table 24. Effect of different levels of N and salinity on Cu concentrations (ug g^{-1}) in wheat roots and shoots

N levels (ug g^{-1} soil)	Salinity levels (dSm^{-1})				
	Control (1.2)	4	8	12	Mean
			Roots		
0	38.70	36.80	32.15	26.15	33.45
60	34.00	32.10	27.95	21.95	29.00
120	31.25	29.00	24.10	18.40	25.69
150	29.40	27.10	22.30	15.75	23.64
Mean	33.33	31.25	26.62	20.56	

LSD (P=0.05) N levels = 1.19

Salinity levels= 1.26

N x Salinity = 1.93

N levels (ug g^{-1} soil)	Control (1.2)	4	8	12	Mean
			Shoots		
0	10.45	10.10	9.10	7.70	9.34
60	10.00	9.45	8.30	7.00	8.69
120	8.90	7.25	7.00	6.75	7.47
150	8.10	6.80	6.40	5.90	6.80
Mean	9.36	8.40	7.70	6.84	

LSD (P=0.05) N levels = 0.36

Salinity levels = 0.51

N x Salinity = 0.72

Table 25. Effect of different levels of N and salinity on Cu uptake (ug pot^{-1}) in wheat roots and shoots

N levels (ug g^{-1} soil)	Salinity levels (dSm^{-1}) Control (1.2)	4	8	12	Mean
			Roots		
0	140.80	124.38	104.48	71.12	110.19
60	193.12	178.47	149.53	96.58	154.42
120	238.75	183.57	127.73	84.64	158.67
150	226.67	175.61	84.74	59.06	136.52
Mean	199.83	165.50	116.62	77.85	
LSD (P=0.05)	N levels = 3.18				
	Salinity levels = 3.29				
	N x Salinity = 5.03				
			Shoots		
0	108.68	96.96	74.62	52.36	83.15
60	158.00	145.53	98.77	57.40	114.92
120	169.90	127.60	85.40	56.70	109.90
150	157.14	121.72	60.80	42.48	95.53
Mean	148.43	122.85	79.90	52.23	
LSD (P=0.05)	N levels = 2.99				
	Salinity levels= 3.37				
	N x Salinity = 5.17				

lowest concentrations of Cu in roots and shoots were found in the treatments having N levels of 150 ug g^{-1} soil and salinity level of 12 dSm^{-1} and highest in the control treatment. Thus, these results indicate that both salinity and N have antagonistic effects on Cu concentrations in plants. Gilbert (1951) suggested that N application causes Cu deficiency by inhibiting transport of Cu from roots to shoots. Hooper and Davis (1968) observed N induced Cu deficiency in wheat. They found that heavy applications of N fertilizers caused Cu deficiency in wheat crop. Kumar et al. (1990) found that addition of N in wheat crop through different N carriers caused severe depression in Cu concentrations of plants and the antagonistic effects of N were more with NH_4^+ than NO_3^- containing fertilizers. The antagonistic effects of N application on concentrations of Cu in wheat and raya crops have also been reported by Chaudhary and Longeragan (1970) and Antil et al. (1988).

The uptake of Cu in roots increased with increasing the rates of N from 0 to 120 ug g^{-1} soil in control treatment and then decreased with further N application (Table 25). However, at 4, 8 and 12 dSm^{-1} salinity levels the increase in Cu uptake was upto N level of 60 ug g^{-1} and at higher N levels it decreased. As the levels of soil salinity increased the uptake of Cu decreased at all levels of N application both in roots and shoots. In general, the uptake of Cu in roots was more than in shoots in all the treatments, it was due to the fact that roots had about three times concentration of Cu than shoots. Several workers found more uptake of Cu at lower levels of N and decrease at higher N levels (Antil *et al*., 1988; Kumar *et al*., 1990). The probable reasosn for depression in Cu uptake with increasing salinity was due to the presence of excess salts in saline soil conditions which inhibit the entry of Cu in plants (Kumar *et al*., 1990).

Concentration and uptake of iron

The concentration of Fe decreased significantly both in roots and shoots with increasing rates of N in soils (Table 26) The depression in concentration of Fe at N levels of 150 ug g^{-1} soil was about 29, 27 and 26 per cent in roots and 25, 28, 26 and 26 per cent in shoots over no N treatments in control, 4, 8 and 12 dSm^{-1} salinity treatments, respectively. The concentration of Fe also decreased with increasing levels of salinity at all N levels. Thus, these results indicate that both N and soil salinity have an antagonistic effect on concentration of Fe in roots as well as in shoots of wheat. Farah and Hatata (1985) found no significant effect of N application on Fe concentration of corn. Soliman (1959) found N and Fe were synergistic to each other and concentration of Fe increased with increasing the N content of corn plants. Similarly under saline soil conditions the antagonistic effects of salinity on Fe concentrations may be due to unavailability of Fe due to the presence of excess Ca salts in saline conditions. Moreover, under saline soil conditions, the presence of other cations like Mg^{++}, Na^{+} along with Ca^{++} may compete on roots absorption

Table 26. Effect of different levels of N and salinity on Fe concentrations (ug g^{-1}) in wheat roots and shoots

N levels (ug g^{-1} soil)	Salinity levels (dSm^{-1})				
	Control (1.2)	4	8	12	Mean
			Roots		
0	874	772	665	528	710
60	752	655	575	441	606
120	718	578	503	405	551
150	621	560	493	391	516
Mean	741	641	559	441	
LSD (P=0.05)	N levels = 28				
	Salinity levels = 39				
	N x Salinity = 52				
			Shoots		
0	380	355	305	240	320
60	330	302	263	205	275
120	300	265	232	185	245
150	285	260	225	178	237
Mean	324	296	256	202	
LSD (P=0.05)	N levels = 5.16				
	Salinity levels = 5.77				
	N x Salinity = 8.63				

Table 27. Effect of different levels of N and salinity on *the uptake* (ug pot^{-1}) of Fe in wheat roots and shoots

N levels (ug g^{-1} soil)	Salinity levels (dSm^{-1})				
	Control (1.2)	4	8	12	Mean
			Roots		
0	3181	2612	2161	1436	2347
60	4274	3642	3076	1940	3233
120	5489	3659	2666	1863	3419
150	4790	3629	1873	1466	2939
Mean	4433	3385	2444	1676	
LSD (P=0.05)	N levels = 80				
	Salinity levels = 91				
	N x Salinity = 126				
			Shoots		
0	3952	3408	2501	1632	2873
60	5214	4650	3130	1681	3669
120	5730	4664	2830	1554	3694
150	5529	4654	2137	1282	3400
Mean	5106	4344	2650	1537	
LSD (P=0.05)	N levels = 83				
	Salinity levels = 96				
	N x Salinity = 139				

sites with K, thus restricting the entry of Fe in plants in saline soil conditions.

The Fe uptake in roots increased significantly upto N levels of 120 ug g^{-1} at 1.2 dSm^{-1} salinity level (control) and at 4, 8 and 12 dSm^{-1} salinity level the increase was only upto N levels of 60 ug g^{-1}, whereas in shoots, a similar increase in Fe uptake at 1.2 (control), 4 and 8 dSm^{-1} salinity levels was found like roots, but at 12 dSm^{-1} salinity level there was no significant difference in Fe uptake at N levels of 0, 60 and 120 ug g^{-1} soil and uptake decreased significantly at N levels of 150 ug g^{-1} soil. Increasing levels of salinity in soil decreased the uptake of Fe both in shoots and roots (Table 27). Thus, decrease was mainly due to the decrease in dry matter yields and concentration of Fe of shoots and roots. Devasenapaty and Subburayalu (1986) and Adinarayano and Tiwari (1989) found that application of N increased the uptake of Fe in different crops.

Concentration and uptake of Mn

The concentrations of Mn also decreased with increasing levels of N and salinity like Fe, Zn and Cu in plants (Table 28). However, the decrease in the concentration was more above 8 dSm^{-1} salinity level as compared to lower salinity levels. The concentrations of Mn were half or less than half at 12 dSm^{-1} salinity levels compared to 1.2 dSm^{-1}, salinity level (control) at all the levels of applied N both in roots and shoots. In roots the concentrations of Mn in all the treatments were

Table 28. Effect of different levels of N and salinity on Mn concentrations (ug g^{-1}) in wheat roots and shoots

N levels (ug g^{-1} soil)	Salinity levels (dSm^{-1}) Control (1.2)	4	8	12	Mean
			Roots		
0	50.35	47.37	37.02	24.57	39.83
60	44.08	39.83	30.91	20.14	33.74
120	39.83	35.53	26.59	16.18	29.53
150	37.61	32.87	25.05	14.86	27.60
Mean	42.96	38.90	29.89	19.09	
LSD (P=0.05)	N levels = 3.68				
	Salinity levels= 3.88				
	N x Salinity = 5.32				
			Shoots		
0	26.50	24.80	19.80	13.80	21.22
60	23.70	21.30	16.10	10.60	17.92
120	21.30	18.90	14.30	8.30	15.70
150	19.90	17.30	13.40	7.70	14.40
Mean	22.85	20.57	15.92	10.10	
LSD (P=0.05)	N levels = 1.63				
	Salinity levels = 1.77				
	N x Salinity = 2.19				

Table 29. Effect of different levels of N and salinity on the uptake (ug pot^{-1}) of Mn in wheat roots and shoots

N levels (ug g^{-1} soil)	Salinity levels (dSm^{-1}) Control (1.2)	4	8	12	Mean
Roots					
0	183	160	120	67	133
60	250	221	165	89	181
120	304	225	141	74	186
150	290	213	95	56	163
Mean	257	205	130	72	
LSD (P=0.05)	N levels = 7.1				
	Salinity levels = 8.0				
	N x Salinity = 12.6				
Shoots					
0	275	238	162	94	192
60	374	328	192	87	245
120	407	332	174	70	246
150	386	310	127	55	219
Mean	360	302	164	77	
LSD (P=0.05)	N levels = 9.2				
	Salinity levels = 9.9				
	N x Salinity = 15.6				

almost two times than shoots. The decrease in Mn concentrations due to N application may be due to dilution effect, as N applications increased dry matter yield, which resulted in the dilution of Mn per unit of dry matter produced. Similar antagonitic effects of N application on Mn concentrations in plants were observed by Chang and Doiron (1974) and Moraghan (1991).

The uptake of Mn decreased both in shoots and roots with increasing salinity levels (Table 29). However, the reduction was more at 8 and 12 dSm^{-1} soil salinity levels. Nitrogen application to some extent ameliorate the adverse effects of salinity as the increase in Mn uptake at 1.2 dSm^{-1} salinity levels (control) was upto N levels of 120 ug g^{-1} soil and at higher salinity levels it was only upto N levels of 60 ug g^{-1} soil both in roots and shoots. The highest uptake of Mn was found in the treatment containing N levels of 120 ug g^{-1} soil and 1.2 dSm^{-1} salinity (control) and lowest in the treatment receiving 150 ug N g^{-1} soil at salinity level of 12 dSm^{-1}. Many earlier workers found the beneficial effects of N application of Mn uptake by wheat plants (Rothstein et al., 1959).

Availability of nitrogen in soil after harvest of wheat crop

The amount of NH_4^+ and NO_3^--N in soil were determined after harvest of wheat (70 days). Nitrogen application significantly increased the contents of both NH_4^+ and NO_3^--N in soil at all salinity levels (Table 30). The NH_4^+ and NO_3^--N increased with increasing salinity levels from 1.2 (control) to 4.0 dSm^{-1} and

Table 30. Effect of different levels of N and salinity on the content of NH_4^+-N and NO_3^--N in the soil after harvest of wheat

N levels ($ug\ g^{-1}$ soil)	Salinity levels (dSm^{-1}) Control (1.2)	4	8	12	Mean
		NH_4^+-N ($ug\ g^{-1}$ soil)			
0	13.70	16.10	14.20	11.80	13.95
60	22.50	27.40	20.45	18.50	22.21
120	29.75	31.70	23.75	22.00	26.80
150	34.82	37.10	26.80	24.50	30.80
Mean	25.19	28.07	21.30	19.25	
LSD (P= 0.05)	N levels = 0.98				
	Salinity levels = 1.02				
	N x Salinity = 1.46				
		NO_3^--N ($ug\ g^{-1}$ soil)			
0	11.30	13.50	12.40	12.00	12.30
60	27.30	31.25	25.82	21.80	26.54
120	51.80	54.88	47.00	41.30	48.75
150	62.80	60.10	52.10	46.81	53.96
Mean	36.81	39.93	34.33	30.60	
LSD (P=0.05)	N levels = 2.62				
	Salinity levels = 2.69				
	N x Salinity = 3.28				

then decreased at 8 and 12 dSm^{-1} salinity levels. The increase in NH_4^+ and NO_3^--N due to N application was more at lower salinity levels than at higher salinity levels. The contents of NH_4^+-N increased from 13.70 to 34.82 ug g^{-1} soil at 1.2 dSm^{-1} salinity level (control), while at 12 dSm^{-1} salinity level this increase was from 11.80 to 24.50 ug g^{-1} soil with increasing levels of N from 0 to 150 ug g^{-1} soil, respectively. Similar trend was observed in NO_3^--N. The results indicate that inspite of less uptake of N at higher salinity levels the contents of mineral N in soil left at harvest were less at higher salinity levels than control (1.2 dSm^{-1}), this was ought to be mainly due to higher NH_3 volatilization losses with increasing salinity. As indicated in experiment 2 b, increasing salinity increased the losses of NH_3 from applied urea, therefore, less availability of N in soils of higher salinity was attributed mainly due to higher volatilization losses. Several workers found higher losses of NH_3 volatilization due to increase in soil salinity (McClung and Frankenberger, 1985; Singh and Bajwa, 1987).

CHAPTER - 5

SUMMARY AND CONCLUSIONS

The dynamics of applied N was studied in normal, saline and sodic soils. The study consists of two laboratory and a screen house experiment. In first laboratory expoeriment, kinetics of urea transformation in normal, saline and sodic soils were studied at constant temperature (25°C $\pm$ 1°C). In this experiment effects of water content (F.C. and flooding), salinity levels (1.2 to 16 dSm^{-1}), type of salinity (100% Cl, 100% SO_4; Cl^-; SO_4^{2-};50:50;25:75 and 75:25) and ESP levels (7.0 to 90) in different soils were studied on hydrolysis and nitrification of added urea. The rate of urea hyrolysis (K) and $t_{½}$ values were also calculated for urea hydrolysis. To study the effects of above factors on nitrification of urea soil sampling was done at 0, 7, 14, 21 and 28 days and NH_4^+, NO_2^- and NO_3^--N were determined. In the second experiment the effects of different salinity (1.2 to 16 dSm^{-1}) and ESP levels (7.0 to 90) on ammonia volatilization losses in Hisar and Kaul soils were studied upto 21 days. In the third experiment effects of different N (0 to 150 ug g^{-1} soil) and salinity levels (1.2 to

16 dSm^{-1}) were studied on dry matter yield, concentration and uptake of N, P, K, Zn, Cu, Mn and Fe in wheat at 70 days.

The salient findings of above investigation are presented below:

A. Urea hydrolysis

1. The rate of hydrolysis of added urea in different soils was found in the following order: Morni soil > Kaul soil > Hisar soil > Balsamand soil at both the moisture levels (F.C. and flooding). After 24 h at F.C.; 75, 93, 100 and 65 per cent and at flooding 55, 75, 90 and 50 per cent of the added urea was hydrolyzed in Hisar, Kaul, Morni and Balsamand soils, respectively. The hydrolysis of urea was significantly more at F.C. than at flooding in all the soils studied.

2. Increasing levels of salinity from control to 16 dSm^{-1} found to decrease simultaneously the rate of urea hydrolysis in both the Kaul and the Hisar soils. The reduction in the rate of urea hydrolysis at 16 dSm^{-1} salinity level over control was about 9 and 11 per cent at 24 h in Hisar and Kaul soils, respectively. The K values of first order rate constant (K) decreased from 0.0406 to 0.0291 h^{-1} in Hisar soil and from 0.0591 to 0.0460 h^{-1} in Kaul soil with increasing soil salinity upto 16 dSm^{-1}.

3. At similar salt concentrations chlorides were found to have more harmful effects than sulpohates on the hydrolysis of added urea in soils. The rate of urea hydrolysis was 5 to 10% more in 100% SO_4^{-2} dominated salinity as compare to 100% Cl^- dominated salinity.

4. Increasing levels of ESP (7 to 90) found to decrease the hydrolysis of urea in both the Hisar and Kaul soils. The K values for Hisar soil decreased from 0.0406 to 0.0276 h^{-1} and for Kaul soil from 0.0591 to 0.0442 h^{-1} with increasing ESP from 7 to 90.

B. Nitrification of urea

1. Following addition of urea in soil, the contents of NH_4^+-N increased as the incubation period advanced. At 28 d; 16, 11, 9 and 32 per cent of added N as urea at F.C. was found as NH_4^+-N in Hisar, Kaul, Morni and Balsamand soils, respectively. The contents of NO_2^--N increased upto 14 d and then decreased at both the moisture levels.

2. Increasing levels of soil salinity from control to 16 dSm^{-1} decreased the rate of nitrification in both the Hisar and Kaul soils. The contents of NO_3^--N at 28 d in Kaul soil were 79, 75, 69, 64 and 58 ug g^{-1} soil at 1.5, 4, 8, 12 and 16 dSm^{-1} salinity levels, respectively indicating that increasing salinity depresses the rate of nitrification in soils. The recovery of applied N at 28 d in Kaul soil was about 90 per cent in control treatment and about 77 per cent in 16 dSm^{-1} salinity treatment.

3. Nitrtification was fast in 100% SO_4^{-2} dominated salinity and relatively slow in 100% Cl^- dominated salinity; as amounts of Cl^- in soil decreased the rate of nitrification increased.

4. Increasing ESP of soil decreased the rate of nitrification in soil. There was accumulation of NO_2^--N in soil as ESP increased. At 28 d of incubation the recovery of added N was about 90 per cent in control treatments and was less than 50 per cent in 90 ESP treatment indicating that about 50 per cent of added N was lost as NH_3 due to volatilization.

C. Ammonia volatilization losses

1. The NH_3 volatilization losses increased with increasing the ESP of both the Kaul and Hisar soils. About 90 per cent of the total volatilization losses occurred during first week of N application. The cumulative NH_3 volatilizationk losses in control, 30, 60 and 90 ESP were about 35, 39, 46 and 56 per cent in Hisar soil and about 28, 33, 39 and 45 per cent in Kaul soils, respectively.

2. Similarly, increasing salinity also found to increase the volatilization losses in both the soils. The cumulative volatilization losses increased from 35 to 44 per cent in Hisar soil and 28 to 35 per cent in Kaul soil with increasing soil salinity over control to 16 dSm^{-1}.

D. Dry matter yield, concentration and uptake of nutrients in wheat

1. Application of N upto 120 ug g^{-1} soil increased the dry matter yield of wheat at all salinity levels, whereas increasing salinity decreased the yield of both shoots and roots.

2. The concentrations of N and K increased *significantly* with increasing N as well as salinity levels. Whereas P concentration in wheat roots and shoots increased significantly with N application, however, there was significant decrease in P concentration with the increase in soil salinity from 1.2 to 12 dSm^{-1}. In general, there was a synergistic effects of N on concentrations of P and K in plants. Quantitatively N, P, K uptake was three-fold greater in shoots than roots.

3. The effect of N and salinity on concentration of Zn, Cu, Mn and Fe was found antagonistic. Generally, the concentrations of these metals was more in roots than shoots indicating their poor mobility in plants.

The findings of these investigations revealed that increasing salinity and alkalinity (ESP) in soil decreased the rate of urea hydrolysis and nitrification whereas NH_3 volatilization losses increased in soils. Most of the NH_3 volatilization losses occurred during first week following N fertilizer application. Therefore, necessary technology should immediately be evolved to reduce these losses otherwise a major part of the applied N fertilizer may be lost through volatilization.

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*Original not seen.

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The NH_3 volatilization losses increased with increasing the salinity and ESP levels in soils. The losses started on first day following urea application in soils and the peak values of volatilization losses of N occurred between day 2 and 5 which after 7 days, declined drastically. Thus, more than 90% of the total volatilization losses occurred during the very first week of the fertilizer urea N application. The cumulative losses of NH_3 over 21 days of incubation were about 35, 39, 46 and 56 per cent in Hisar soil and 28, 33, 39 and 45 per cent in Kaul soil in control, 30, 60 and 90 ESP treatments, respectively.

Application of N upto 120 ug g^{-1} soil increased the dry matter yield of wheat and the yield decreased significantly at higher soil salinity levels (8 and 12 dSm^{-1}). The concentrations and uptake of N, P and K increassed with increasing N levels upto 120 ug g^{-1} soil. The effects of N on concentrations of Zn, Cu, Fe and Mn was found antagonistic, generally concentrations of othese nutrients were more in roots than shoots indicating their poor mobility from roots to shoots.