NITROGEN NUTRITION MANAGEMENT AND FERTILIZER USE EFFICIENCY IN WHEAT UNDER DIFFERENT SOIL CONDITIONS

A THESIS

SUBMITTED IN PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR THE DEGREE OF DOCTOR OF PHILOSOPHY

IN

BIOLOGICAL SCIENCES

MUHAMMAD ARSHAD

DEPARTMENT OF BIOLOGICAL SCIENCES
QUAID-I-AZAM UNIVERSITY,
ISLAMABAD

1999

This thesis is accepted in its present form by the Department of Biological Sciences as satisfying the thesis requirements for the degree of Doctor of Philosophy in Biological Sciences.

Supervisor: Tahira Ahmad 22.11.1999.

Co-Supervisor: 31.7.2000

External Examiner: 31/7 DR AHMAD SAEED BHATTI

External Examiner: Dr. Zabta K. Shinwari NARC - Islamabad.

Chairman :

Date: 31.7.2000

LIST OF TABLES

LIST OF FIGURES

ACKNOWLEDGEMENTS

In the name of Allah, the most beneficent and most merciful.

I would like to express my appreciation and gratitude to my supervisor, Dr. Tahira Ahmed, Associate Professor, Quaid-i-Azam University, Islamabad, Co-Supervisor, Dr. M. Shareef Zia, Chief Scientific Officer, National Agricultural Research Centre, Islamabad for their scholarly guidance and sympathetic attitude. They also shared their knowledge and experiences with such a patience and read this thesis with critique and criticism.

I would like to thanks former Chairmen, Dr. M. A. Hafeez, Dr. Riaz A. Pal and present Chairman, Dr. Mahmud Ahmed, Department of Biological Sciences, Quaid-i-Azam University, Islamabad for providing the opportunity to study in the department.

I feel obliged to Dr. M. Azam Khan, Vice Chancellor, University of Arid Agriculture, Rawalpindi for according me permission to complete this work.

I would like to express my sincere thanks to Imran-ul-Haq, M. Aslam, Amer Sohail Cheema, Dr. Mazhar Qayyum, especially to Audil Rasheed for their friendship, encouragement and co-operation all the time.

The help of Sajjad Rasheed is also acknowledged with thanks for the laborious typing work.

This acknowledgment will look incomplete without paying special thanks to my father in-law Mr. M. Rafique and family who never forgot me in their prayers.

My deepest thanks and love are for my children and especially for my wife who has always been a source of help, encouragement and never complained about not giving her enough time.

Lastly I am greatly indebted to my parents who put me on the track but could not survive to see this work get through.

(Muhammad Arshad)

ABSTRACT

Nitrogen fertilizers are the major input being used for crop production especially for wheat in Pakistan. However, wheat yields are low, almost stagnant and nitrogen use efficiency is poor. Efforts are underway to improve wheat production and enhance nitrogen use efficiency. In this connection, different studies were carried out. In one study in which the effect of mixed NH_4^+- N and NO_3^- -N nutrition was investigated, it was found that wheat yield (var. Inqlab 91) and nitrogen utilization efficiency significantly improved when mixed NH_4^+-N and NO_3^- -N in 50:50 ratio was used as compared to when these sources were used alone. It was further observed that balanced nitrogen nutrition was helpful to overcome the adverse effect of drought and salt stress. In another study on the effect of nitrogen carrier and dicyandiamide (DCD), it was found that nitrogen sources significantly affected the wheat yield and nitrogen use efficiency. Calcium ammonium nitrate (CAN) was found to be the most efficient nitrogen source followed by ammonium sulphate and urea. Use of DCD with CAN improved wheat (var. Rohtas 90) yield by 29 per cent and plant nitrogen recovery by 34 per cent. This is because DCD inhibited nitrification process and maintained an ideal NH_4^+- N : NO_3^- -N ratio in the soil where CAN was used. However, DCD was not helpful to improve efficiency of urea and ammonium sulphate, because of inhibition of nitrification process with the result ammoniacal nitrogen dominated in the soil when these fertilizers were used. Dominant presence of this nitrogen form disturbed the ideal balance of NH_4^+- N : NO_3^- -N ratio of 50:50. Therefore, no improvement in wheat yield and nitrogen use efficiency was registered. As regard the effect of gypsum and nitrogen sources on wheat yield and nitrogen utilization it was observed that the use of gypsum improved wheat yield from 30 per cent to 46 per cent and plant nitrogen recovery from 25 per cent to 39 per cent. Improved nitrogen use efficiency was attributed to reduction in soil pH and ammonia volatilization losses. In another study potassium helped to improve efficiency

CHAPTER 1

INTRODUCTION

Wheat occupies a pivotal position in the Agricultural Economy of Pakistan. It is the most important staple food of our country and accounts for 75% of total food grain production and covers the largest area (8.4 m ha) under any crop in Pakistan (MINFAL 1998). However, its production remains low and is only 18.7 million tons. The average yield of the crop is much below the world average. Pakistan occupies 45th highest average yield position for wheat in the world league table of crop yields.

Low wheat yields in Pakistan seems to be linked with low fertilizer use, the fertilizer use in United Kingdom, China, Japan and Egypt, is 300, 320, 365 and 400 kg NPK ha^{-1}, (IFA 1992), respectively and their wheat yields are 6.6, 5.0, 3.6 and 3.0 t ha^{-1}, respectively. On the contrary, fertilizer use in Pakistan is only 115 kg ha^{-1} and the yield of wheat is less than 2.5 t ha^{-1}. It has been reported that the yield of wheat crop in Indian Punjab was 4.2t ha^{-1} where the fertilizer use was 168 kg ha^{-1} (Khan 1993). Thus increase in fertilizer use can play a dominant role in boosting wheat yields in Pakistan.

Total fertilizer use (NPK) in Pakistan is 2148 thousand nutrient tons. Out of this, major quantity (over 46%) is used for wheat production and phosphorus and potassium constitutes 19.6 and 0.8%, respectively of the total fertilizer consumption. (NFDC 1998). This imbalanced use of fertilizers could also be one of the reasons for low crop yields in Pakistan.

Nitrogenous fertilizers are used as major inputs for wheat production in the country. Over the course of last decade, nitrogen use on wheat has risen steadily but this has not demonstrated proportionate increase in the wheat yield, which indicates that the use of nitrogen for wheat production is not efficient. For upland crop like wheat, an average of 50-60 percent of applied N is utilized (Baligar and Bennet 1986, Craswell 1987, Scharf and Alley 1988, Smith *et al.* 1989, Smith and Whitefield 1990). The fate of the rest of the nitrogen is by no means clear (Roy and Chandra 1979). A small percentage is taken up by the succeeding crop and much of it is lost due to volatilization as ammonia, denitrification, leaching and run off.

Poor recovery of N by crop suggests that there is a considerable scope for reducing nitrogen losses and improving fertilizer use efficiency. Improving fertilizer use efficiency by 20% for wheat will have an impact of Rs. 2.85 billion at the national level. Nitrogen losses can be reduced and use efficiency improve through proper management of fertilizers and crop management practices. Judicious management of fertilizers relates to choice of proper fertilizer source, its optimum rate, proper method and time of application (Campbell *et al.* 1977, Pearman *et al.* 1977, Ellen and Spiertz 1980). Addition of ammoniacal and nitrate sources do affect the crop yields and the N use efficiency. Yield's of several crops have been increased by 40 to 70% by adding NH_4^+ to NO_3^- supplied in hydroponic cultures (Cox and Reisenauer 1973 Blacquierer *et al.* 1988. Herberer and Below 1989, Stephen and Streeter 1994). In contrast, enhanced NH_4^+ supplying in green house soil culture has increased crop yield on an average of only 11% (Malhi *et al.* 1990). In Wisconsin 11% yield of hybrid maize was recorded when all applied N was in ammoniacal form (Urea). Ammonium nitrate (50% NH_4^+& 50% NO_3^-) and KNO_3 (100%NO_3^-) followed the order (Huffman 1989). Studies have revealed that under normal conditions higher crop yield may be obtained with a mixture of ammonium and nitrate than either source alone (Bock 1986, Hageman 1984, Olsen 1986). Mixed ammonium and nitrate nutrition has an energy saving effect or minimizes pH changes and or optimizes ATP synthesis (Cox and Reisenauer 1973). In hydroponic studies beneficial effects of mixed nitrogen nutrition (NH_4^+ and NO_3^-) have been reported on the yield of wheat (Sandoval- villa *et al.* 1995, Ali *et al.* 1995) and barley (Ali 1993). However, such information regarding the effect of mixed ammonium and nitrate nutrition on nitrogen utilization by wheat is lacking especially under Pakistani soil conditions.

Nitrification inhibitors are also helpful in increasing nitrogen use efficiency, because of their potential to reduce N leaching losses by inhibiting the conversion of relatively immobile ammonium (NH_4^+- N; mineralized from organic N) to mobile NO_3^- -N. In orders to reduce denitrification losses nitrification of the ammonium containing fertilizers is retarded by the use of nitrification inhibitors (Meisenger *et al.* 1980, Slanger and Kerkhoff 1984, Hauck 1985, McCarty and Bremener 1986). However, the effects on crop yield and nitrogen uptake have been inconsistent varying from positive to little or no effects (Chancy and Kamprath 1982, Mikkelsen *et al.* 1986, Walter and Malzer 1990, Malhi and Nyborg 1992, Schroder *et al.* 1993 and Francis *et al.* 1995). But from calcareous alkaline conditions like Pakistan little information is available regarding their effect on retarding nitrification and improving yield of arable crops.

The stress conditions have marked influence on plant metabolism, especially N metabolism. It is generally observed that, there is tendency of amino acids and amides to accumulate in salt and water stressed plants due to inhibited protein synthesis (Frota and Tucker 1978, Helal and Mengal 1979). The activity of nitrate reductase enzyme which plays a key role in nitrogen metabolism is inhibited under salt and water stress (Huffaker *et al.* 1970). In Pakistan 6.2 million hectare of land are affected by salinity and sodicity (MINFAL 1998). On salt affected soil a substantial reduction in cereal crops yield has been reported. (Naeem *et al.* 1998). Ahmed *et al.* (1997) reported marked reduction in straw and grain yield of wheat at ECe 15 dS m^{-1}. A 50 percent reduction in wheat yield occurred at Ec 8.5 dS m^{-1} (Hummadi 1977). The extent of salinity inhibition of growth however, may be affected by the nutritional status of plant (Bernstein *et al.* 1974). Increasing NH_4^+ proportion in the total of 6 mM nitrogen in the nutrient solution increased wheat shoot dry weight, did not change nitrogen concentration in the dry mass but increased phosphorus percentage either with or without 60 mM NaCl (Silberbush and Lips 1991). Shaviv *et al.* (1990) reported larger wheat dry matter and protein yield with ammonium and nitrate than nitrate alone on sandy or clay soils. The relative increase in yield and nitrogen, phosphorus accumulation due to mixed nitrogen nutrition was significantly higher in salinized soil. Under salt stress conditions higher yield of barley grown in nutrient solution with mixed N-nutrition was produced as compared to ammonium and nitrate alone, (Ali 1993) indicating that mixed N-nutrition helps to alleviate the harmful effect of salinity. Also the utilization of water by plant fed by NH_4^+ was adversely affected and thus may adversely affect the uptake of other nutrients. Under water stress conditions, protein synthesis in wheat is retarded (Todd and Yoo 1964, Hsiao 1973, Frota and Tucker 1978). On the other hand Prihar *et al.* (1989) reported that response of wheat to both soil nitrate and freshly applied nitrogen was increased with increasing water supply. Conversely, Mitrosuhardjo (1983) has reported reduced nitrogen utilization by wheat under moisture stress. But the addition of nitrogen to wheat even under moisture stress conditions significantly increased the grain yield (Korentajer and Berliner 1988). Variability in soil moisture will have a dramatic influence on yield response to fertilizer and fertilizer efficiency which can be maximized only through increasing stored soil moisture (Havlin 1986).

An application of gypsum to soil plays important role in improving the N fertilizer use efficiency. Due to prevailing soil (Calcareous alkaline) and climatic conditions (severe hot during summer) in Pakistan, N losses due to ammonia volatilization are predominant and there is a close relationship between the extent of N volatilized and the soil pH (Whitehead and Raistrick 1990, Bayrakli 1990). Ammonia volatilization losses ranging from 22 to 53 percent has been reported from Pakistani soils (Hussain and Naqvi 1998).

Ammonia volatilization loss as high as 32 percent have been reported from calcareous soils in Northern China (Zhang *et al.* 1992).

Urea is the major nitrogen fertilizer used for crop production in our country and it is susceptible to hydrolysis followed by NH_3 volatilization due to conversion to ammonium carbonate, which may temporarily raise soil pH to above 9.0 in both acid and calcareous soils (Fenn and Hossner 1985). This releases NH_3 at high soil pH. Similarly other nitrogen fertilizers when added to calcareous alkaline soils may liberate NH_3 depending upon the degree of calcareousness and alkalinity of the soil. Addition of soluble calcium salts to nitrogen fertilizers can reduced ammonia volatilization to as much as 90 percent (Fenn *et al.* 1981a). Gypsum is inexpensive in Pakistan, it may lower the soil pH and ultimately may reduce ammonia volatilization losses.

Potassium appears to play a critical role in ammonium utilization (Dibb and Welch 1976). Although it is not a structural component of plant, it is involved in numerous biochemical and physiological process. It is important in the regulation of photosynthetic supply to developing ear. Major involvement of K in N metabolism of plant has been widely discussed (Touraim and Grignon 1982, Mengal and Kirkby 1987).

Potassium and nitrogen play critical role in the process of meristematic growth a pre-requisite of crop production. For optimum growth, nitrogen and potassium should be present in sufficient and balanced quantities. It was further shown that other processes such as utilization of nitrogen for grain production are influenced by potassium (Mengal 1989). Generally the better the crop supplied with nitrogen the greater is the yield increase due to potassium (Gartner 1969, Heathcote 1972). On the other hand applied nitrogen only is fully utilized when potassium supplied is adequate (Mengal and Kirkby 1987). International Fertilizer Development Center (IFDC 1984) summarized some of the results showing substantially improved response to nitrogen when potassium was applied in addition. Higher potassium uptake promoted the translocation of nitrogen compounds from roots and straw towards the grain (Koch and Mengal 1977). Stromberger *et al.* (1994) reported that high level of potassium promoted vigorous growth when mixed –N treatments were averaged across all rates. High potassium in conjunction with mixed nitrogen generally enhanced dry matter accumulation and kernel primordial number in corn hybrid. Soil addition of potassium increased the utilization of fertilizers particularly when the ratio of ammonium to nitrate was increased (Shaviv and Hagin 1988). However, high potassium with either ammonium or nitrate generally had a negative effect on dry matter accumulation (Stromberger *et al.* 1994). In order to reduce the cost of crop production and lower the chances of environmental pollution due to nitrogen losses, it is imperative to improve nitrogen use efficiency. Present study is, therefore, an endeavor to investigate the effect of potassium fertilizer application on the efficiency of nitrogen sources for rainfed wheat.

Information on nitrogen nutrition and use efficiency under upland wheat conditions of Pakistan is quite meagre, therefore, present investigations were envisaged with the following objectives in view:

1. Investigate the effect of mixed nitrogen (NH_4^+ & NO_3^-) nutrition of wheat on crop yield and nitrogen recovery under salt and water stress.
2. Determine the comparative efficiency of nitrogen sources with and without nitrification inhibitor on wheat yield and nitrogen utilization.
3. Study the effect of gypsum application on NH_3 volatilization losses and nitrogen utilization by wheat.
4. Study the role of potassium fertilizer on the comparative efficiency of nitrogenous fertilizer for wheat production.

CHAPTER 2

REVIEW OF LITERATURE

Nitrogen is the mineral element, which is required in the greatest amounts by plants (Bloom 1988) and is considered to be a major limiting factor to plant growth. Dry plant material contains about 2 to 4% nitrogen (Mengal and Kirkby 1987). Nitrogen is used by the plants for amino acids, and purines and pyrimidine bases, the nitrogenous building block of protein and nucleic acid, respectively. The increased demand of nitrogen fertilizer for crop production, cost of natural gas, the instability of nitrogen in the soil through volatilization, denitrification and leaching are such factors which contribute to the increasing cost of nitrogen fertilization. Nitrogen is the nutrient most likely to be in short supply for plant growth. It is therefore, imperative to adopt ways and means that are effective in increasing the yield per unit of fertilizers applied and also to reduce the losses of nitrogen from the root zone. There have not been organized research studies on nitrogen nutrition and use efficiency of wheat in Pakistan and the information is still scanty. However, the research work carried out on the topic is reviewed as under.

2.1 Behaviour of Nitrogen fertilizers in soil

The poor efficiency with which crops utilize the nitrogen fertilizer has been emphasized by Allison (1955, 1966) who suggested that the average recovery of fertilizer nitrogen in the above ground parts of the crop is about 50%. Elsewhere in numerous research studies (Scharf and Alley 1988, Smith *et al.* 1989, Smith and Whitefield 1990, Rashid and Saleem 1992) the recovery of added fertilizer nitrogen seldom exceeded 50% for upland crops. Poor nitrogen use efficiency for crop production is due to numerous nitrogen transformation mechanisms to which this nutrient element is subjected.

2.2 NITROGEN TRANSFORMATION IN THE SOIL

The low recovery of applied nitrogen by crops raises the question of the fate of the fertilizer nitrogen that is not absorbed by the crops. This nitrogen may be lost from the soil-plant system through ammonia volatilization, denitrification and leaching.

2.2.1 Ammonia volatilization

Most of the agriculturally important soils of Pakistan are alkaline calcareous in nature and low in organic matter. Application of nitrogen fertilizer in these soils is necessary for realizing good crop yields. Consequently use of N fertilizer in Pakistan has increased substantially during last two decades (NFDC 1996) but it is still lower than developed countries of the world.

Efficiency of various fertilizers containing N in ammonium form or producing ammonium in the soil upon application is discouragingly low under our soil conditions. High soil pH and hot climatic conditions in our country are conducive for N losses through ammonia volatilization. Ammonia volatilization losses ranging from 22 to 53 percent have been reported from calcareous soils of Pakistan (Hussain and Naqvi 1998) and 32 percent from calcareous soils in Northern China by Zhang *et al.* (1992).

Many greenhouse and laboratory studies have shown that ammonia volatilization is influenced by different factors which are discussed as under.

Purakayastha *et al.* (1997) studied the effects of different additives like coaltar (CT) neem cake (NC), mustard cake (MC) and organic nutrient source like green manure (GM) and farmyard manure (FYM) on urea hydrolysis, NH_4^+ - N content, ammonia volatilization loss and soil pH in three different types of soils i.e. alfisol, vertisol and inceptisol. Coating of urea with MC retarded urea hydrolysis and consequently reduced ammonia volatilization loss, whereas coating of NC accelerated the ammonia loss from urea. Application of GM with urea effectively reduced pH of soil and retarded ammonia loss from urea in vertisol and inceptisol but not in alfisol. Maximum ammonia volatilization loss occurred between two to four days after fertilizer application in vertisol and alfisol and between four to six days in case of inceptisol.

Hussain and Naqvi (1998) reported that the ammonia losses were more from the urea than from the ammonium sulphate in the incubation studies conducted in salt affected soils.

Factors affecting ammonia volatilization

Many studies have shown that ammonia volatilization is influenced by soil factors such as nitrogen fertilizer sources, application method, soil cation exchange capacity, temperature, soil salinity and sodicity, soil pH, soil moisture, soil organic matter and nitrogen application rates. Research conducted in this regard is reviewed as under.

- ***Nitrogen Fertilizer Sources***

Volatilization losses of ammonia from ammonium containing fertilizers applied to surface of a calcareous soil were investigated by Fenn and Kissel (1973). They reported that loss of ammonia was greatest from NH_4F, intermediate with $(NH_4)_2SO_4$ and $(NH_4)_2HPO_4$ and lowest with NH_4NO_3, NH_4Cl and NH_4I.

Sommer and Jensen (1994) made comparison of ammonia volatilization from different nitrogenous fertilizers. The study revealed that cumulated daily loss of ammonia from urea followed a sigmodial expression, while the cumulated ammonia loss from diammonium phosphate showed a logarithmic relationship with time after application. However, from ammonium sulphate and calcium ammonium nitrate no significant losses of ammonia were observed.

Ammonia losses from various N sources have been measured under field conditions by Hargrove *et al.* (1977), Hargrove and Kissel (1979), Keller and Mengal (1986) and Urban *et al.* (1987). These studies indicated that potential of ammonia losses was greatest with urea, intermediate with urea ammonium nitrate (UAN) solution and least with ammonium salts on non calcareous soils but greatest with ammonium sulphate and much less with urea and ammonium nitrate on calcareous soils. According to Fenn and Kissel (1973) with calcareous soils, the solubility of the calcium salts found largely determined this magnitude of ammonia loss from N fertilizer, with greater ammonia losses from N sources forming the least soluble calcium reaction products.

Hargrove *et al.* (1977) reported that in field conditions ammonia losses ranged from 3 to 10% of the applied N from ammonium nitrate and from 36 to 45% for pelleted ammonium sulphate applied to the surface of calcareous soils.

Ammonia volatilization from urea, diammonium phosphate, ammonium sulphate and calcium ammonium nitrate was determined by Sommer and Jensen (1994) for surface application to winter wheat and grassland. The fertilizers were applied at the rate of 8-12 g N m^{-2} to plots on a non-calcareous sandy loam. Mean cumulated ammonia loss from plots receiving urea, diammonium phosphate, ammonium sulphate and calcium ammonium nitrate were 25%, 14%, 5%, and < 2% respectively during 15-20 days measuring period.

Gezgin and Bayrakli (1995) studied ammonia volatilization losses from surface applied ammonium sulphate, ammonium nitrate and urea to winter wheat and observed that losses from ammonium sulphate, ammonium nitrate and urea varied from 13.6 – 19.5%, 4.4 – 6.4% and 3.9 – 12% depending on the compounds and their levels added as N fertilizers.

Christianson *et al.* (1995) reported 50% N loss applied in the form of ammonia volatilization and when urea was mixed with KCl 30–50% reduction in loss was observed. KCl was more effective when the urea was applied as solution (51% reduction) rather than granular form (32% reduction).

- ***Application Method***

Methods of application of nitrogen fertilizer also affect the ammonia volatilization. Ernst and Massey (1960) inferred that ammonia losses from broadcast urea are markedly reduced if the fertilizer is mixed with the surface 4cm of the soil. According to Overrein and Moe (1967) banding rather than surface broadcasting of ammonium or amide fertilizers reduces volatilization losses considerably. Although urea bands need to be deeper in sandy soils than in clay soils (Fenn and Kissel 1976, Meyer *et al.* 1961) recommended that urea be moved into the soil by water or mechanically incorporated. Otherwise, it may produce excessive volatilization losses of ammonia after biological hydrolysis to $(NH_4)_2CO_3.H_2O$.

Fenn and Miyamoto (1981) elucidated that ammonia losses from surface applied urea decreased with increasing amounts of applied water. They also pointed that surface placement of urea, ammonium sulphate and ammonium carbonate to moist soil resulted in maximum ammonia losses of 66, 63 and 74% of N applied respectively. Placement at 2.5cm depth resulted in 41% loss from urea and 52% from ammonium sulphate, ammonium carbonate and anhydrous ammonia (P=0.01). Placement of urea, ammonium carbonate and anhydrous ammonia at 5cm resulted in 0, 0 and 13% ammonia loss respectively compared to 35% NH_3-N from ammonium sulphate (P=0.01). Ammonia losses from ammonium sulphate placed at 7.5cm resulted in 27% losses and again none from urea ammonium sulphate or anhydrous ammonia.

- ***Cation Exchange Capacity (CEC)***

Various investigators noted that CEC of soil influences the degree of ammonia volatilization. Work by Fenn and Kissel (1973) with ammonium sulphate showed that ammonia loss from Houston black clay reached 50% at a CEC of 58 meq /100 g soil. However, the same type of research on sand resulted in ammonia losses reaching 90% of applied N. Significant reduction in ammonia loss due to CEC obviously occurs but potential losses are still substantial even in high CEC soils.

The addition of calcium with urea to reduce ammonia loss was found to be most effective in soils of low CEC (Fenn *et al.* 1982). With a pure sand which lacks CEC, there was no sink to reduce the effective calcium concentration. Therefore, the principal reactions occurred only between the decomposing urea and the calcium in solution. The same urea-calcium concentration added to a soil with moderate CEC resulted in less control of ammonia loss.

- ***Temperature***

Chemical reactions are influenced by temperature. Inorganic reaction rates are said to be doubled with every 10°C increase in temperature (Fenn and Kissel 1974). Organic reaction rates increase linearly in response to temperature increase (Gould *et al.* 1973).

The effect of temperature on ammonia losses was most pronounced with NH_4NO_3 and least with ammonium sulphate (Fenn and Kissel 1974).

Ammonia losses from urea closely approximate those from ammonium sulphate at a temperature range from 12 – 32°C (Fenn and Miyamoto, 1981). However, the trend for lower initial ammonia losses from urea but higher long-term ammonia loss at the lower temperatures was not emphasized in the same article. The rate of soil surface drying is slower at the lower temperature, although greater time for microbial activity and urea hydrolysis before the surface dries. Total ammonia losses from urea at the two temperatures tend to approximate each other after increasing period of time (Fenn and Kissel 1973).

Gould *et al.* (1973) stated that the Arrhenius plot of urease activity increased linearly with increase in temperature from 2 to 45°C. They also reported that the accepted optimal temperature for urease activity was 37°C but they found a linear increase in activity upto 45°C.

- ***Soil Salinity/Sodicity***

There is unanimous agreement among various researchers such as Gandhi and Paliwal (1976), McClung and Frankenberger (1985), that the increase in soil salinity increases the ammonia losses. According to them increase in soil salinity progressively decreases nitrification thereby more

NH_4-N remains in the soil, which is subjected to ammonia volatilization. In some other studies higher losses have been reported in soils saturated with sodium (Martin and Chapman 1951 & Sharma *et al.* 1992).

Hussain and Naqvi (1998) conducted soil incubation experiment to assess the extent of ammonia loss from salt affected soils. The results revealed that the mean cumulative ammonia losses from the fertilizer applied to salt affected soils were about 15 times more as compared to those when applied to normal soil. Maximum ammonia losses occurred from sodic soil with highest pH and sand content.

- ***Soil pH***

Urea is the major nitrogen fertilizer used for crop production in Pakistan, but it is susceptible to hydrolysis followed by ammonia volatilization due to conversion into ammonium carbonate which may temporarily raises soil pH to above 9.0 in both acid and calcareous soils (Fenn and Hossner 1985). This releases ammonia at high soil pH. Similarly other nitrogen fertilizer added to calcareous alkaline soils may liberate ammonia depending upon the degree of calcareousness and alkalinity of soil.

Ammonia volatilization is enhanced by increase in pH (Park *et al.* 1958). They observed that at pH 7 little ammonia volatilization occurred but at pH 9.2 one half of the nitrogen was lost as ammonia volatilization.

Terman (1979) observed that slight ammonia volatilization losses occur in soils of pH 6 to 7, but losses increases markedly as the pH of soil increases.

According to Bremner and Douglas (1971) and Fenn and Richards (1984) urease gradually loses its hydrolytic activity at pH values below 4 to 5. They elucidated that when acids were added with urea to reduce the soil pH below 4, effective inhibition of ammonia losses occurred. The reduction in ammonia loss took place as a result of inhibited urea hydrolysis.

Paulson and Kurtz (1969) found no correlation with urease activity in the normal range of soil pH values. Work by Fenn and Richards (1984) has demonstrated that extensive ammonia losses occurred from soils with pH value as low as 4. The placement of urea only slightly below an acidic soil surface effectively eliminates ammonia losses (Touchton and Hargrove 1982).

The N loss from vertisols was estimated by Patra *et al.* (1996). The results indicated that losses were influenced by pH and they observed 37, 42 and 40.5 % losses at pH values 7.7, 8.2 and 9.3, respectively.

Application of green manure with urea effectively reduced pH of soil and reduced ammonia loss from urea in vertisol and inceptisol but not in alfisol (Purakyastha *et al.* 1997).

- ***Soil Moisture***

The variation in soil moisture content is one of the most important factors affecting ammonia loss from surface-applied urea. Ammonium sulphate or ammonium nitrate need only be solubilized to achieve maximum ammonia losses (Fenn and Escarzaga 1976). Adequate surface soil moisture has to exist to permit optimum rates of urea hydrolysis. Conditions for urea hydrolysis have to exist more than two days; other wise no significant ammonia losses will occur (Fenn *et al.* 1981, Fox and Hoffman 1981). Lack of urea hydrolysis on the soil surface will allow down ward movement of urea with subsequent rainfalls (Fenn and Miyamoto 1981). Hydrolysis of urea within the soil does not result in substantial ammonia losses. Fox and Hoffman (1981) found that if a rainfall of as little as 10mm fell within two days of application, very little ammonia loss occurred from surface applied urea. They found that if the same 10mm rainfall fell within three days, less than 10% ammonia loss occurred. However, if 3 to 5mm fell within five days or 7 to 9mm within nine days, ammonia losses were from 10 to 30%. They also reported that no rainfall within six days after surface application resulted in greater than 30% ammonia loss.

Vlek and Carter (1983) have shown that urea hydrolysis at permanent wilting point (PWP) (15 bar) is still relatively rapid, but decreases rapidly with further soil drying. Below the PWP soil moisture limited urea hydrolysis and ammonia loss. Reduced urea hydrolysis rates due to limited soil moisture are similar to and react like reduced urea application rates.

Patra *et al.* (1996) reported in experiment conducted on heavy textured vertisol with surface applied urea. There were two contrasting moisture treatments, one near field capacity (wet) and other intermittent wetting and drying (moist–dry). It was observed that losses were influenced markedly by moisture treatments being more from moist–dry treatment. The recovery of added N after 7 days was significantly reduced and this was even more marked when the N^{15} technique was used.

- ***Soil Organic Matter***

The existence and maintenance of soil urease activity are related to organic matter content in soil. Myers and McGarity (1968) sampled urease activity with soil depths and found the greatest urease activity at the soil surfaces where the greatest organic matter content existed and where the most recent organic depositions were found. Progressively decreasing urease activity was found with increasing depth.

Paulson and Kurtz (1969) observed that a steady level of soil urease activity was maintained for long periods. The addition of urea, in presence of easily decomposable organic residue causes a stimulation of urease production from ureolytic organisms. The addition of organic residue caused a 20-fold increase in ureolytic microorganisms.

Gould *et al.* (1973) inferred by comparing virgin soils with cultivated soils, that the virgin soil had a 2 to 6 fold greater urease activity. One sample was the surface litter, which had 12.4% total carbon content and a 6-fold greater urease activity. The second horizon, an Ah horizon had lower organic matter content but still a much higher urease activity level than found in cultivated soils.

Fenn *et al.* (1984) has shown that certain soils may have inadequate supply of urease for maximum ammonia loss. Addition of fresh organic residues can double ammonia losses in many cases, especially at lower rate of urea addition.

- ***Nitrogen Application Rates***

Research by Fenn and Kissel (1974) with NH_4NO_3 applied to Housten black clay showed no increase in %N lost with increasing rates of surface application of NH_4NO_3. The rates used were 33, 55, 110, 275, and 550 kg NH_4^+-N ha^{-1}. However, the application of ammonium sulphate, which reacted with calcium carbonate, did show N application rate effect on total NH_3 loss. The rate effect was measurable from 66 to 550 kg N ha^{-1}. The percentage of total N loss as ammonia at the low and high application rate at different temperatures were approximately the same. Ammonia loss differences with increasing N application rate were most strongly influenced by temperature. The largest initial losses occurred at the highest temperature, with slower ammonia losses at the lower temperature.

A volatilization diffusion experiment was carried out by Roelcke *et al.* (1996). Urea was surface applied at the rate of 210 kg N ha^{-1} to a soil with 10% $CaCO_3$ and a pH of 7.7. The amount of ammonia volatilized as well as the concentration profiles of ammoniacal-nitrogen in the upper 50mm of the soil columns after 4, 7 and 10 days were measured. There was significant increase in ammoniacal-nitrogen concentration between 4^{th} and 7^{th} day despite ammonia volatilization losses, that was due to on going urea hydrolysis. Highest ammonia fluxes were measured after 4-7 days, with total cumulative losses after 13 days was 60% to the total applied N.

2.2.2 Denitrification

It is dissimilatory reduction of nitrate (or nitrite) to gaseous products including NO, N_2O and N_2 (Knowles 1981). Because denitrification is an anaerobic microbial transformation it is influenced by the aeration, organic carbon contents, temperature and pH of the soil (Firestone 1982).

$$2HNO_3 \xrightarrow[-2H_2O]{+4H} 2HNO_2 \xrightarrow[-2H_2O]{+2H} 2NO \xrightarrow[-H_2O]{+2H} N_2O\uparrow \xrightarrow[-H_2O]{+2H} N_2\uparrow$$

Research on denitrification has been hampered by the inadequate techniques available for measuring gaseous fluxes from soils under natural conditions. In the case of denitrification, the main problem is that small changes in N_2 the main gaseous product are hard to measure against this background of atmospheric N_2, which already constitute 78% of the atmosphere. However, the research conducted in this regard is reviewed as under.

Ryden (1983) measured denitrification losses from a loam under cut ryegrass sward receiving 0, 250 and 500 kg N ha^{-1} a^{-1} in four equal amounts during 14 months using the acetylene inhibition technique. The rate of denitrification responded rapidly to changes in soil water contents as affected by the rain. Mean rate of denitrification exceeded 0.2 kg N ha^{-1} day^{-1} only. When the soil water contents was > 20% (w/w) and nitrate was > 5μg N g^{-1} in the upper 20cm of the profile and when the soil temperature at 2cm was > 5-8°C. When the soil dried to a water content < 20% denitrification decreased to < 0.05 kg N ha^{-1} day^{-1}. Highest rate i.e., upto 2.0 kg N ha^{-1} day^{-1} was observed following application of fertilizer to soil at water contents of about 30% (w/w) in early spring. Denitrification in the control plot during this period was generally about a hundredth of that in plots treated with ammonium nitrate. High rates of N_2O loss up to 0.3 kg N ha^{-1} day^{-1} were invariably associated with high rates on denitrification (> 0.2 kg N ha^{-1} day^{-1}) however, within 2-3 weeks following application of fertilizer to the plot receiving 250 kg N ha^{-1} day^{-1} the soil acted as sink for atmospheric N_2O when its water content was > 20% and its temperature > 5-8°C. Annual nitrogen losses arising from denitrification were 1.6, 11.1 and 29.1 kgN ha^{-1} for the plots receiving 0, 250 and 500 kg N ha^{-1} a^{-1} respectively. More than 60% of the annual loss occurred during the period of 8 weeks when fertilizers were applied to soil with a water contents > 20%.

Vos *et al.* (1993) applied N^{15} labeled ammonium nitrate to spring barley growing on a Cambisol. They observed that fertlizer N disappeared shortly after its application mainly through immobilization by soil microorganisms and atmosphere of the crop. According to them some of added nitrogen was denitrified as a result of humid condition during the first day after the fertilizer application. At the end of growing season 31% of the added N was recovered from the aerial barley plants and 56% was immobilized by microorganisms.

De-Klein and Van-Lojtestijin (1994) carried out denitrification measurements in grazed perennial ryegrass swards on sand, loam and peat soils, each receiving two rates of N fertilizers. Denitrification was measured monthly using a coring system with acetylene inhibition. Denitrification rates were highly variable throughout the season but tended to increase with increasing soil water content. High denitrification rate (0.1kg N ha^{-1} day^{-1}) was observed in spring and autumn and was associated with rainfall or grazing in combination with high water content. Estimated seasonal denitrification losses range between 1 and 20% of the fertilizer input and showed significant effect of fertilizer application rates.

Liang and Mackenzie (1994) conducted field experiments to investigate the effects of nitrogen fertilizer rates on soil NO_3^- -N under corn on two soils of contrasting textures. Denitrification as affected by previous N fertilizer rates was estimated for the non-growing season. Denitrification varied from 7-24 kg ha^{-1} during the non-growing season, increasing with N fertilizer rates only in the clay soil. In comparison with total NO_3^- -N disappearance over the same period losses of NO_3^- -N due to denitrification were relatively small.

Estavillo *et al.* (1997) studied N balance in a poorly drained clayey loam soil under natural grassland supplied with either calcium ammonium nitrate or cattle slurry at two application rates. The aim was to determine the efficiency of the nitrogen applied and the factors which affect this efficiency. The difference between cattle slurry and N fertilizer was that the slurry behaved as a slow release fertilizer, its supply of mineral N being greater in the periods of time when fertilizer was applied long time ago.

Denitrification losses (up to 17% of the N applied) are suggested to be the main factor to mitigate in order to increase N use efficiency.

Studies were conducted by Mahmood *et al.* (1997) on denitrification in the plough layers of an irrigated sandy clay loam under wheat-maize cropping system receiving different fertilizer treatments. The results indicated that denitrification was not an important N loss mechanism in this well drained irrigated sandy clay loam under wheat-maize cropping system receiving fertilizer inputs in the range of 100-200 kg N $ha^{-1}year^{-1}$.

Nitrous oxide emissions were measured from an irrigated sandy-clay loam cropped to maize and wheat, each receiving urea at 100 kg N ha^{-1} (Mahmood *et al.* 1998). They observed that N_2O emissions under maize were significantly correlated with denitrification rate and soil NO_3^- -N but not with soil NH_4^+ -N or soil temperature. On the other hand under wheat cultivation nitrous oxide emissions showed a strong correlation with soil NH_4^+ -N, soil NH_2^+ -N and soil temperature but not with denitrification rate.

2.2.3 Leaching

A key step in the chain of events leading to leaching losses from upland soil is the nitrification of the fertilizer ammonium-nitrogen. Since ammonium ion is more strongly absorbed by the soil exchange complex than nitrate ion. Urea is weekly absorbed by soil clays but is usually hydrolyzed rapidly to ammonium ion (Broadbent *et al.* 1958). According to Focht and Verstraete (1977) the leaching losses of applied fertilizer nitrogen may depend on the rate of nitrification, which is a biological transformation affected by substrate ammonium levels, oxygen, carbon dioxide and pH. In dry temperate region where evapotranspiration exceeds precipitation, nitrate from fertilizer nitrogen not utilized in the current crop season can accumulate deep in the profile of some soils (Herron *et al.* 1968). Such down ward movement of nitrate may not be a loss to the cropping system, since corn can recover nitrates as deep as 120 cm in the soil profile (Gass *et al.* 1971). In subtropical Queensland, Strong and Cooper (1980) observed that when drought limited crop growth, yield and nitrogen uptake from nitrate at 90 cm was greater than from 7.5 cm depth. In the semi arid tropics nitrate leached down to 120 cm by heavy rains in the wet season could be extracted by deep rooted crops such as pearl millet (Wetselaar and Norman 1960) or may move to the soil surface during the dry season Wetselaar (1962). Thus the losses due to leaching may not be important in semi arid and arid regions, the upward and down ward movement of fertilizer derived nitrate may influence the efficiency with which crops recover fertilizer nitrogen.

Aamio and Martikainen (1995) studied the effect of fast release urea, slow release urea, formaldehyde and a mixture of the two in different proportions on the soil microbial activities and observed that urea fertilization enhanced nitrification, which can cause nitrogen leaching.

Growth, nitrogen uptake and nitrogen allocation between roots, stem, leaves and grains were measured and simulated in winter wheat on a clay soil in three treatments including daily irrigation and fertilization by Kaetterer *et al.* (1997). The results showed that frequent irrigation in combination with single dose fertilization increased crop growth and nitrogen leaching compared with non irrigated but single dose fertilized control. Whereas, irrigation together with daily fertilization increased crop growth and N uptake and the leaching losses were minimum.

2.3 FERTILIZER USE EFFICIENCY FOR CROP PRODUCTION

The key role played by the N- fertilizer in the world food production is widely recognized. The average nitrogen fertilizer application rate is 54.5 kg ha^{-1} $annum^{-1}$ (Salim *et al.*1986) but the recovery of applied N by the crop is very low.

Fertilizer use efficiency indicates the degree of utilization of nutrients by growing plants and depends on a number of factors. Although the fertilizer usage in Pakistan has increased many fold during the last few decades, but fertilizer use efficiency reported is low. Elsewhere in numerous research studies such as Smith and Whitefield (1990) Smith *et al.* (1989) Scharf and Alley (1988) the recovery of the added fertilizer nitrogen seldom exceeded 50 percent for upland crops. Fertilizer use efficiency has attracted global attention due to increasing demand for inorganic fertilizer and associated high-energy requirements. Moreover, the socioeconomic and environmental constraints have made it more imperative to increase fertilizer use efficiency. This can be achieved by adopting such practices and means, which may help in allowing greater yield per hectare and thus enhance the recovery of N by the crop.

Factors affecting fertilizer use efficiency

Numerous strategies such as use of nitrogen sources, fertilizer rates, fertilizer placement and application methods, time of application, nitrification inhibitors and concept of mixed nitrogen nutrition have been devised to improve nitrogen fertilizer use efficiency (Slanger and Kerkhoff 1984, Freney *et al.* 1992)

- ***N-Fertilizer Sources***

Sources of N are also known to affect fertilizer use efficiency for wheat. According to Biswas *et al.* (1985) calcium ammonium nitrate and ammonium sulphate have been found superior to urea especially in the alkaline soil condition.

The comparative effects of ammonium nitrate, urea or combined 1-1(w / w) ammonium nitrate / urea granular fertilizer were investigated for the efficiency of dry matter production and N^{15} recovery by perennial ryegrass grown in pots under controlled conditions by Watson (1987). He indicated that ammonium nitrate was the most efficient N source and urea the least efficient in terms of all the parameters studied. At the end of experiment 60% of the N from urea was recovered compared with 95% from ammonium nitrate.

Rashid and Saleem (1992) tested 3 N sources with 3-application levels for wheat under rainfed conditions. The sources tested were ammonium nitrate, urea and sulpher coated urea (SCU). Ammonium nitrate and (SCU) proved better as compared to urea regarding the grain and straw yield and N recovery.

In a pot experiment conducted in the green house condition to determine the best N source for wheat, the highest wheat yield (grain and straw) and N uptake was recorded with combined application of urea and ammonium nitrate (Aslam *et al.* 1992). Maximum N recovery by crop was recorded in the case of urea and ammonium nitrate followed by ammonium sulphate and ammonium nitrate, when applied with gypsum. Ammonium sulphate and ammonium nitrate gave better N recovery than urea.

Rashid and Yasin (1993) conducted a field experiment to find out the most efficient source of N for sorghum and observed that difference between ammonium nitrate and sulphur coated urea with respect to yield, N uptake, N recovery and agronomic efficiency were non-significant but both were significantly better than urea.

Under local conditions calcium ammonium nitrate (CAN) have been found to be slightly more efficient than urea and ammonium sulphate for wheat (Nizami 1995), but under dense sodic soil conditions, urea and ammonium sulphate were more efficient as compared to CAN (Zia *et al.* 1996).

- ***Fertilizer Rates***

The literature contains many references to an effect of N-application rate on efficiency. Singh *et al.* (1975) elucidated that grain yield of wheat in rainfed conditions increased progressively with application of N upto 120 kg N ha^{-1} . Grain yield at 80 kg ha^{-1} was significantly lower than at 120 kg N ha^{-1}. Straw/grain ratio also increased from 1.5 to 1.8 with increasing rates of N application under arid conditions.

El-Shafei and Darwesh (1980) studied the effect of N on wheat yield under moisture stress conditions. In field study, N fertilizer @ 0, 25, 75, 100 and 125 kg N ha^{-1} was applied. The yield was maximum with 75-100 kg N ha^{-1}. Straw/grain ratio also increased with increasing N rate.

Sanmaneechai *et al.* (1984) demonstrated that there was no significant increase in wheat yield with over 135 kg N ha^{-1}. However, the concentration of N in the straw and grain continued to increase with N rates of 180 and 270 kg ha^{-1}.

Sud *et al.* (1990) in a field experiment on sandy loam soil applied in common irrigation at crown root stage to wheat crop. Crop was fertilized with 40, 80 and 100 kg N ha^{-1}. They observed that increasing rate of N fertilizer and irrigation levels was synergistic in increasing grain yield, N uptake and utilization of N fertilizer.

Nelson and Halvorson (1991) studied the effect of N fertilization on water use and yield of dryland wheat, and elucidated that grain yield increased with increase in N applied upto 56 kg N ha^{-1}. Increased usage of N fertilizer is considered to be a primary means of improving wheat grain yield and N recovery in Ethiopia (Asnakew *et al.* 1991, Tanner *et al.* 1993).

Awasthi and Bhan (1993) carried out a field experiment on wheat to find out the optimum level of N for realizing maximum yield under moisture stress conditions. They observed that application of 60 kg N ha^{-1} resulted in the maximum yield, which was significantly higher than that obtained with 0, 20 and 40 kg N ha^{-1}. The various yield parameters and N recovery were improved with increasing dose of N.

Francis and Schepers (1994) conducted experiment on N uptake efficiency in maize. Significant increase in stover N concentration was noted with increased fertilizer rates. They achieved maximum yield near 100 kg N ha^{-1} rate.

- ***Fertilizer Placement and Application Methods***

The efficient use of applied N is not only influenced by the interaction of native soil N but also to various soil depths in the soil profile. In Pakistan, different sources of N fertilizers are available and applied indiscriminately as broadcast and hence are subjected to atmospheric losses due to calcareous nature and high pH of the soils. Nitrogen is also applied to the soil by surface mixing or placement. The latter is considered to be an effective practice particularly when the surface layer is likely to be dry in the absence of irrigation or rainfall. (Cochran *et al.*1978, Choudhry and Qureshi 1982).

Winter wheat was grown in the field in 60 cm diameter and 180 cm deep metallic cylinders sealed at the bottom by Sharma and Choudhry (1984). The cylinders were filled with loamy sand soil. The contribution of different soil depths in the root zone towards total N uptake was calculated and compared with the experimentally measured N uptake by wheat plants. Under non-irrigated conditions with surface mixing of N concentrations of nitrate, root lengths and water uptake rates were high only in the upper soil layers. With deep placement of N the lower layers also contributed significantly towards total N uptake. The total N uptake was greater with deep placement of N than with surface mixing of N.

Three field experiments using N^{15} tracer techniques and manual injection on small plot, to identify optimum injection intervals and injection depth for spring-point injection of urea-ammonium nitrate (UAN) solution were established at two sites in southern Alberta and Canada by Janzen and Lindwall (1989). The optimum longitudinal interval was approximately 40 cm and the optimum injection depth was observed to be approximately 10 cm. When the injection depth was increased from 2.5 to 10 cm grain yield response and fertilizer N recovery in the wheat increased four and three fold, respectively.

Qayyum *et al.* (1994) conducted field experiment on N use efficiency in wheat and compared the broadcast with deep placement of N application method and elucidated that grain and straw yields were improved significantly due to dibbling N (deep placement). It was concluded that wheat uptake of N was increased and was used more efficiently with deep placement as compared to broadcasting.

Field studies were conducted by Lamond and Mayer (1983) to evaluate two fertilizer application techniques for established tall Fescue (*Festuca arundinacea,* Schreb). The fertilizers solution were either surface broadcast through flat fan-spray nozzles or injected (Knifed) 15 to 20 cm deep behind shanks on 38 cm spacing. Knifed fertilization method was observed to be superior to broadcast applications of fertilizer and significantly increased forage yields, N content, N uptake, K uptake and sometimes K concentrations and P uptake.

Shah *et al.* (1992) conducted field experiment to evaluate the efficiency of different methods of urea application to maize crop. The study revealed that band placement significantly increased the yield and protein content of grain as compared to any other method. Highest grain yield, total dry matter, grain protein content and residual soil N were recorded by banding of dose of urea-N at sowing and remaining half by side dressing at knee high stage of the crop. Top dressing was found least effective even compared with broadcasting and incorporations of full dose of urea-N at sowing time.

- ***Time of application***

The time of application of fertilizer depends on the soil, climate, nutrients and crop. Researchers in other countries have frequently shown split application to be superior to applying all N at sowing in areas of high seasonal precipitation. Split application increases N management flexibility and potentially reduces N losses (Vaughan *et al.* 1990).

Shah *et al.* (1992) elucidated that the highest grain yield, total dry matter, grain protein content and residual soil N were recorded by banding of dose of urea-N at sowing and remaining half by side dressing at knee high stage of maize crop. This was followed by banding full dose of urea-N at sowing time.

Alcoz *et al.* (1993) reported increase in total N uptake, apparent N recovery in split application of N to wheat while Fischer *et al.* (1993) reported a decline in apparent N recovery with late N dressings.

Tilahun *et al.* (1996) conducted field trials on two wheat cultivars and mentioned that in general split application of N and use of large granular urea as N source enhanced grain and total N uptake, apparent N recovery and agronomic efficiency of N.

- ***Nitrification inhibitors***

Nitrification is the biological oxidation of ammonia to nitrate. It is two step process in which the ammonium is first converted into nitrites (NO_2^-) and hence to nitrate (NO_3^-).

$$2NH_4^+ + 3O_2 \rightarrow 2NO_2^- + 2H_2O + 4H$$
$$2NO_2^- + O_2 \rightarrow 2NO_3^-$$

Nitrification inhibitors are compounds that delay bacterial oxidation of the ammonium-ion by depressing over a certain period of time the activities of Nitrosomonas bacteria in the soil. They are responsible for transformation of ammonium into nitrite, which is further changed into nitrate by Nitrobacter and *Nitrosolobus* bacteria. Nitrification inhibitors through inhibition of nitrification of ammonia significantly reduce leaching losses of nitrogen and movement of nitrate into water supplies, while maintaining N availability to crops (Watson *et al.* 1994, Grant *et al.* 1996). They also reduce emissions of N_2O and NO (Delgado and Mosier 1996). Objective of using nitrification inhibitors is therefore, to control leaching of nitrate by keeping N in ammonia form longer, to prevent denitrification of nitrate-N and to increase the efficiency of the N applied. In normal soil condition, ammonium is oxidized into nitrate within a short time. In order to maintain a predetermined ammonium-nitrate ratio this oxidation process has to be inhibited during the major part of plant growth. Nitrification inhibitors provide possible means for maintaining predetermined ammonium-nitrate ratio in soil (Hauck 1980, Amberger 1986, Hoeft 1984, Shaviv *et al.* 1987).

Shaviv *et al.* (1987) conducted green house experiment on a loamy sand soil. Wheat was grown to maturity and was followed by millet harvested green. Nitrogen was applied as calcium nitrate and ammonium sulphate with Dicyandiamide (DCD) a nitrification inhibitor . The predetermined ammonium to nitrate ratio was maintained through out the experiment. Ammonium-nitrate nitrogen mixtures generated a higher yield and a higher organic nitrogen and P content in millet. Reduced-N and P accumulation in wheat grain was significantly higher in the 75 / 25 ammonium-nitrate mixtures than in nitrate only treatments.

Somda *et al.* (1990) compared atrazine and simazine herbicides with two nitrification inhibitors (nitrapyrin and terrazol) for their effects on biological nitrification and corn growth. The combination of either herbicides with nitrapyrin or terrazol significantly reduced the corn dry weight with substantial accumulation of Kjeldhal N and nitrate in tissues of plants.

In field experiments carried out over several years by Hege and Munzert (1991) DCD-stabilized fertilizers gave different degrees of efficiency with different crops. The increase in yield as well as the economic benefit was significant with crop planted at a greater row width (maize, maize for silage-with fertilizer band application), with a longer vegetative period and with a preference for ammonium-N (Potatoes). However, with winter cereal, winter rape and sugar beet no increase or only nominal increase in yield was obtained, through improved yields these crops have shown the best reaction to nitrification inhibitors (Zerulla and Aktiengesellschaft 1996).

Amberger (1991) emphasized the advantages of using DCD containing fertilizers. With only one or two applications of stabilized fertilizers the application costs of fertilization can be reduced significantly as compared to the several dressings with calcium ammonium nitrate. Spielhaus (1991) also confirms that same yield can be obtained from only one or two applications of stabilized fertilizers, as that from conventional fertilizers, which have to be applied in more dressings.

Schroder *et al.* (1993) conducted field experiment in order to study the effect of DCD, time and rate of slurry and N fertilizer on maize yield and losses to the environment. They showed that DCD addition to autumn-applied cattle slurry retarded nitrification, thus reducing nitrate losses during winter-spring applied slurry without DCD, however, on average it was associated with even lower losses and higher maize yield.

Freney *et al.* (1992a) conducted field experiment to evaluate the effectiveness of several nitrification inhibitors to prevent nitrogen fertilizer applied to cotton. They observed that in absence of nitrification inhibitor only 50% of N applied was recovered in the plant and soil at crop maturity. The recovery was increased to 70%, 74%, 78% and 92% by addition of phenylacetyline, nitrapyrin, coated calcium carbide and ethynylpyridine respectively. Lint yield was also increased by addition of nitrification inhibitors.

Crawford and Chalk (1993) conducted experiment on sources of nitrogen uptake by wheat and nitrogen transformations in soil treated with a nitrification inhibitor. Rates of N uptake by spring wheat as ammonium and as nitrate, and rates of nitrification, gross N immobilization and gross N mineralization were measured in a pot experiment in a clay soil. Soil treatments included an unfertilized control and addition of $^{15}NH_4\ NO_3$ or $NH_4\ ^{15}NO_3$ in absence and presence of N-serve. Incorporation of ammonium into the soil organic N pool was considerably higher in presence as compared to absence of Nitrapyrin. Both dry matter and grain yield as well as N uptake by wheat were enhanced in presence of inhibitor in N fertilized soil, despite the increased immobilization of N. On the other hand, inhibitor application had a detrimental effect on yield and N uptake by wheat in unfertilized soil.

The effects of urea-ammonium nitrate (UAN) time of application, method of application and rate of DCD nitrification inhibitor on the flag N, grain N and grain yield of winter wheat were measured by Sawyer and Carter (1993). Grain yields responded differentially to time and method of UAN application as DCD rate increased. With spring broadcast N application, yield decreased while with fall application and with spring dribble application yield increased. As the rate of DCD increased, yields tended to increase with fall application but decreased with spring application.

Prakasha and Puttana (1994) experimentally proved that DCD+urea treated perennial aromatic grass *Java citronella* improved the nitrogen use efficiency and resulted in significantly higher herb and essential oil yield as compared to the plant treated with urea alone.

Sharma and Prasad (1996) conducted a two years field experiment to study the effects of DCD and neem cake on the efficiency of applied prilled urea nitrogen in a maize-wheat cropping system. Prilled urea (PU) neem cake coated urea (NCU) and DCD blended urea (DCDU) were applied to maize at two levels of N i.e. 60 and 120 kg ha^{-1}. In first year maize responded well to N upto 60 kg N ha^{-1}. At this level PU increased maize yield by 1.03 t ha^{-1} whereas, NCU and DCDU increased maize yield by 1.55 and 1.18 t ha^{-1} over the control which was equivalent to an application of 127 and 94 kg N ha^{-1} as PU respectively.

- ***Concept of Mixed Nitrogen Nutrition (NH_4^+-N, NO_3^--N)***

Whether NH_4^+ - N or NO_3^- - N is a superior N source for plant growth has long been extensively studied, however, contradictory results were frequently found in literature due to difference in plant species examined and experimental conditions such as pH control and level of N supply in the growing media.

1. Effect of Mixed N Nutrition on Growth

Plant physiological studies indicate that higher crop yield may be obtained with a mixture of nitrate and ammonium than with either source alone (Hageman 1984, Bock 1986). The work of different scientists / researchers in this regard has been reviewed as under.

Gashaw and Mugwira (1981) reported that triticale, wheat and rice grown in nutrients solution containing NH_4^+ - N / NO_3^- - N ratios i.e. 0 /100, 25 /75, 50 / 50, 75 / 25 and 100 /0 produced higher dry matter with the combination of 25 / 75, 50 /50 and 75 /25 NH_4^+ - N / NO_3^- - N ratio than with either N source alone.

Gentry *et al.* (1989) reported that mixed N nutrition increased wheat growth significantly than with either N source alone. Heberer and Below

(1989) conducted green house experiment to study the effect of N supplied as either mixture of NO_3^- and NH_4^+ or as all NO_3^- on wheat. Nitrogen treatments consisted of all nitrate or mixtures (75 / 25 or 50 / 50 of NO_3^- and NH_4^+) they observed that plants grown with mixed N nutrition produced higher grain yield compared to plants receiving only nitrate as the source of nitrogen.

Below and Heberer (1990) demonstrated that compared to growth on all nitrate, a continuous supply of both NO_3^- and NH_4^+ increased grain yield of wheat by 33 %. Corresponding increases in the total accumulation of dry matter (32 %) and reduced N (48 %) were also observed. Plants continuously supplied with mixed N have 46 % more corn than nitrate fed plants.

Sandoval et al. (1992) studied that wheat plants (21 days old) were grown in one of the five solutions containing one of the following 7 / 0, 5 / 2, 3.5 / 3.5, 2 / 5 or 0 / 7 meq. l^{-1} of NH_4^+ / NO_3^-. After two weeks of treatments of applications the highest dry matter production in both roots (0.235 g $plant^{-1}$) and shoots (1.135 g $plant^{-1}$) was observed in plants receiving the 2/5 NH_4/NO_3 ratio. Similar response was observed on the accumulation of soluble protein also.

Stephen and Streeter (1994) studied the effect of nitrate and ammonium nutrition in ryegrass and revealed that the vegetative growth rate of plants receiving lower ratios of nitrate / ammonium was up to twice those receiving total nitrate or 75 / 25 nitrate / ammonium. Total primary tiller number was 30 % greater in plants receiving 25 / 75 and 0 / 100 nitrate / ammonium. However, floral tiller number increased up to 55 % with increasing ammonium-N to nitrate-N, while vegetative tiller number was not significantly affected. They indicated that differences in plant growth and development resulted from greater N use efficiency from mixture of ammonium and nitrate nutrition.

Ali *et al.* (1995) illustrated that wheat grown in solution culture containing ammonium nitrate ratio 100: 0, 75:25, 50:50, 25:75 and 0:100 showed both fresh and dry weight highest for 25:75 ammonium: nitrate ratio. The root / shoot ratio was maximum for 100 % nitrate treatment. But both shoot and root growth was less when ammonium was present as sole source of nitrogen and increased significantly as the share of nitrate increased in the solution. They noted similar trend in dry weight of the plant.

Sandoval-Villa *et al.* (1995) evaluated the response of wheat to different ammonium / nitrate ratios under hydroponic conditions. The best response was observed with 2/5 ratio NH_4 / NO_3 (meq. l^{-1}). Dry matter production, grain yield and grain quality (100 grain weight) increased when the ammonium ratio was increased (2/5 and 3.5/3.5 NH_4/ NO_3 ratio) the number of productive tillers were higher at 2/5 ratio and the harvest index was highest in the 3.5 / 3.5 ratio.

2. Effect of Mixed N Nutrition on Nutrient uptake

The form of nitrogen, ammonium or nitrate, affects the uptake of other nutrients by plants and plays a role in the concentration of nutrients found in plant tissue (Cox and Reisenauer 1973, Haynes and Goh 1978). Ammonium competes with other cations during uptake and as the ammonium level increases, cations uptake decreases in most plant species. In contrast, nitrate generally stimulates cation uptake and inhibits anion uptake (Cox and Reisenauer 1973). Ammonium also suppresses nitrate uptake and is particularly detrimental to Ca, Mg and K uptake.

Cox and Reisenauer (1973) found increasing levels of nitrate were associated with increased Ca, K and Mg uptake, while increasing levels of ammonium resulted in decreased Ca, K and Mg uptake in wheat. This resulted in higher concentrations of Ca, K and Mg in the nitrate treated plants. However, they found lower P concentration in ammonium treated plants.

Shrader *et al.* (1972) found 37 % increase in total N absorption for plant grown on 50:50 % mixture of ammonium and nitrate over nitrate grown plants.

A study was conducted by Gashaw and Mugwira (1981) to demonstrate the effect of ammonium- N and nitrate-N on mineral composition of Triticale, wheat and rye in a solution culture containing different NH_4–N / NO_3 –N ratios. The ratios were 0 / 100, 25 / 75, 50 / 50, 75 / 25 and 100 / 0. They reported that there was increase in the uptake of N, P and Fe when ammonium ratio was increased in the mixture. Whereas, nitrate –N increased the uptake of Mg, Ca, Mn and nitrate nitrogen.

Goyal and Huffaker (1984) and Olsen (1986) reported that ammonium supplied plant root along with nitrate results in higher nitrogen contents than either form alone, and pointed out that balanced ammonium-nitrate nutrition may induce a desirable acid content in plant tissue.

Gentry *et al.* (1989) reported that mixed N nutrition increase N uptake in two wheat cultivars (cv. Len and cv. Inbar). Compared to nitrate grown plants, mixed N nutrition increased total N uptake 27 % for Len and 52 % for Inbar. The greater total N uptake by Inbar compared to Len when grown with mixed N was the result of greater uptake of both nitrate (36 %) and ammonium (31 %). Both cultivars absorbed more N, P and K when grown with mixed N nutrition.

Fen and Barker (1990) reported that different forms of nitrogen were applied to the plants in different proportions of plant nutrient. Nitrogen supplied as ammonium suppressed cation accumulation in plants, but cation absorption was enhanced by increased nitrate –N supply.

Behaviour of different plant species towards various ammonium–nitrate concentrations was studied by Errebhi and Wilcox (1990). The results revealed that the K content in melon and corn leaf increased with ammonium-N upto 28 ppm. The K content in tomato and cabbage tissue was reduced at 28 ppm ammonium. The K content in all the species tested was reduced with 77:77 ppm ammonium : nitrate-N concentration treatment. Calcium composition reduction in all the plant species was affected at 28 ppm ammonium –N with reduction to 50 % that of all nitrate nutrition at 77 ppm ammonium –N. Mg composition of corn was most severely reduced by the 77:77 ppm NH_4–N:NO_3–N nutrition. Bean Mg composition was not affected by the ammonium-N concentration in the 14 to 77 ppm range. Mg was reduced in cabbage, melon and corn by ammonium –N when concentration was above 28 ppm.

Smith *et al.* (1990) found that in treatments containing both ammonium and nitrate, uptake of ammonium was higher than nitrate in the first two weeks after transfer to the solution. Nitrate uptake was highest during grain filling stage. Barber *et al.* (1991) reported that nitrogen uptake varied with plant growth stage (GS) and source of N. At GS 3 nitrogen uptake showed similar response to N source. Plants supplied with urea + nitrate have 27% more N content than those supplied with urea. At GS 5 plants fertilized with urea + calcium nitrate contain 25% more N than those fertilized with calcium nitrate only. At GS 9 difference in N uptake was 23% lower for urea – calcium nitrate treated plants than for those treated with ammonium nitrate. They concluded that mixed N nutrition resulted in

24 to 34 % more N uptake than all ammonium as urea or all nitrate as calcium nitrate.

McCrimmon *et al.* (1992) evaluated the effects of clipping regime and N–form on the tissue concentration, micronutrients and macronutrients uptake in creeping bentgrass (*Agrostis palustris* Huds). The plugs of grass were grown in nutrient solution. With a combination of three nutrient solutions (100 % nitrate, 100 % ammonium and 50:50 ratio of ammonium: nitrate) and to cutting regimes (cut and uncut). Uncut nitrate treated plants accumulated higher concentrations of K, Ca, Mg, B and Cu in the shoot tissue and P, K, Ca, Mg, B, Cu, Mn and Zn in the root tissue compared to uncut ammonium treated plants. Plants grown with uncut 50:50 treatment absorbed more ammonium than nitrate. Plants grown with nitrate and 50:50 treatments, under both cutting regimes resulted in higher concentration of most macro-and micronutrients and greater nutrient uptake compared to the ammonium treated plants.

Ali *et al.* (1995) reported that maximum N and P uptake was observed when 50:50 ammonium –nitrate ratio was applied to wheat. Similar trend was observed in N uptake rate. N uptake was lowest in plants where all the N applied was ammoniacal form. However, for K uptake the most effective treatment was 25:75 ammonium –nitrate ratio and least effective treatment was when all nitrogen was applied in ammoniacal form. Similar trend was noticed in K uptake rate.

3. Effect of mixed N nutrition under salinity regime

The effectiveness of mixed ammonium-nitrate nutrition to increase crop yields and N (protein) accumulation has been established. It has been known for a long time that an excessive amount of salts in the root environment reduces the growth of plants and results in low crop yields.

However, little is known about the effect of varying ammonium-nitrate proportions on salinity stressed crops.

Feigen (1988) emphasized the antagonism between nitrate and chloride as a possible mechanism to reduce the effects of salinity stress on growth of several crops.

Neuman *et al.* (1988) narrated that chloride accumulation is one example of many possible mechanisms by which salinity affected plant growth such as specific ion effect, osmotic stress, reduced nutrient availability and cell wall hardening.

Pessarakli and Tucker (1985) observed that cotton plants grown in an ammonium nitrate solution continued to accumulate ammonium under salt stress in spite the lower dry matter production. Sodium chloride apparently inhibited ammonium metabolism and reduced protein synthesis in cotton plants without affecting its uptake was reported by Pessarakli and Tucker (1985a).

Ben-Hayyin and Goffer (1988) reported that the citrus cell cultures grew faster in the media containing ammonium nitrate than in those with nitrate only. Addition of sodium chloride accentuated the difference between the two. A significant reduction of sodium uptake in cells equally supplied with both N sources as compared to nitrate nutrition alone was observed.

Pessarakli and Tucker (1988) found that dry matter production of tomato plants was significantly decreased by increasing sodium chloride salinity. They also reported that medium and high levels of salinity substantially reduced the N^{15} uptake rate by plants. Kafkafi *et al.* (1982)

found a decline in dry matter yield of tomatoes with increasing sodium chloride concentration in solution at all NO_3^- and $H_2PO_4^-$ levels.

Pessarakli *et al.* (1989) reported that increase in osmotic pressure of the culture solution also decreased dry matter production, N absorption and water uptake of corn. There was also a substantial reduction in N^{15} uptake and significant decrease in dry matter production of egg plant as a result of increasing the salinity of culture solution (Pessarakli and Tucker 1988).

Dry matter yield and nitrogen uptake of tomato plants subjected to salinity (NaCl) were studied in green house by Al-Rawahy *et al.* (1990). The treatments consisted of low (control media 14 bars) and high (8 bars) salinity. They found that dry matter production and nitrogen uptake were significantly lower for the saline treatments as compared with the control.

Shaviv *et al.* (1990) conducted green house experiment on wheat under artificially induced salinized conditions. Ammonium and nitrate mixture in ratio of 0:100, 25:75 and 50:50 ratio along with DCD a nitrification inhibitor were applied with irrigation water. Salinity significantly reduced dry matter (DM) yield and N and P content in grain and stover. A mixed ammonium and nitrate N source produced larger DM and protein yields than nitrate alone especially in grain. The relative increase in yields and N and P accumulation, due to mixed N nutrition were significantly higher in salinized soil and increased with increasing proportions of ammonium. Grain DM and N yield at medium salinity with a 50:50 N mixture were equal to or higher than those in non-salinized soil fertilized with nitrate only.

Silberbush and Lips (1991) reported that sodium chloride reduced shoot dry weight of wheat in all treatments. Dry weight production was increased in response to an increase in the ammonium proportion of N in the nutrient solution both with and without 60 mM sodium chloride. Plant total nitrogen and nitrate contents were affected by N and sodium chloride concentrations in the nutrient solution but not by the ammonium / nitrate ratio. Increase in ammonium in the medium resulted in increased P concentration in the leaf. Calcium concentration was decreased with increasing ammonium proportions of the nitrogen in the medium. K concentration in the leaves was significantly affected by N, K and sodium chloride concentrations in the nutrient solution. The distribution of K between main and secondary tillers was not affected by ammonium / nitrate ratio. The ammonium / nitrate ratio in the medium significantly affected leaf chloride as well as the distribution of chloride between primary and secondary tillers.

Leidi *et al.* (1991) concluded that shoot dry weight declined with sodium chloride concentration in nutrient solutions containing either form of N. Plant growth also decreased with increasing pH, this effect was more pronounced in ammonium fed plants. The significant growth reduction observed in ammonium grown plants at high pH could be related to a specific ammonium toxicity effect due to the prevalence in the medium of ammonia at high pH. The ratio of shoot to root dry weight was not affected by pH, overall the salinity ranges studied. The shoot / root ratio was unaffected by pH in the nitrate containing medium. The shoot / root ratio was higher but decreased with pH for ammonium grown plants. The higher shoot /root ratios exhibited by ammonium fed plants were the consequence of the marked inhibitions of root growth observed in the ammonium containing medium.

Shaviv and Hagin (1993) conducted a pot experiment in order to study the interaction of salinity and enhanced ammonium and K nutrition with or without nitrification inhibitors i.e. DCD and N-serve. Significant higher wheat grain yield and N uptake were found in 1% DCD and 1% N-serve treatments. However, 5% DCD treatment showed a yield depression. In the lower N level treatments, a significant yield increase generated by 1% DCD and N-serve was found in the salinized soil as compared to the non-saline soil. Soil salinity reduced N uptake when nitrification inhibitors were not present. In treatments having the inhibitors, N uptake was equal or greater in the salinized than in the non-saline soil.

Khan *et al.* 1994 reported that increased salinity (0-100 mM NaCl) substantially reduced the dry weight of roots and shoots, relative growth rate of the plant, relative multiplication rate of roots, mean extension rate of roots, number of root branches and root length. The promotive effect of nitrate –N was more pronounced on shoot and root dry weight and root lengths, while number of root tips relatively increased more by ammonium-N on all salinity levels. Moreover, salinity affected root length per plant relatively more than number of root tips per plant. It was inferred that the extent of moderation of salinity effects depended on N forms, concentration and growth stages.

4. Effect of Mixed N nutrition under moisture regime

Wheat in Pakistan is grown under irrigated and under rainfed conditions. Under rainfed conditions, the crop suffers from moisture stress due to erratic and uncertain rainfall. Even under irrigated conditions, the crop suffers from limited water supplies. It is well established that subjecting plants to water stress conditions reduces their growth, water absorption, nutrient uptake and metabolism due to the reduced rate of movement to plant roots through diffusion and mass flow. This results in reduced biomass production with the consequence of lower crop yield (Fardad and Pessarakli 1995)

Sud *et al.* (1990) in a field experiment on a sandy loam soil applied a common irrigation at crown root stage to wheat crop. The irrigation was subsequently applied at 35, 50 and 65% depletion of available moisture. Crop was fertilized with 40, 80 and 100 kg N ha^{-1}. They observed that increasing levels of irrigation and N fertilizer were synergistic in increasing grain yield, N uptake and utilization of N fertilizers.

Abreu *et al.* (1993) carried out a field experiment in order to study the N uptake in relation to available water in wheat. Wheat was grown on a clay soil (vertisol) at three water treatments i.e. rainfed (W0) with 80 mm of irrigation (W1) and with 50 mm and 70 mm irrigations (W2). All treatments received 50 kg ha^{-1} of N prior to sowing and were top-dressed with 140 kg ha^{-1} of N splitted in two applications. Results revealed that N uptake after anthesis was 40 % of the total in W2, but was not noticeable in other two treatments. N concentrations in the total above ground plant dry matter and in both yellow leaves and stem were not very different according to treatments, but water availability increased grain N concentration.

Rashid and Yasin (1993) conducted a field experiment in order to find out most efficient source of N for Sorghum under different water regimes. Ammonium nitrate, sulphur coated urea and prilled urea were applied as N sources with three irrigations i.e. 25 % < [Evapotranspiration (ET) I_1] equal to ET (I_2) and 50% > ET (I_3). Irrigation regimes had significant effect on fodder yield, N uptake, N recovery and agronomic efficiency were more in I_2 as compared to I_1 and I_3 irrigation regimes. Interaction between fertilizer treatment and irrigation regimes was also significant. Combination of ammonium nitrate (F1) and irrigation equal to ET (I_2) was found to be best regarding fodder yield, N uptake, N recovery and agronomic efficiency.

Sakarvadia and Yadav (1994) reported a yield depression in groundnut, when subjected to soil moisture stress as compared to the normal irrigation, where dry matter, pod and haulm yield were significantly higher. They also observed that water stress also reduced the uptake of N, P, K, Ca, Mg and S by plant at 46, 62 and 78 days and by haulm and pods at harvest.

The inter-relationship between biomass and soil moisture was studied by Fardad and Pessarakli (1995) in wheat and barley. The treatments consisted of two irrigation intervals 7 and 14 days. Six water levels 100, 80, 60, 40, 20 and 0 % of the crops total water requirements were used at each irrigation interval. Plant height was not significantly affected by water shortage for either species at either irrigation interval at different water levels. However, there was a significant difference in the dry matter production in terms of straw and grains for both barley and wheat irrigated at different irrigation intervals with various water level. The 7 day interval irrigated plants had a typical growth pattern and dry matter yield whereas, the 14 day interval irrigated ones showed reduced and delayed growth, especially at the lower (0,20,40%) water levels. The reduction in grains dry matter yield caused by water stress was more severe for wheat than for barley plants.

The yield of sunflower significantly increased with irrigation and N application as reported by Rambe *et al.* (1997). The yield under irrigation schedule of 0.75 irrigation water / cumulation per evaporation (IW / CPE), 1.00 IW / CPE and 10 days interval were comparable but significantly superior to 0.5 IW / CPE. The sunflower yield increased significantly with increasing levels of nitrogen for no nitrogen to 100 kg N ha^{-1}. The nutrient uptake at harvest of sunflower was found to be influenced by irrigation schedules as well as N application. Irrigation either at 1.00 IW / CPE or 10 days interval showed significantly highest uptake of N, P and K. While it was maximum for 100 kg N ha^{-1}.

- *Effect of amendments and other nutrient elements*

Some of the amendments like gypsum and salts like potassium are helpful in reducing the soil pH and improving nitrogen use efficiency for crop production.

1. Effect of Gypsum

Sufficient literature is available about the role of gypsum in improving physical conditions of soil and crop yields, but information about the role of gypsum in nitrogen fertilizer use efficiency is altogether meager.

Among the chemicals, gypsum is the most commonly used amendment for reclamation of sodic soils. Its application to sodic soils causes tremendous improvement in soil physical properties (Mehta 1983).

Patel and Suthar (1993) conducted experiment to evaluate the effect of gypsum on properties of sodic soil, infiltration rate and crop yield. According to them the application of gypsum decreased the pH, Ec and ESP after harvest of the crop at all the locations. The initial average infiltration rate for gypsum treated soil (38.6 mm h^{-1}) was much higher than that for the untreated soil (17.2 mm h^{-1}). The reclamation of highly sodic soils in farmers' field brought about considerable improvement in soil properties and increased the yield of different crops. The highest beneficial effect of gypsum application was observed with millet followed by peanut and sorghum.

Ilyas *et al.* (1993) reported that application of gypsum significantly increased the field saturated hydraulic conductivity, increased the root growth and enhanced crop growth.

According to Singh *et al.* (1993) application of gypsum improved the quality and yield of peanuts and demonstrated that addition of gypsum had significantly increased the pod and haulm yield and quality parameters such as shelling percentage, oil, protein and P contents.

Tripathi and Sharma (1994) evaluated pyrite and gypsum as a source of sulphur in mustard-rice cropping sequence and reported that application of sulphur gave significantly higher seed and oil yield in mustard. The residual effect of sulphur to mustard reflected maximum grain yield of succeeding rice. The uptake of nutrients i.e. N, P, K, S and Fe also increased significantly with increase in sulphur levels.

Tiwari (1994) conducted field experiment to study the effect of gypsum on yield of mustard cultivar on salt affected soil. He reported that increasing level of gypsum decreased the sodicity levels and significantly increased the yield of crop. He also worked on properties of salt affected soil and reported that the change in pH, ECe, water soluble cations and anions, exchangeable cations, exchangeable sodium percentage and calcium carbonate of salt affected soils are highly influenced by gypsum application, while saturation percentage, water soluble potassium, cation exchange capacity and carbonate were not affected by level of gypsum application. Increasing level of gypsum application decreased the salt and increased the water soluble calcium, exchangeable calcium, magnesium, potassium and calcium carbonate.

Jaggi *et al.* (1998) demonstrated that the application of nitrogen at different sulphur levels increased N concentration at flowering and pod formation stage in linseed. Sulphur application, at different N levels significantly interacted in increasing N concentration in seed and straw. Minimum N uptake in seed and straw was observed when N, in the absence of S was applied.

Minhas *et al.* (1995) concluded that addition of both gypsum and farmyard manure (FYM) resulted in reduction in pH and SAR of soil from 30 to 22. In the same study rice did not respond to added gypsum with respect to grain yield, Whereas, following wheat responded beneficially to both gypsum and FYM addition. Average yield increases were 18 and 24 % with FYM and gypsum respectively. No response to FYM was observed without gypsum.

Significant increase in grain and straw yield of rice were recorded on application of gypsum urea as compared to urea (Tripathi *et al.* 1997). At 60 kg level of N as gypsum urea the grain yield of rice increased upto 4.49 t ha^{-1}. An increase of 13 % and 6% increase in apparent recovery of N and agronomic N use efficiency respectively were recorded with the application of 60 kg N ha^{-1} through gypsum urea over prilled urea. The results indicate that gypsum urea not only increased the grain yield but also increased the N recovery by rice plant and reduced leaching losses of N.

2. Role of Potassium

It is well known that N and K are plant nutrients being required in high amounts for good crop growth. The physiological role of N is well understood. N is an essential element of bio molecules such as amino acid, protein and nucleic acid, phytochrome and a number of coenzymes. It is deeply involved in synthesis of deoxyribonucleic acid and nuclear proteins.

In contrast to nitrogen, potassium is not a structural component. It is involved in numerous biochemical and physiological processes (Mengal and Kirkby 1987). Potassium and nitrogen play crucial role in the process of meristematic growth a pre-requisite of crop production. For optimum growth N and K should be present in sufficient and balanced quantities. It was further shown that other processes such as the utilization of N for grain production are influenced by K (Mengal 1989). So the interaction between N and K is reviewed as under.

Shaviv and Hagin (1988) conducted experiment in green house to determined the effect of K on N utilization by wheat and concluded that K addition in soil increased the utilization of N fertilizer particularly when the ratio of ammonium to nitrate was increased. The highest uptake of reduced N was at the highest level of the ammonium to nitrate nitrogen ratio (50/50). When K was applied, tillering was enhanced by an increased ammonium ratio in the nitrogen mixture and by K.

Significant N and K interaction has been reported by Ebelhar *et al.* (1987) in their experiment conducted on a loamy sand to determined the effect of N and K rate on growth, grain yield and concentrations of N, K, Ca and Mg in the leaves of corn.

The effects of N and K application on fruit yield and quality of processing tomatoes were investigated by Ashcroft and Jones (1993). The number of green and rotten fruits increased significantly with increasing N and K rates. However, fruit size was not consistently affected by N or K. Total soluble salts (TSS) contents increased with increasing N rate although K alone had no significant effect on TSS contents. A significant N and K interaction was found.

Premaratne and Oertli (1994) demonstrated that the dry matter yield, nodule parameters (nodule number and fresh weight of nodules per plant, average weight of nodules) and total nitrogen accumulation in the plants increased with increasing K supply. The lowest potassium level, 1.0 mM was suboptimal for normal growth, nodulation and N accumulation, whereas 5.0 mM K was found to be an optimal level for the same parameters. However, the nitrogenase activity which was determined non-destructively, was not affected by an increased supply of K. So it can be concluded from this study that plants which receive a sufficient supply of K are in a position to synthesize more carbohydrates by photosynthesis, resulting in rapid turnover of carbohydrates thus allowing better development of nodules and consequently a higher N accumulation.

In a study conducted by Stromberger *et al.* (1994) to examine interactions of K with N and N sources, it was found that high K in conjunction with mixed-N generally enhanced dry matter accumulation and kernal primordia number for all hybrids. However, high K with either ammonium or nitrate generally has negative effect on dry matter accumulation and primordia number.

Abd-Alla and Wahab (1995) reported that the use of K increased the resistance of plant to water stress in his work on broad bean in which three week old nodulated faba bean plants were subjected to two levels of water stress (0.5 and 0.25 field capacity, soil water content of 20 and 10 %) for five weeks. Half of the stressed plants were treated with potassium chloride at 10 and 150 mg K kg^{-1} at the beginning of the water deficit. Nodulation, nitrogenase activity, total nitrogen and dry matter yield were significantly decreased by increasing stress but they were significantly higher with the two levels of K supply.

Hussain *et al.* (1997) described that all the growth parameters in radish viz. root diameter, root length, root weight and total biomass increased when the nitrogen was applied @ 200 kg ha^{-1} in combination with P and K as compared with control treatment i.e. nitrogen alone.

CHAPTER 3

MATERIALS AND METHODS

In Pakistan wheat yields are low and stagnant and factor productivity is declining. With a view to improve the yields and enhance fertilizer use efficiency various investigations were carried out under laboratory and field conditions. Detailed methodology of these studies is given as under:

3.1 Effect of salinity and mixed NH_4^+-N and NO_3^--N nutrition on wheat.

A pot culture experiment was conducted in the green house of the National Agricultural Research Center Islamabad to investigate the effect of mixed ammoniacal (NH_4^+) and nitrate (NO_3^-) nitrogen on wheat under different salinity regimes. The study was conducted on normal Gujranwala loam soil (Udic Haplustalf) collected from farmland of the centre. The soil was collected from 0-15cm soil depth. The soil was dried and passed through 2mm sieve before use. Physico-chemical characteristics of soil are given in the Table-1. Five kg of sieved soil was used in plastic pots. The soil was artificially salinized to three-salinity level i.e., 0, 6 and 12 dS m^{-1} using sodium chloride. Salinity regimes were created one week before sowing of wheat and moistened to field capacity.

NH_4^+–N and NO_3^-–N treatments are tabulated as under.

Mixed NH^{+}_{4}–N and NO_3^{-}–N treatments

Treatment No.	NH_4^{+}-N (%)	NO_3^{-}-N(%)	N sources
T1	0	0	–
T2	100	0	Urea
T3	75	25	$(NH_4)_2SO_4$, NH_4NO_3
T4	50	50	NH_4NO_3
T5	25	75	HNO_3, NH_4NO_3
T6	0	100	HNO_3

The same H ion concentration was maintained in all treatments using HCl in treatments where HNO_3 was not used. Nitrogen was applied @ 150 mg kg^{-1} in solution form and well mixed in the pots before sowing of wheat. Dicyandiamide was used as a nitrification inhibitor @ 2.5 mg kg^{-1} in all treatments to maintain above mentioned ammoniacal and nitrates ratios. The experiment was organized in completely randomized design. Phosphorus and potassium were applied @ 100 and 50 mg kg^{-1} respectively. The seeds of wheat cultivar inqlab 91 were sown in moist soil and covered with plastic sheet to avoid moisture loss through evaporation and to facilitate the germination. Experimental treatments were replicated thrice. After germination and establishment five plants per pot were kept. Crop was grown to maturity and watered as and when required. Grain and straw yield were recorded at the time of harvesting and nitrogen concentrations were determined in the plant material by Kjeldhal method. Harvest index, nitrogen uptake and apparent nitrogen recovery were calculated by using following formulae.

$$\text{Harvest index} = \frac{\text{Economic yield (grain yield)}}{\text{Biological yield (biomass)}}$$

$$\text{Apparent N recovery (\%)} = \frac{\text{N uptake}_F - \text{N uptake}_C}{\text{kg N applied}}$$

Where 'F' stands for fertilized crop and 'C' unfertilized control.

All the data were subjected to statistical analysis and treatment differences determined using LSD.

3.2 *Effect of mixed NH_4^+-N and NO_3^--N nutrition on wheat under different moisture regimes.*

A pot culture experiment was conducted in the glass house of National Agricultural Research Centre, Islamabad to investigate the effect of mixed ammoniacal (NH_4^+) and nitrate (NO_3^-) nitrogen nutrition on wheat under different moisture regimes. The study was conducted on normal Gujranwala loam soil collected from farmland of the centre. The soil was collected from 0-15 cm soil depth. The soil was dried and passed through 2mm sieve before use. Physico-chemical characteristics of soil are given in Table 1. Five kg of the sieved soil was used in plastic pots. Mixed NH_4^+ -N and NO_3^- -N treatments and sources of fertilizers and other most of the details as given in section 3.1 were used.

After germination and establishment, 5 plants per pot were kept and crop was grown under following three moisture regimes till maturity.

High moisture regime (HMR) with soil matric potential varying from 0 to -10 k Pa.

Medium moisture regime (MMR) with soil matric potential varying from –10 to –100 k Pa.

Low moisture regime (LMR) with soil matric potential varying from –100 to –1500 k Pa.

Crop was grown to maturity and watered as and when required to make up the water loss. Grain and straw yield were recorded at the time of harvesting and nitrogen concentration determined in the plant material. N uptake and recovery were calculated. All the data were subjected to statistical analysis and treatment differences determined using LSD.

3.3 *Effect of nitrogen sources and dicyandiamide (DCD) on wheat*

A field experiment was conducted at the campus of University of Arid Agriculture, Rawalpindi to investigate the effect of nitrogen sources and DCD, a nitrification inhibitor on the yield and nitrogen efficiency by wheat. The physico-chemical characteristics of soil used for experiment are given in the Table-2. Treatments for nitrogen carriers/sources and nitrification inhibitor (DCD) are appended below

T1 = control

T2 = urea (U)

T3 = Ammonium sulphate (AS)

T4 = Calcium ammonium nitrate (CAN)

T5 = U + 2% DCD

T6 = AS + 2% DCD

T7 = CAN + 2% DCD

The experiment was organized in randomized complete block design using four replications. Plot size was 3m x 5m. Fertilizers were applied at the time of sowing @ 100, 100 and 50 kg NPK ha^{-1}, respectively. In T5, T6 and T7 2% solution of DCD was sprayed on the fertilizers, which was then dried and applied in the field. Phosphorus was applied as single super phosphate. Potassium was applied as potassium sulphate. Wheat variety Inqlab-91 was sown during the last week of October. Crop was grown under rainfed condition and no irrigation was applied. Weeds were controlled manually. Mineral nitrogen (NH_4^+-N and NO_3^-–N) dynamics was studied by taking soil sample from 0-22 cm soil depth at an interval of 2 weeks up to 105 days. Nitrate N in the soil was estimated immediately by extracting with 0.5 M $NaHCO_3$ and then the concentration was determined by colorimetric method. Results were then expressed on oven dry basis. Ammoniacal nitrogen was extracted by K_2SO_4 and concentration determined by colorimetric method. Crop was grown to maturity. Productive tillers, grain and straw yields were recorded at the harvest. Thousand-grain weight was recorded. Harvest index was calculated by formula mentioned in section 3.1.

Nitrogen concentration in grain and straw was determined by Kjeldhal method using kjeltech apparatus. Nitrogen uptake and N recovery was then calculated. Agronomic and physiological efficiencies were calculated according to the following formulae.

$$\text{Agronomic efficiency (kg yield/kg N)} = \frac{\text{Grain yield}_F - \text{Grain yield}_C}{\text{kg N applied}}$$

$$\text{Physiological efficiency (kg yield/kg N utilized)} = \frac{\text{Grain yield}_F - \text{Grain yield}_C}{\text{N uptake}_F - \text{N uptake}_C}$$

All the data were subjected to statistical analysis and treatment differences determined by using Duncan's Multiple Range Test.

3.4 Effect of gypsum on NH_3 volatilization losses and efficiency of different nitrogen fertilizer for wheat.

The studies were organized on normal Gujranwala loams soil collected from the National Agricultural Research Centre, Islamabad. The soil was air dried, ground and passed through 2mm sieve before use. Physico-chemical characteristics of the soil are given in Table 1.

3.4.1 Effect of nitrogen sources and gypsum application on soil pH

A kilogram of prepared soil was placed each in 20 plastic bags and brought to field capacity. The treatments included no nitrogen and 200-mg N kg^{-1} of soils each from urea, urea nitrophos (UNP), ammonium sulphate (AS) and calcium ammonium nitrate (CAN). All treatments were applied with and without gypsum to give Ca/N (equivalent) ratio 0.5. The treatments were replicated twice. The soil in each bag was incubated at controlled temperature, 30 ^{0}C. A 20-gram portion from each bag was sampled to measure soil pH using 1:1 soil : water ratio at 0,3,24 and 96 hours after fertilizer addition and treatment means were determined.

3.4.2 Effect of gypsum on ammonia volatilization loss.

This part of the study was carried out in plastic jars each containing 500-g of air-dried soil. Fertilizer treatments as given in section 3.4-1 were applied in solution form @ 200 mg N kg^{-1} soil. Before the addition of fertilizer, soil moisture was brought to field capacity level and gypsum was applied at the rate to obtained Ca/ N equivalent ratio of 0.5. Soil in the jars was mixed well with fertilizers. Ammonia gas evolved was trapped in 2 % boric acid placed at the soil surface in beaker. Beakers containing boric acid with bromocresol green indicator which were removed at 6, 12, 24, 48, 96, and 192 hours after the addition of fertilizer solutions and replaced with beakers containing fresh boric acid. Ammonia was determined by titrating excess boric acid against 0.005 M H_2SO_4 (Blaise *et al.* 1996).

3.4.3 Effect of gypsum on efficiency of different nitrogen fertilizer for wheat

Investigations on the efficiency of nitrogenous fertilizer for rainfed wheat as influenced by gypsum application were carried at the National Agricultural Research Centre, Islamabad on a normal (non-saline non-sodic) loam soil. Nitrogen sources and rates of gypsum used in the study are:

T1 = Control + G0

T2 = Urea + G0

T3 = Urea nitrophos (UNP) + G0

T4 = Ammonium sulphate (AS) + G0

T5 = Calcium ammonium nitrate (CAN) + G0

T6 = Control + G1

T7 = Urea + G1

T8 = UNP + G1

T9 = AS + G1

T10 = CAN + G1

T11 = Control + G2

T12 = Urea + G2

T13 = UNP + G2

T14 = AS + G2

T15 = CAN + G2,

GO, G1 and G2 are the rates of the gypsum applied at the rate of 0, 300 and 600 kg gypsum ha^{-1}. Nitrogen was applied @ 100 kg ha^{-1}. Phosphorus and K were applied @ 100 and 50 kg ha^{-1}, respectively. Phosphorus was applied as single superphosphate and potassium as potassium sulphate. All the fertilizers and gypsum were applied before seeding of wheat and well incorporated in to soils. Plot size was 5 x 3 m^2. The study was organized in randomized complete block design using 3 replications. Wheat variety Rohtas-90 was sown during the 3rd week of November. Crop was grown under rainfed conditions and no irrigation was given. Weeds were controlled by hand weeding. Crop was grown to maturity. Productive tillers, grains and straw yields were recorded at the time of harvesting. Thousand-grain weight was also recorded. Harvest index was calculated by using formula mentioned in section 3.1. Nitrogen concentration in grain and straw was determined by Kjeldhal method using kjeltech apparatus. Nitrogen uptake in grain and straw was also calculated. Agronomic and physiological efficiencies and apparent nitrogen recovery were calculated according to Craswell and Gedwin (1984) by using formulae mentioned in section 3.3. All the data were subjected to statistical analysis and treatment differences determined using Duncan's multiple range tests.

3.5 *Effect of potassium fertilization on the efficiency of different nitrogen fertilizer for rainfed wheat.*

Investigation on the efficiency of nitrogenous fertilizers for rainfed wheat as influenced by potassium application were carried at the National Agricultural Research Centre, Islamabad on a normal (non-saline non-sodic) loam soil. Nitrogen sources and rates of potassium used in the study are;

T1 = Control + KO

T2 = Urea + KO

T3 = Ammonium sulphate (AS) + KO

T4 = Calcium ammonium nitrate (CAN) + K1

T5 = Control + K1

T6 = Urea + K1

T7 = AS = K1

T8 = CAN + K1

T9 = Control + K2

T10 = Urea + K2

T11 = AS + K2

T12 = CAN + K2

KO, K1 and K2 are the rates of potassium applied at the rate of 0, 50 and 100 kg K ha^{-1}. Nitrogen and phosphorus were applied @ 100 and 50 kg ha^{-1}, respectively. Phosphorus was applied as single superphosphate and potassium as potassium sulphate. All the fertilizers were applied before seeding of wheat and well incorporated in to soils. Plot size was 5 x 3 m^2. The study was organized in randomized complete block design using three replications. Wheat variety Rohtas-90 was sown during the 3rd week of November. Crop was grown under rainfed conditions and no irrigation was given. Weeds were controlled by hand weeding. Crop was grown to maturity. Number of productive tillers, grains and straw yield were recorded at the time of harvesting. Thousand-grain weight was also recorded. Harvest index was calculated by using formula mentioned in section 3.1.

3.6. *Soil Analyses*

The analysis of soil samples were carried out as under:

1. Preparation of Soil Samples

Soil samples under study were air dried, processed with pestle and mortar and passed through 2 mm sieve. These were later stored for the estimation of various physical and chemical characteristics. The methods used are described below.

2. Saturation Percentage

It was determined by preparing a saturated soil paste. A sample of about 250g of soil was taken. Distilled water was added to it slowly while stirring it with spatula. The soil water mixture was consolidated from time to time during the stirring process by tapping the container on the laboratory bench. After the saturation point, the sample was allowed to stand for about an hour.

A sample from saturated soil paste was taken in a tared china dish and placed in the oven at 105 °C for 24 hours. The sample was weighed again. Loss in weight indicated moisture content and saturation percentage was worked out according to the formula (Page *et al.* 1982).

$$\frac{\text{Loss in weight (g)}}{\text{Weight of oven dry soil}} \times 100$$

3. Mechanical Analysis

A 40 g soil was weighed and placed into a 400-ml beaker. 250 ml of distilled water and 100 ml of sodium hexametaphosphate solution (1%) were added into it. The sample was allowed to soak over night.

The sodium hexametaphosphate treated samples were transferred to a dispersion cup and the contents were mixed with electric mixer for 5 minutes. The contents were added to a one-liter sedimentation cylinder and the volume was made up with distilled water. Silt + clay and clay fractions were computed with the help of a Bouycous-hydrometer and sand was worked out by subtraction. The textural class was determined from ISSS textural triangle (Gee and Bauder 1986).

4. Soil pH

A 25 g soil sample was taken in a 100 ml Erlenmeyer flask and 25 ml distilled water was added into it. The contents were mixed and then the flask was placed on a reciprocal shaker for 30 minutes. The soil pH was recorded with pH meter (Page *et al.* 1982).

5. Electrical conductivity

It was measured by preparing a saturated soil paste and getting the extract with the help of vacuum pump. The conductivity of the extract was measured with the help of conductivity meter after calibrating the instrument at the temperature of the solution (Rhodes 1982).

6. Calcium Carbonate

A sample of 10 g of soil was taken in a 150 ml beaker, to which 30 ml of 0.5 N hydrochloric acid was added. The beaker was covered with a watch glass and the solution was boiled gently for 5 minutes, then cooled, filtered and washed all the acid from the soil with water. Two drops of one percent phenolphthalein indicator were added in 60 percent ethanol and titrated against 0.25 N sodium hydroxide solution (Hussain and Jabbar 1985).

7. Organic Matter

A 2 g soil sample was taken in a 500 ml Erlenmeyer flask, to which 10 ml of 1 N potassium dichromate were added and the flask was swirled to mix the soil contents. Then 20 ml of concentrated sulphuric acid was added in the soil suspension. Flask was swirled for one minute and allowed to stand for 30 minutes. 200 ml of water, 10 ml of phosphoric acid and 1 ml of diphenylamine indicator were added into the flask. The contents of flask were titrated against 0.5 N ferrous sulphate solution until color changed from blue to red (Page *et al.* 1982)

8. Phosphorus

Phosphorus was extracted from the soil with 0.5 M $NaHCO_3$ at pH 8.5. A 5 g soil and 100 ml of extracting solution (0.5 M $NaHCO_3$) were added to a 250 ml Erlenmeyer flask. One tea spoon of carbon black was also added. The flask was shaken for 30 minutes with a mechanical shaker. The suspension was filtered through Whatman filter paper No. 40. A 5 ml aliquot of the extract was taken into a 25 ml volumetric flask and acidified with 5 N H_2SO_4 to pH 5. Thereafter, distilled water and 4 ml of ammonium molybdate-ascorbic acid were added to it for color development. Transmittence was observed with spectrophotometer at 880 nm. Standard curve was prepared with dilute P solution containing 2-25 mg of P placed in 25ml flasks. After color development with ascorbic acid, percent transmittence was plotted against P concentration (Olsen and Sommers 1982).

9. Potassium

Potassium was determined by placing 40 g soil sample in a centrifuge tube and 25 ml of ammonium acetate was added to it. The flask was shaken for 10 minutes and it was centrifuged until the supernatant was clear. The supernatant was decanted into a 100 ml flask and the volume was made up to the mark with ammonium acetate. Potassium was later determined by flame photometer. The curve was prepared by preparing standard solutions of 0, 5, 10, 20, 30, 40, 50…..100 ppm (Knudsen *et al.* 1982).

10. Total Nitrogen

Total nitrogen was determined by Kjeldhal's method. A weighed sample was placed in a micro Kjeldhal digestion flask. 3 g of K_2SO_4 catalyst mixture was added to it and 3 ml of concentrated sulphuric acid were poured in the flask. The flask was heated gently on the digestion stand. When the frothing ceased, the heat was increased until the digest was clear. Thereafter, the contents were boiled for about 5 hours.

After completion of digestion, the flask was allowed to cool and about 20 ml of distilled water was added slowly. The flask was swirled and the contents were transferred to distillation flask. Enough distilled water was added to indicate a volume of 50 ml and the stopcock was closed connecting the funnel and distillation chamber. A 5 ml boric acid indicator solution was added to 50 ml Erlenmeyer flask and placed under the condenser of the distillation apparatus. A 20 ml of 10N NaOH was slowly added into the distillation chamber by opening the funnel stopcock. Enough water was added so as to indicate the volume of 80 ml. The funnel stopcock was closed and distillation was commenced. When the distillate reached the 35 ml mark on the receiver flask, the distillation was stopped. Ammonium nitrogen in the distillate was estimated by titration with 0.01 N H_2SO_4 (Bremner and Mulvaney 1982).

11. Nitrate Nitrogen

A 2.5 g soil samples were weighed into 250 ml Erlenmeyer flasks, 0.25 g carbon black and 50 ml 0.5 M $NaHCO_3$ extracting solution were added to it. The flasks were placed on a flat bed shaker for 30 minutes and then filtered using Whatman filter paper No. 42.

A 1.0 ml of clear filtrate was transferred to 25 ml test tube. 3 ml working copper sulphate solution, (0.25%), 2 ml working hydrazine sulphate solution (Prepared by diluting 22.5 ml of 2.7% hydrazine sulphate solution to 1 liter) and 3 ml working sodium hydroxide solution (0.3 N) were added to each test tube. The contents were mixed and heated in a water bath (38 °C) for 20 minutes.

After removing from the water bath, 3 ml of color reagent (sulfanilamide + N- (1-napthyl-ethylenediamine dihydrochloride + H_3PO_4) were added to it to stand for 20 minutes. Later absorbency was read at 540 nm on spectrophotometer (Winkleman *et al.* 1990).

12. Ammoniacal Nitrogen

A 5.0 g soil sample was weighed into 250 ml Erlenmeyer flask, to which 50 ml extracting reagent (1 N K_2SO_4) was added. The flask was shaken for 15 minutes and then contents were filtered using Whatman filter paper No.40. 7.0 ml of filtrate was transferred to 25 ml test tube and 4 ml sodium phenate and 3 ml sodium hydrochlorite were added to the tube. The contents were mixed on vortex mixure and heated in a water bath (70 °C) for 20 minutes. After removing from water bath it was allowed to stand for 30 minutes at room temperature. Later absorbency was read at 660 nm on spectrophotometer (Winkleman *et al.* 1990).

13. Determination of soil matric potential

Matric potential of soil sample was determined using pressure plate (Klute 1986).

3.7 Plant Analysis

1. Biomass Estimation

At maturity plants were harvested and weighed and yield was converted in kg ha^{-1}.

2. Sample Processing:

After harvesting of the crop, straw and grain samples were dried in oven at 70 °C till their weight was constant. After drying straw and grain samples were ground separately and were stored in air tight bottles (Winkleman *et al.* 1990).

3. 1000 grain weight

Grains were taken randomly and counted with the help of grain counter and weighed by means of electric balance.

4. Nitrogen determination

The samples were digested in concentrated sulphuric acid containing K_2SO_4 and Se to increase the reaction temperature (420 ^{0}C) and accelerate digestion. After digestion, the reaction mixture was cooled, diluted and made alkaline using 10 N NaOH, then distilled into 4 percent boric acid solution.

A 0.5 g dried ground plant material was placed in clean dry digestion tubes, 10 ml concentrated sulphuric acid were added to it. The contents were mixed by swirling the tubes. The material was digested in the exhaust chamber for about 60 minutes. The tubes were allowed to cool. After cooling, 75 ml of distilled water was added into each digested sample, which was distilled, and distillate was received in 25 ml 4 percent boric acid solution contained in 250 ml receiver flasks. It was titrated against 0.1 N HCl (Winkleman *et al.* 1990).

5. Calculation for Recovery of Nitrogen

Uptake of nitrogen by wheat grain and straw from fertilized treatments minus its uptake from unfertilized (control) treatments was taken as the recovery applied fertilizer nitrogen by the wheat and it is expressed as a percentage of applied fertilizer.

1. Statistical Analysis

The data collected for various characteristics were analyzed statistically by analysis of variance technique. The treatment means were compared by Duncan's multiple range (DMR) test (Steel and Torrie 1980).

Table 1: Physico-chemical characteristics of the soil.

Characteristics	Unit	Gujranwala loam series
pH (1:1)	-	7.80
EC	dSm^{-1}	0.25
$CaCO_3$	%	3.50
Organic matter	%	0.59
Olsen P	$mg\ kg^{-1}$	4.50
Available K	$mgkg^{-1}$	0.76
Total N	%	0.04
$NH^{+}_{4}-N$	$mgkg^{-1}$	10
$NO_3^{-}-N$	$mgkg^{-1}$	13

Table 2: Physico-chemical characteristics of the soil

Property	Unit	Rawalpindi Soil Series
Sand	%	36
Silt	%	40
Clay	%	24
Textural class	-	Loam
Saturation Percentage	-	34.0
ECe	dS m^{-2}	0.25
Soil pH	-	6.90
Organic matter	%	0.55
Olsen P	mg kg^{-1}	4.5
Available K	mg kg^{-1}	110.0
NH^{+}_{4}–N	mg kg^{-1}	6.86
NO_3^{-}–N	mg kg^{-1}	17.80
Total–N	%	0.05

CHAPTER 4
RESULTS AND DISCUSSION

The results of various nitrogen management experiments conducted to investigate the effect of fertilizer management practices on wheat yield and nitrogen utilization are discussed as under:

4.1 Effect of salinity and mixed NH_4^+ -N and NO_3^- -N nutrition on wheat

The investigations were carried out on originally normal (non-saline, non-sodic) soil, which was alkaline in reaction (pH 7.8). The soil was low in organic matter, total and mineral N. It was medium in available P and K (Table 1) the soil was artificially salinized to 0,6 and 12 dS m^{-1}.

- **Physical Crop Responses**

Data relating to tillers, grain and straw yield, total biomass and harvest index is given in Table 3.

Productive tillers were significantly affected by N fertilizer treatments and the salinity regimes. Maximum number of tillers were recorded in zero salinity treatment. Increasing levels of salinity significantly reduced the tillers. Lowest-tillers were recorded at the highest salinity level (12 dS m^{-1}). Mixed NH_4^+-N:NO_3^- -N nutrition treatment had significant effect on productive tillers. Maximum number of tillers were recorded with 50:50 NH_4^+-N:NO_3^--N ratio. This effect was more pronounced at 6 dS m^{-1} salinity level. Difference in tillers due to 75:25 and 25:75 NH_4^+-N: NO_3^- -N ratio was non-significant. However, application of either 100 per cent NH_4^+-N or NO_3^- -N gave lower number of tillers than the ideal NH_4^+-N: NO_3^- -N ratio.

Table 3 Effect of different ratios of NH_4^+–N and NO_3^-–N nutrition and salinity on wheat.

Treatments: *Nitrogen* *NH^+_4-N:NO^-_3-N*		*Salinity regimes (dSm^{-1})*	**Productive tillers** *(No pot^{-1})*	**Grain yield** *(g pot^{-1})*	**Straw yield** *(g pot^{-1})*	**Biomass** *(g pot^{-1})*	**Harvest index**
0	0	0	3.33 ghi	3.21 l	3.47 l	6.67 n	0.481 ab
100	0	0	9.00 c	25.08 c	27.66 d	52.71 d	0.475 ab
75	25	0	10.67 b	29.54 b	33.43 b	62.95 b	0.469 ab
50	50	0	12.0 a	32.97 a	36.82 a	69.78 c	0.472 ab
25	75	0	9.67 bc	29.08 b	31.13 c	60.08 c	0.484 ab
0	100	0	7.67 d	23.96 d	26.83 e	50.79 e	0.472 ab
0	0	6	2.67 hi	1.66 m	1.77 m	3.43 o	0.484 ab
100	0	6	3.33 ghi	13.20 g	14.23 h	27.43 I	0.481 ab
75	25	6	4.33 fg	14.90 f	17.25 g	32.13 g	0.463 abc
50	50	6	6.33 e	17.87 e	18.42 f	36.28 f	0.492 a
25	75	6	4.67 f	14.39 f	16.77 g	31.16 fi	0.462 abc
0	100	6	3.33 ghi	11.84 h	13.87 h	25.72 j	0.461abcd
0	0	12	2.33 I	0.72 n	1.01 m	1.73 p	0.412 f
100	0	12	3.00 hi	6.08 k	8.08 k	14.15 m	0.43 ef
75	25	12	3.67 fgh	7.16 j	9.25 j	16.4 l	0.436 cdef
50	50	12	4.67 f	8.05 I	10.67 I	18.73 k	0.431 def
25	75	12	3.33 ghi	7.18 j	8.48 jk	15.66 l	0.459 bcde
0	100	12	3.00 hi	6.01 k	7.74 k	13.75 m	0.438 cdef

Values followed by same letters are not significantly different from each other at 5 per cent level of significance.

Wheat grain and straw yield and total biomass were significantly affected by the salinity level and mixed NH_4^+-N and NO_3^- -N nutrition treatments. Salinity treatments significantly reduced the yield and total biomass and the lowest yield and biomass were recorded at the highest salinity level. Mixed NH_4^+-N and NO_3^- -N treatments had also significant effect on these yield parameters. Significantly the highest yield and total biomass were recorded at NH_4^+-N : NO_3^- -N ratio of 50:50. The ratios of 75-25 and 25-75 gave significantly lower yields than the ideal ratio of 50:50. However, the difference due to formers ratio were non-significant. Use of either NH_4^+-N or NO_3^--N alone gave significantly lower yields.

Harvest index was not significantly affected by mixed NH_4^+-N : NO_3^- -N nutrition treatments. Salinity levels had some effect on harvest index. It was significantly reduced at the highest level of salinity. Wheat yield reduction at higher salinity levels could be attributed to increased hydrostatic and osmotic pressures. Similar results were reported by Hira and Singh (1973) who recorded marked reduction in wheat at ECe 12 dS m^{-1}. Hummadi (1977) reported 50 per cent reduction in yield at ECe 8.5 dS m^{-1}.

Higher wheat yields with mixed NH_4^+-N : NO_3^- -N nutrition than NH_4^+-N or NO_3^- -N can be attributed to balanced uptake of the soil nutrients (Ali 1993). Similar results were reported by Shaviv *et al.* (1990), Bock (1986), Ali *et al.* (1995) and Ali (1993).

Ammoniacal-N alone reduced the uptake of K, Ca and Mg. Nitrate-N alone reduced the uptake of sulphate, phosphate and some micronutrients (Ota and Yamamoto 1987, Ali 1993). Mixed NH_4^+–N : NO_3^--N favoured the balanced uptake of anions and cations, therefore, gave higher yields than other treatments.

● Nitrogen Utilization by Wheat

Nitrogen concentration in wheat grain was much higher than in straw (Table 4). Nitrogen concentration was significantly affected by salinity levels and mixed NH_4^+-N : NO_3^- -N nutrition treatments. Nitrogen concentration decreased with increasing salinity levels. Thus lowest concentration was recorded at the highest salinity level (12 dS m^{-1}). Similar results have been reported by Ali (1993). Nitrogen concentration was the highest with mixed NH_4^+-N : NO_3^- -N ratio of 75-25 and it was significantly lower with either NH_4^+-N or NO_3^- -N than the mixed NH_4^+-N : NO_3^- -N nutrition.

Nitrogen uptake in the grain, straw and grain + straw (total) was significantly affected by salinity levels and mixed NH_4^+-N and NO_3^- -N nutrition. Increasing levels of salinity significantly reduced the nitrogen uptake. Thus lowest uptake was recorded at the highest salinity level (12 dS m^{-1}). In general N recovery in wheat was the highest in N treatment without salinity. Increasing salinity levels significantly reduced N recovery. Thus lowest N recovery was recorded at the highest salinity levels (Table 4). Nitrogen recovery was significantly affected by different N treatments. It was the highest with mixed NH_4^+-N : NO_3^- -N ratio of 50: 50. Recovery was significantly lower with either NH_4^+-N or NO_3^- -N alone (Fig.1).

Fig.1 Effect of salinity and mixed ammonium and nitrate nutrition on nitrogen utilization by wheat.

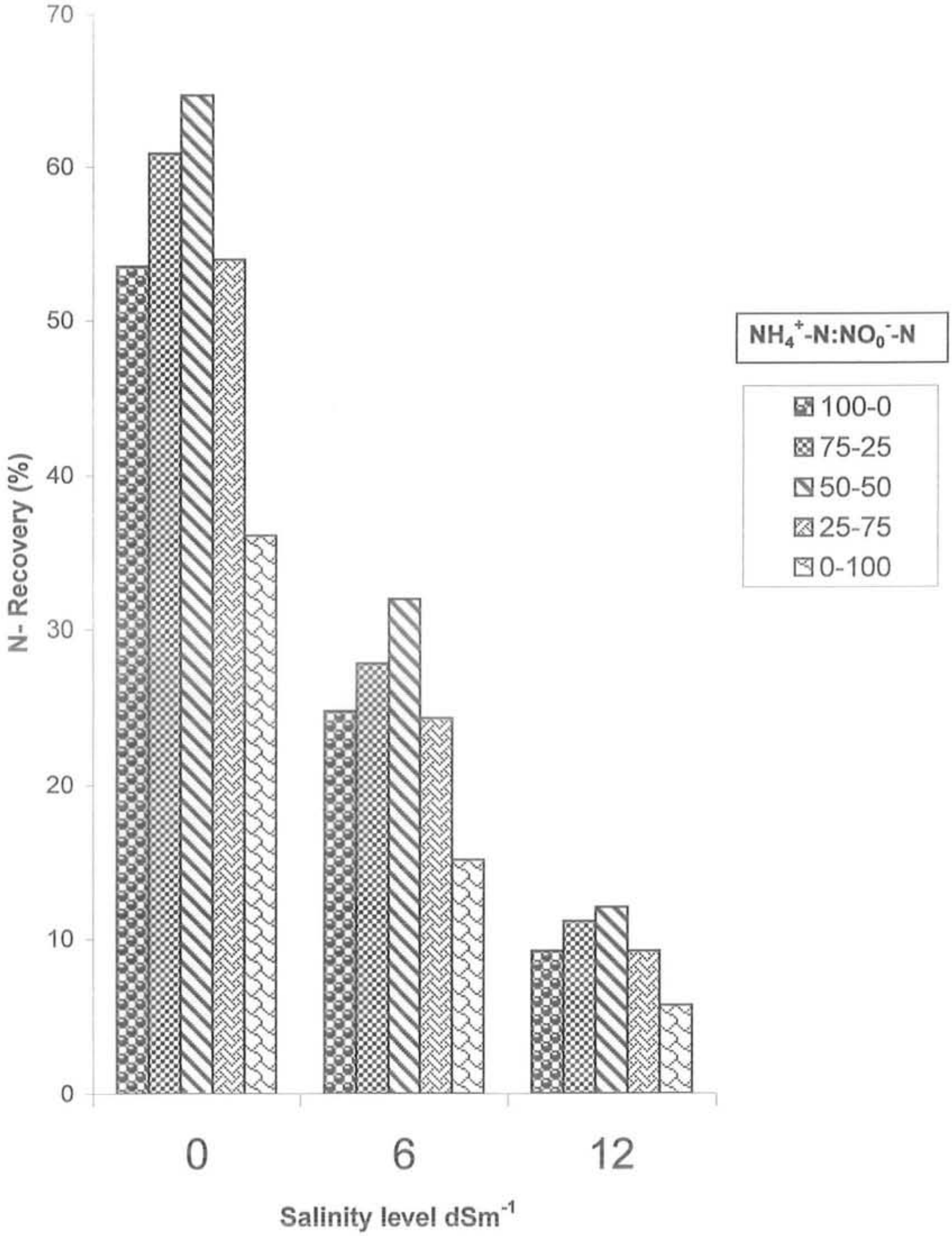


Table 4 Effect of salinity and mixed ammonium and nitrate nutrition on nitrogen utilization by wheat.

Treatments			N. Conc (%)		Nitrogen uptake mg/pot			N-Recovery (%)
Nitrogen NH^{+}_{4}-N	NO^{-}_{3}-N	*Salinity regimes* (dSm^{-1})	*Grains*	*Straw*	*Grains*	*Straw*	*Total*	
0	0	0	0.26 l	0.110 l	8.36 m	3.92 k	12.27 m	-
100	0	0	1.25 a	0.360 a	314.3 d	99.54 b	413.8 c	53.54 c
75	25	0	1.20b	0.340 b	354. 2 b	114.8 a	469.0 b	60.9 b
50	50	0	1.16 c	0.310 c	382.4 a	115.3 a	497.8 a	64.74 a
25	75	0	1.11 d	0.300 c	322.8 c	94.41 c	417.2 c	53. 99c
0	100	0	0.92 h	0.230 g	220.4 e	62.6 d	283.0 d	36. 10 d
0	0	6	0.17 m	0.077 n	2.81 mn	1.35 kl	4.16 n	-
100	0	6	1.13 d	0.287 d	149.1 h	40.80 f	189.9 g	24.77 g
75	25	6	1.12 d	0.267 e	166.9 g	46.02 e	212.9 f	27.83 f
50	50	6	1.11 d	0.247 f	198.3 f	45.46 e	243.7 e	31.94 e
25	75	6	1.04 e	0.217 h	150.2 h	36.36 g	186.6 g	24.33 g
0	100	6	0.79 j	0.183 I	93.89 i	25.42 h	117.9 h	15.17 h
0	0	12	0.10 n	0.037 o	0.71 n	0.38 l	1.08 n	-
100	0	12	0.92 h	0.177 I	56.15 k	14.28 I	70.43 k	9.25 j
75	25	12	0.98 f	0.159 j	70.44 j	14.51 I	84. 95 j	11.18 i
50	50	12	0.96 g	0.137 k	77.29 j	14.55 I	91.85 i	12.1 i
25	75	12	0.85 i	0.113 l	60.79 k	9.6 j	70.39 k	9.24 j
0	100	12	0.61 k	0.097 m	36.68 l	7.46 j	44.07 l	5.73 k

Values followed by same letters are not significantly different from each other at 5 per cent level of significance.

Highest N recovery NH_4^+-N : NO_3^- -N at 50 : 50 is attributed to highest biomass production in this treatment due to balanced uptake of anions and cations. For greater biomass production more nitrogen was utilized by wheat. As a result N recovery was significantly improved with ideal NH_4^+-N : NO_3^- -N ratio. With either NH_4^+-N or NO_3^- -N alone wheat biomass production was significantly reduced due to hampered uptake of anions, cations and nitrogen. Increasing salinity levels caused significant reduction in N utilization and recovery due to increased hydrostatic and osmotic pressures resulting in reduced uptake of water and nutrients included nitrogen. Therefore, increasing salinity levels caused a progressive decrease in N recovery by wheat.

4.2. Effect of mixed NH_4^+-N and NO_3^--N nutrition on wheat under different moisture regimes.

The investigations were carried out on originally normal (non-saline, non-sodic) soil, which was alkaline in reaction (pH 7.8). The soil was low in organic matter, total and mineral nitrogen. It was medium in available P and K (Table 1).

- ***Physical Crop Responses***

Data relating to tillers, grain and straw yield, total biomass and harvest index is given in Table 5. Nitrogen fertilizer treatments and soil moisture regimes significantly affected productive tillers. Highest number of tillers were recorded at high moisture regimes (HMR). Increasing soil matric potential significantly reduced the tillers. Lowest number of tillers was recorded at low moisture regime (LMR). Mixed NH_4^+ - N : NO_3^- - N nutrition treatment had significant effect on productive tillers. Maximum tillers were recorded with 50:50 NH_4^+-N : NO_3^--N ratio. This effect was more pronounced at medium moisture regime (MMR). Differences in tillers due to 75:25 and 25:75 NH_4^+ - N: NO_3^- - N ratios were non-significant. However, application of either $NH4^+$ - N or NO_3^- - N gave less number of tillers than the ideal NH_4^+ - N:NO_3^- - N ratio (50:50).

Table 5 Effect of different ratios of NH_4^+–N and NO_3^-–N on wheat yields parameters under different moisture regimes.

Treatments			Productive tillers	Grain yield	Straw yield	Biomass	Harvest
Nitrogen		*Moisture*	tillers	*(g pot^{-1})*	*(g pot^{-1})*	*(g pot^{-1})*	Index
NH_4^+-N : NO_3^--N		*regimes*	*(No.pot^{-1})*				
0	0	LMR	3.0 k	2.56 n	2.60 o	5.16 p	49.93 a
100	0	LMR	4.67 I	8.71 l	9.83 m	18.54 n	46.97 a
75	25	LMR	4.67 I	11.82 j	12.78 k	24.61 l	48.03 a
50	50	LMR	6.33 h	15.17 h	16.50 I	31.66 j	47.93 a
25	75	LMR	4.67 I	13.84 I	14.32 j	28.16 k	49.13 a
0	100	LMR	4.33 ij	10.32 k	11.49 l	21.80 m	47.30 a
0	0	MMR	3.33 jk	3.42 m	3.54 no	6.96 o	49.07 a
100	0	MMR	7.33 gh	22.44 g	24.02 h	46.45 i	48.30 a
75	25	MMR	8.67 ef	25.80 e	25.03 g	50.84 g	50.80 a
50	50	MMR	10.33 bcd	27.76 d	29.74 e	57.49 e	48.23 a
25	75	MMR	9.33 de	25.72 e	27.12 f	52.84 f	48.63 a
0	100	MMR	8.00 fg	24.27 f	25.15 g	49.42 h	49.13 a
0	0	HMR	3.67 ijk	3.44 m	3.85 n	7.28 o	47.1 a
100	0	HMR	9.00 ef	27.74 d	29.04 e	56.78 e	48.83 a
75	25	HMR	10.67 bc	32.02 b	33.13 c	65.14 c	49.17 a
50	50	HMR	12.0 a	35.73 a	37.99 a	73.72 a	48.50 a
25	75	HMR	11.33 ab	32.17 b	34.52 b	66.69 b	48.23 a
0	100	HMR	9.67 cde	30.45 c	31.28 d	61.73 d	49.57 a

LMR= Low moisture regime, MMR= Medium moisture regime, HMR= High moisture regime.

Values followed by the same letters are statistically non-significant at 5% level of significance.

Wheat grain and straw yield and total biomass were significantly affected by the soil moisture regimes and mixed NH_4^+ - N and NO_3^- - N nutrition treatments. Soil moisture regimes significantly reduced the yield and total biomass and the lowest yield and biomass were recorded at the LMR (Table 5). Mixed NH_4^+-N and NO_3^--N treatments had also significant effect on these yield parameters. Significantly the highest grain yield (35.7 g pot) and total biomass (73.7 g pot) were recorded at NH_4^+–N:NO_3^-–N ratio of 50:50. The 75:25 and 25:75 ratio gave significantly lower yields than the ideal ratio of 50:50, however, the difference between former ratios were non-significant. Use of either, NH_4^+–N or NO_3^-–N alone gave significantly lower yields.

Harvest index was not significantly affected by mixed NH_4^+–N:NO_3^-–N nutrition treatments. Wheat yield reduction at LMR could be attributed to reduced uptake of water, nitrogen and other nutrients. Similar results were reported by Prihar *et al.* (1989) and Fardad and Pessarakli (1995).

Higher wheat yields with mixed NH_4^+–N:NO_3^-–N nutrition than NH_4^+ - N or NO_3^- - N can be attributed to balanced uptake of the soil nutrients. Similar results were reported by other researchers Shaviv *et al.* 1990, Bock 1986, Ali 1993, and Ali *et al.* 1995. Ammoniacal-N alone reduced the uptake of K, Ca and Mg. Nitrate-N alone reduced the uptake of sulphate, phosphate and some micronutrients. Mixed NH_4^+ - N: NO_3^- - N favoured the balanced uptake of anions and cations therefore, gave higher yields than other treatments.

● Nitrogen Utilization by Wheat

Nitrogen concentration in wheat grain was much higher than in straw (Table 6). Nitrogen concentration was significantly affected by soil moisture regimes and mixed NH_4^+-N:NO_3^--N nutrition treatments. Nitrogen concentration decreased with increasing soil matric potential. The lowest concentration was recorded at LMR. Similar results have been reported by Prihar *et al.* (1989). Nitrogen concentration was the highest with mixed NH_4^+ - N: NO_3^- - N ratio of 75:25 and it was significantly lower with either NH_4^+ - N: NO_3^- - N than the mixed NH_4^+ - N: NO_3^- - N nutrition.

Table 6 **Effect of mixed NH_4^+ and NO_3^- nitrogen on N concentration and uptake in wheat under different moisture regimes.**

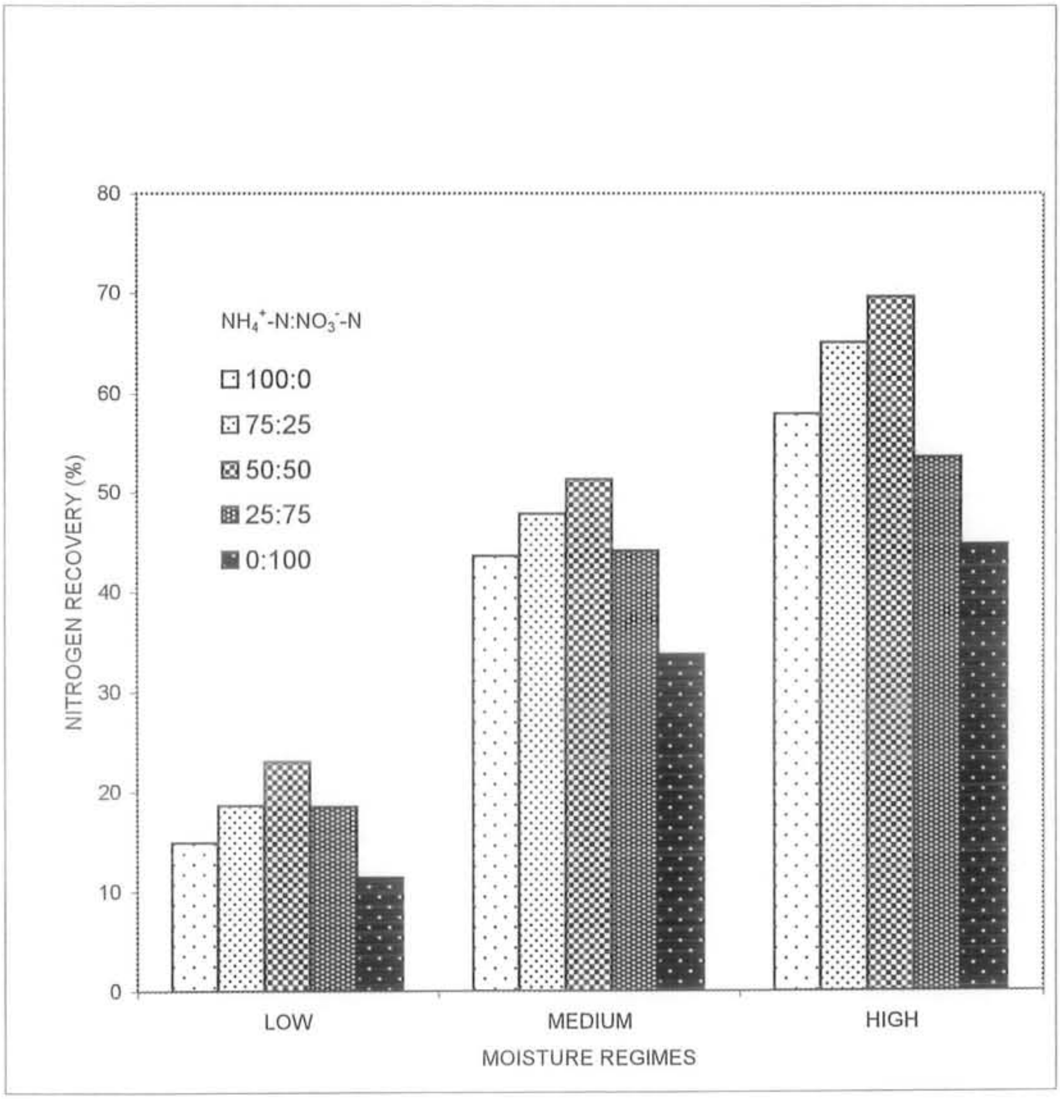
Treatments			**N. Conc. (%)**		**N uptake (mg pot$^{-1)}$**		
NH_4^+ - N	*NO_3^- - N*	*Moisture regimes*	*Grain*	*Straw*	*Grain*	*Straw*	*Total*
0	0	LMR	0.14 i	0.10 i	3.50 i	2.51 m	6.01 n
100	0	LMR	1.05 e	0.27 ef	91.32 j	26.55 k	117.9 j
75	25	LMR	0.96 f	0.25 gh	113.10 i	32.0 j	146.0 i
50	50	LMR	0.93 g	0.23 I	141.1 h	37.96 I	179.0 h
25	75	LMR	0.85 i	0.20 j	117.6 i	27.22 k	144.8 i
0	100	LMR	0.68 j	0.19 j	68.82 k	21.40 l	91.23 k
0	0	MMR	0.25 k	0.11 kl	8.42 l	3.89 m	12.31 l
100	0	MMR	1.17 b	0.32 c	269.2 f	76.81 f	339.3 f
75	25	MMR	1.15 bc	0.30 d	295.9 e	75.11 f	371.0 e
50	50	MMR	1.13 c	0.28 de	312.7 d	84.26 e	397.0 d
25	75	MMR	1.06 e	0.26 fg	272.6 f	70.51 g	343.0 f
0	100	MMR	0.84 i	0.24 hi	204.7 g	60.39 h	265.1 g
0	0	HMR	0.27 k	0.12 k	9.3 l	4.55 m	13.8 l
100	0	HMR	1.24 a	0.36 a	344.8 c	103.6 c	448.4 c
75	25	HMR	1.22 a	0.34 b	390.6 b	111.5 b	502.1 b
50	50	HMR	1.16 b	0.32 c	415.6 a	120.3 a	535.9 a
25	75	HMR	1.10 d	0.29 de	353.9 c	98.98 d	452.9 c
0	100	HMR	0.88 h	0.26 fg	268.0 f	81.32 e	349.3 f

Values followed by same letters are not significantly different from each other at 5 per cent level of significance.

Nitrogen uptake in the grain, straw and grain + straw (total) was significantly affected by soil moisture regimes and mixed NH_4^+-N : NO_3^--N nutrition. Increasing soil matric potential significantly reduced the nitrogen uptake. Thus lowest uptake of N was recorded at LMR. In general, N recovery in wheat was the highest in N treatments at HMR. Increasing soil matric potential significantly reduced N recovery. Thus lowest N recovery was recorded at LMR (Fig. 2). Nitrogen recovery was significantly affected by different N treatments. Nitrogen recovery was the highest with mixed NH_4^+-N : NO_3^-- N ratio of 50:50. Recovery was significantly lower with either NH_4^+ - N or NO_3^- - N alone (Fig. 2).

Highest nitrogen recovery at NH_4^+–N : NO_3^-–N of 50:50 is attributed to highest biomass production in this treatment due to balanced uptake of anions and cations. For greater biomass production more nitrogen was utilized by wheat. As a result N recovery was significantly improved with ideal NH_4^+–N:NO_3^-–N ratio (50:50). With either NH_4^+-N or NO_3^--N alone, wheat biomass production was significantly reduced due to hampered uptake of anions, cations and nitrogen. Increasing soil matric potential caused significant reduction in N utilization and recovery due to reduced uptake of water and nutrients including nitrogen. Therefore, increasing soil matric potential caused a progressive decrease in N recovery by wheat.

Fig. 2 Effect of different ratios of NH_4^+ - N and NO_3^- N on nitrogen utilization by wheat under different moisture regimes



4.3. Effect of nitrogen sources and dicyandiamide (DCD) on wheat

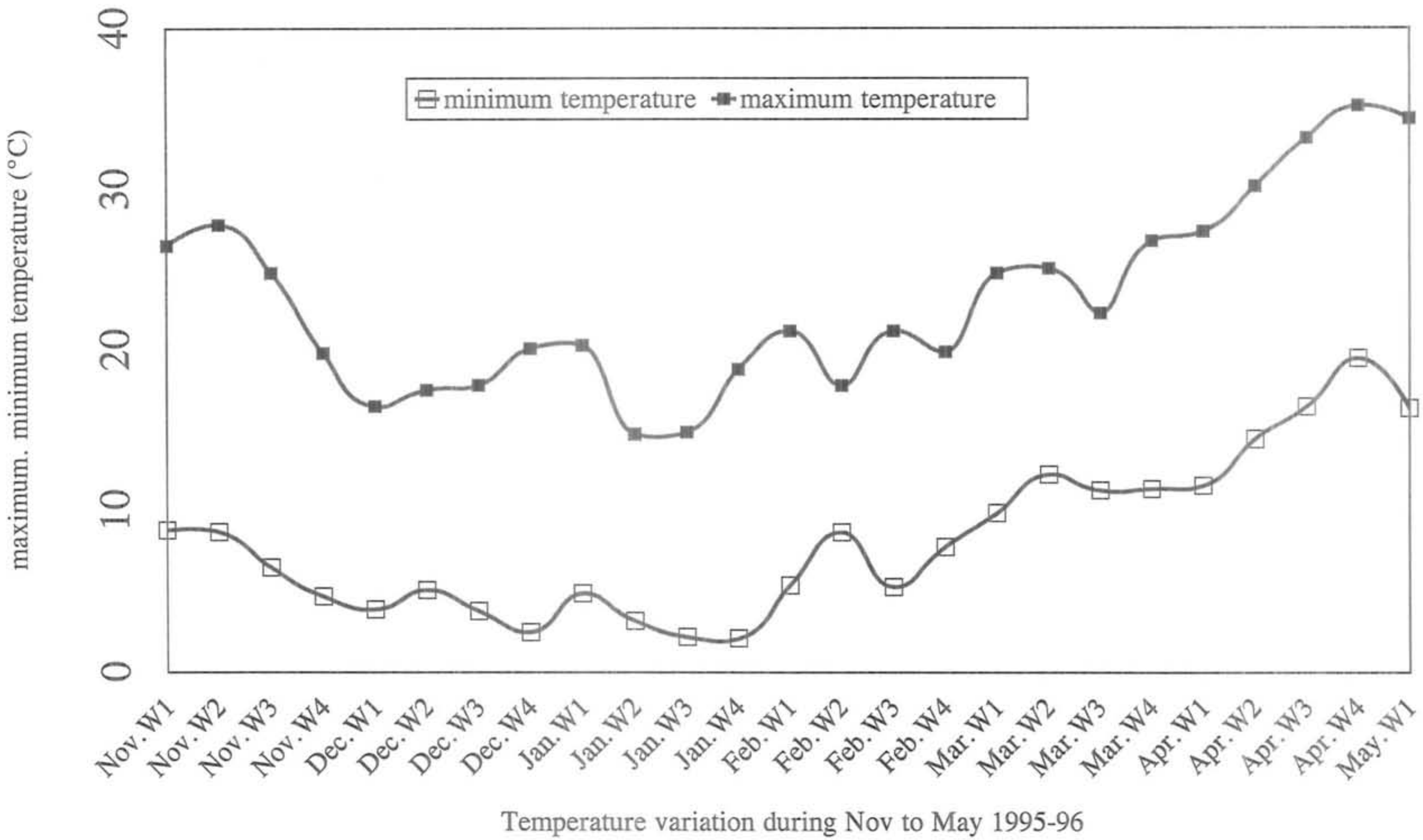
Physico-chemical characteristics of soil are given in Table-2.

- **Weather and soil condition**

The mean maximum temperature decreased from 28 °C to 14 °C in January and again rose to 34 °C in the 4th week of April. The mean minimum temperature decreased from 8 °C to 2 °C in the 4th week of January and then it again rose to a maximum of 20 °C in the 4th week of April (Fig. 3).

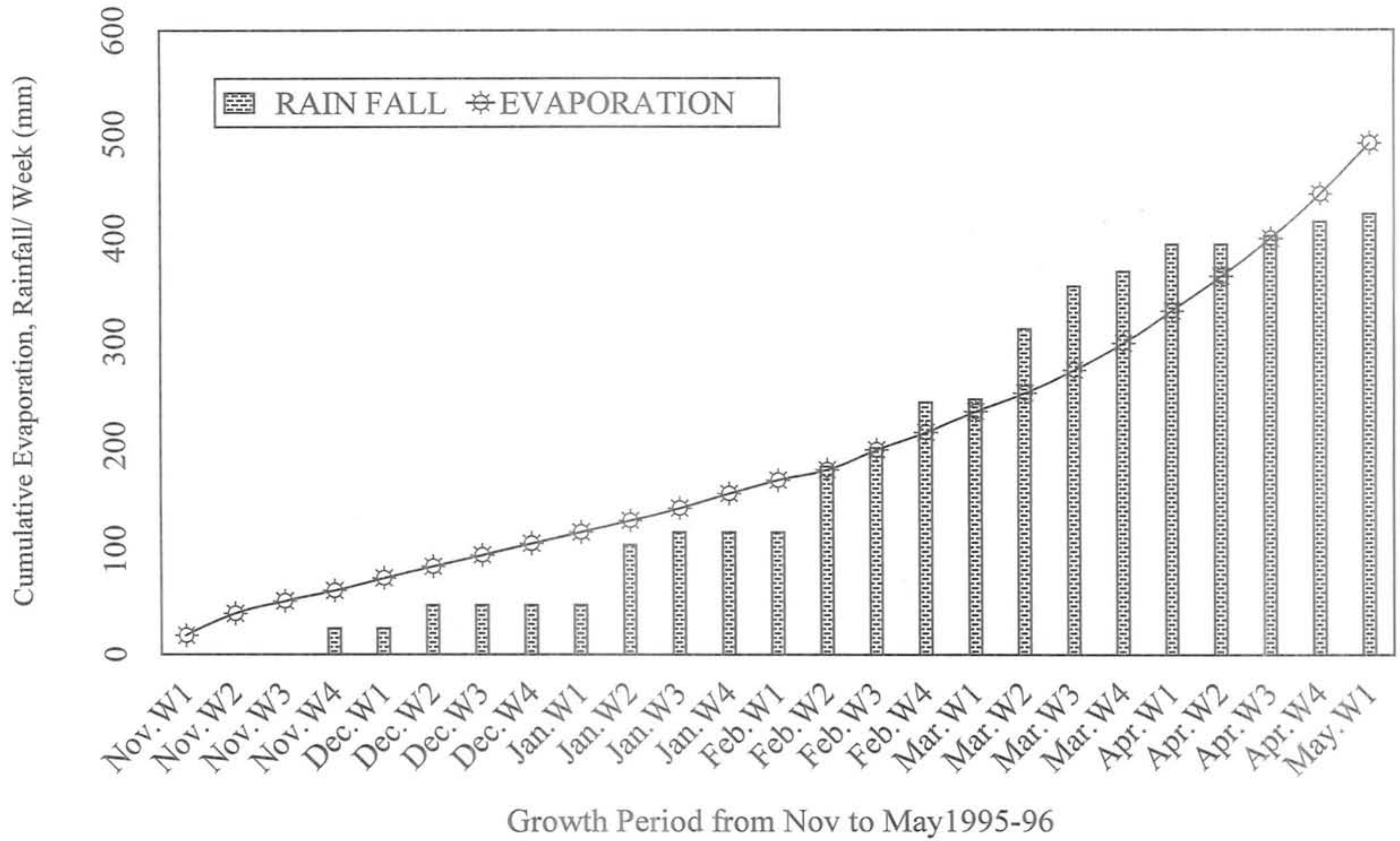
Cumulative rainfall was less than cumulative evaporation during the early growth period of the crop (from November to 1st week of February.) Thereafter it was always greater than evaporation (Fig. 4) indicating enough moisture availability at maximum tillering, anthesis, booting and grain formulation stage. However, as the crop reached maturity, evaporation exceeded rainfall. This is also very well reflected by the line graph of evaporation-rain-fall (Fig. 5). Overall rainfall was well distributed during the entire period of crop growth (Fig.6).

Fig. 3 Mean maximum and minimum temperature during the growth period of crop



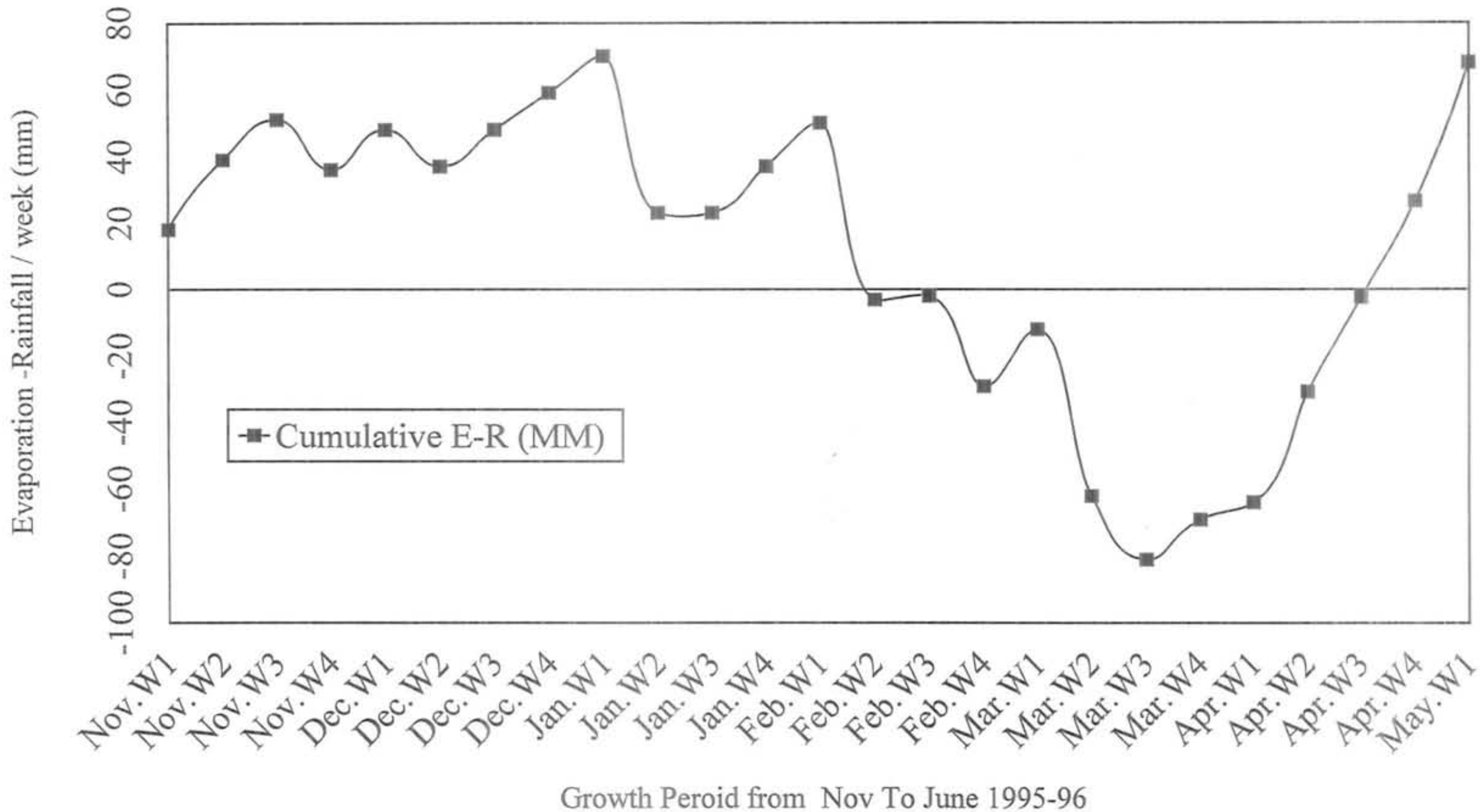
Note: W1, W2, W3 and W4 is the prefix of the weeks.

Fig. 4 Cumulative Rainfall and Evaporation during the growth period of crop



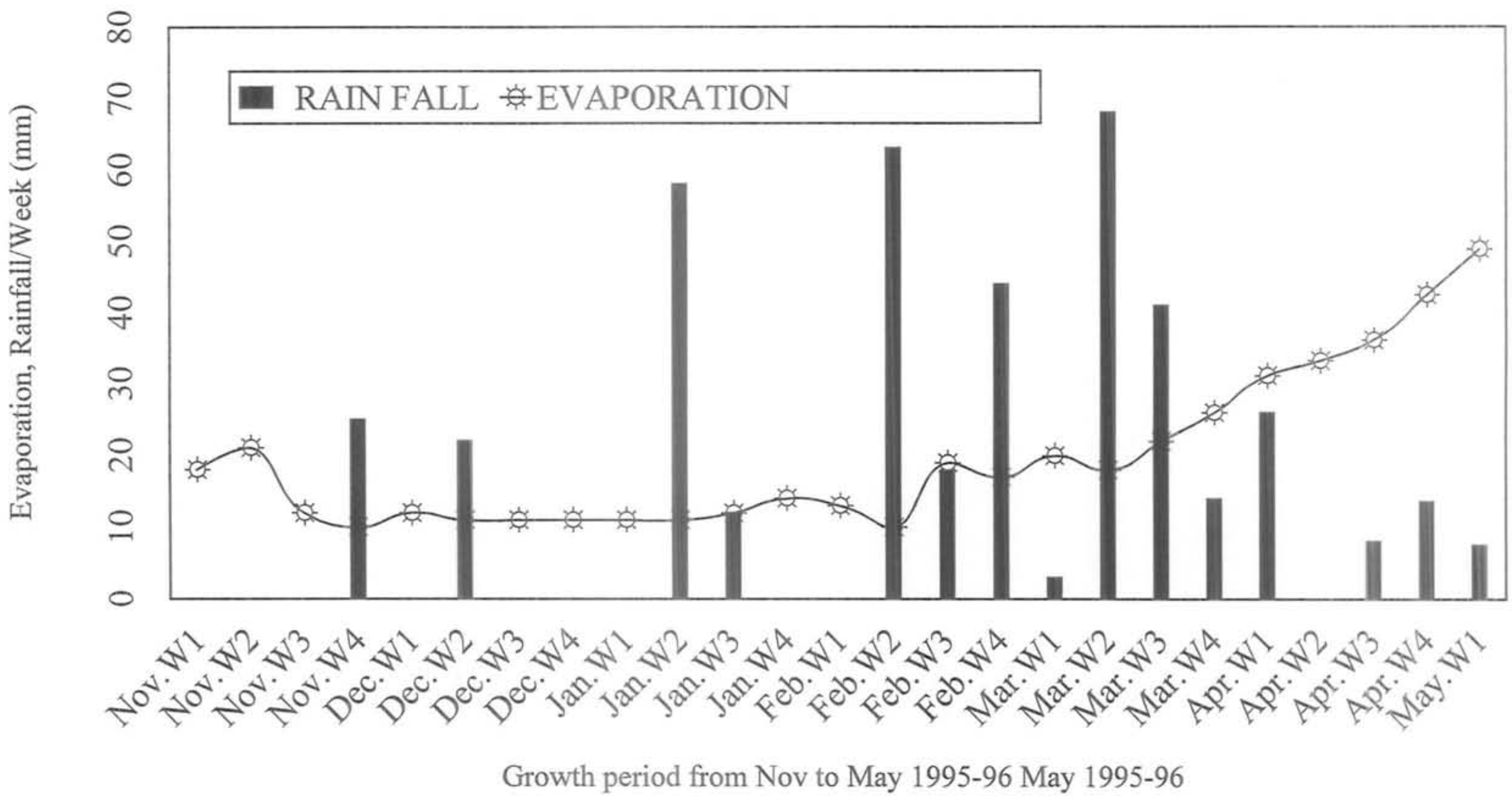
Note: W1, W2, W3 and W4 is the prefix of the weeks.

Fig. 5 Moisture availability during the growth period of crop



Note:W1, W2, W3 and W4 is the Prefix of the weeks.

Fig. 6 Rainfall and Evaporation during the growth period of crop



Note: W1, W2, W3, and W4 is the prefix of the weeks.

- **Mineral Nitrogen Dynamics in Soil**

1. Ammoniacal Nitrogen

Ammoniacal nitrogen in the soil 15 days after seeding (DAS) was higher with urea and ammonium sulphate (AS) compared to calcium ammonium nitrate (CAN) Ammoniacal N was highest with DCD treated AS (Table 7). Thirty days after seeding the ammoniacal values of DCD treated urea, AS and CAN were generally greater than the ammoniacal values of untreated fertilizers. At 75 days after seeding, NH^{+}_{4}-N values of DCD treated fertilizers were almost more than double the values of untreated fertilizers. The same was true even 105 days after seeding.

Table 7 Ammoniacal and nitrate nitrogen in soil at different time intervals after sowing of wheat crops.

`Treatment	Ammoniacal–N (mg kg^{-1}) *Days after sowing*							Nitrate–N (mg kg^{-1}) *Days after sowing*						
	15	30	45	60	75	90	105	15	30	45	60	75	90	105
Control	6.66	5.92	4.8	3.3	2.7	1.2	1.1	12.8	14.8	10.4	8.3	4.9	2.1	1.6
Urea	46.8	36.1	29.2	16.5	11.6	6.5	4.3	18.4	34.5	41.6	10.3	22.1	11.5	6.5
As	47.1	29.2	19.3	11.2	8.7	6.5	4.2	14.9	30.5	38.5	24.2	16.5	10.3	7.2
CAN	36.1	36.1	22.5	11.7	8.5	6.1	4.8	38.4	45.4	31.2	20.9	15.5	10.1	6.8
Urea + DCD	42.8	41.2	39.0	38.7	35.1	24.1	10.1	14.3	13.9	15.2	15.9	16.7	26.8	21.1
AS + DCD	48.3	47.4	45.1	42.5	40.1	31.2	14.2	11.7	12.2	12.9	13.4	16.4	24.2	18.3
CAN + DCD	39.8	39.1	38.4	37.8	36.2	31.4	28.2	37.1	36.4	35.8	34.0	36.2	35.9	22.8

AS = Ammonium sulphate, CAN = Calcium ammonium nitrate, DCD = Dicyandiamide

2. *Nitrate Nitrogen*

Nitrate nitrogen values 15 days after seeding were the highest in case of CAN. With passage of time the NO_3^-–N values in case of untreated fertilizers increased and were maximum, 45 days after seeding especially for urea and AS (Table-7). However, with DCD treatment of these fertilizers the NO^-_3-N values were much lower than those of untreated fertilizers. But during the later stage of crop growth (90 and 105 days after seeding), nitrate values of DCD treated fertilizers were about 3 times higher than those of untreated fertilizers values.

Overall mineral nitrogen ($NH^+_4 + NO^-_3$ was higher in DCD treated fertilizers as compared to untreated ones. The greatest amount of mineral N was in CAN treatment followed by ammonium sulphate and urea.

- **Wheat yield parameters**

1. Productive tillers

In general, application of nitrogenous fertilizers significantly increased the productive tillers (Table-8). Among the nitrogen sources, calcium ammonium nitrate (CAN) produced greater tillers as compared to urea and ammonium sulphate. DCD treated CAN produce significantly the highest tillers. There was no effect of DCD treatment of urea and ammonium sulphate on productive tillers. However, there was a slight depressing of this DCD treated fertilizer on productive tillers.

2. Total Biomass, Grain and Straw Yield

Total biomass, grain and straw yields exhibited almost similar pattern under various fertilizer treatments (Table-8). Application of nitrogen sources significantly increased total biomass, grain and straw yield. Among the various sources, CAN produced most significant effect on wheat yield parameters. The effect on wheat yield was further pronounced when DCD treated CAN was used. Treatment of other nitrogen sources with DCD did not help to improve the wheat yield. Thus CAN turned out to be most efficient source of N fertilizer for increasing wheat yield and its treatment with DCD further made significant contribution in enhancing wheat yield.

Table 8 Effect of nitrogen sources and dicyandiamide on wheat yield.

Treatments	Productive tiller (No. per m^2)	Biomass (t ha^{-1})	Grain yield (t ha^{-1})	Straw yield (t ha^{-1})	Thousand Grain wt. (g)	Harvest index	Agronomic efficiency
Control	109 d	3.36 e	1.37 e	1.99 c	31.1 e	0.408 a	–
Urea	190 c	11.18 c	3.37 c	7.41 cd	36.5 cd	0.355 c	3.76 c
AS	187 c	10.74 d	3.67 cd	7.08 e	35.8 cd	0.343 b	3.65 de
CAN	220 b	14.49 b	4.46 b	10.03 b	41.8 b	0.308 d	4.45 b
Urea + DCD	185 c	11.13 c	3.67 cd	7.47 c	36.0 cd	0.330 c	3.65 de
AS + DCD	184 c	10.79 d	3.69 d	7.20 cd	35.4 d	0.330 c	3.58 e
CAN + DCD	257 a	18.47 a	5.75 a	12.72 a	46.6 a	0.308 d	4.74 a

AS = Ammonium sulphate, CAN = Calcium ammonium nitrate, DCD = dicyandiamide.
Values followed by same letters are statistically non-significant at 5 per cent level of significance.

3. Thousand (1000)-grain weight and harvest index

Grain weight is an important parameter, contributing towards increase in grain yield. Application of N sources without and with treatment of DCD significantly increased the thousand grain weight (Table-8). The highest grain weight was produced by CAN. This was followed by urea and ammonium sulphate, however, the differences between these two sources was non-significant. There was significant improvement in grain weight when DCD treated CAN was used. Whereas treatment of other N sources was not helpful in increasing the grain weight. As regards the harvest index, it was the highest in case of control treatment. It was significantly decreased with application of N sources. Significantly the lowest harvest index was recorded in case of CAN. Generally there was no effect of treatment of N sources with DCD on harvest index.

3. Agronomic and Physiological Efficiencies.

Agronomic efficiency and physiological efficiency were significantly affected by different sources of nitrogen. In general both were greater with CAN than other sources of nitrogen (urea and AS) which were not different from each other (Fig.7). Treatment of CAN with DCD resulted in significant enhancement of these efficiencies. But there was no effect of treatment of other N sources with DCD on agronomic or physiological efficiency.

4. Nitrogen Utilization by Wheat

Nitrogen uptake by wheat grains, straw and total uptake (grain + straw) were significantly affected by the application of N sources and use of nitrification inhibitors. Significantly the highest uptake in grain was registered when CAN was used as a source of nitrogen (Table-9). However, there was no difference in N uptake due to other N sources. Treatment of

CAN with DCD resulted in significant improvement in N uptake. But treatment of urea and ammonium sulphate with DCD resulted in reduction of nitrogen uptake.

Both nitrogen uptake in straw and straw + grain exhibited similar pattern. Maximum uptake was registered in case of DCD treated CAN. Without DCD treatment of CAN N uptake was significantly lower. Urea and ammonium sulphate without nitrification inhibitor behaved similarly. However, when these sources were treated with DCD, ammonium sulphate and urea gave significantly lower uptake than CAN.

Apparent nitrogen recovery in wheat (grain + straw) due to different fertilizers ranged from 55 to 83.7%. The maximum N recovery was recorded when CAN was used as nitrogen source (Fig 7). Recoveries due to other N sources (AS, urea) were significantly lower than CAN. DCD treated CAN gave the highest N recovery (83.7%). However, treatment of other N sources with DCD did not help to improve N recovery.

Higher wheat yield (grain and straw), 1000-grain weight, N utilization and apparent N recovery of CAN as compared to urea and ammonium sulphate is attributed to composition of these fertilizers. Ammonium sulphate and urea are ammonium containing and ammonium forming fertilizers. Whereas CAN contains 50% NH^{+}_{4}-N and 50% NO^{-}_{3}-N. When all the N was in ammoniacal form it depressed the uptake of K, Ca and Mg (Fen and Barker 1990 & Ali *et al.* 1995). As a result plant growth was adversely affected as reported by Ali (1993), Ota and Yamamoto (1987) therefore, ammonium sulphate and urea gave lower yield as compared to CAN. Since CAN contained both N forms (NH^{+}_{4} and NO^{-}_{3}) in balanced form, therefore it helped in balanced uptake of the anions and cations. As a result it produced more wheat yield than in presence of urea and ammonium sulphate. Also N utilization and crop recovery of N was much greater with CAN than other N sources, when these sources of fertilizers were not treated with DCD. But when CAN treated with DCD was used it helped to maintain NH^+_4-N:NO^-_3-N ratio of 50:50 (Table-10) throughout the growing period of crop. This is an ideal condition for the uptake of cations and anions. Therefore DCD treated CAN give the highest wheat yield, agronomic efficiency and the N recovery as compared to other fertilizer.

Fig. 7 Comparative efficiencies of nitrogen souces for wheat as affected by Dicyandiamide

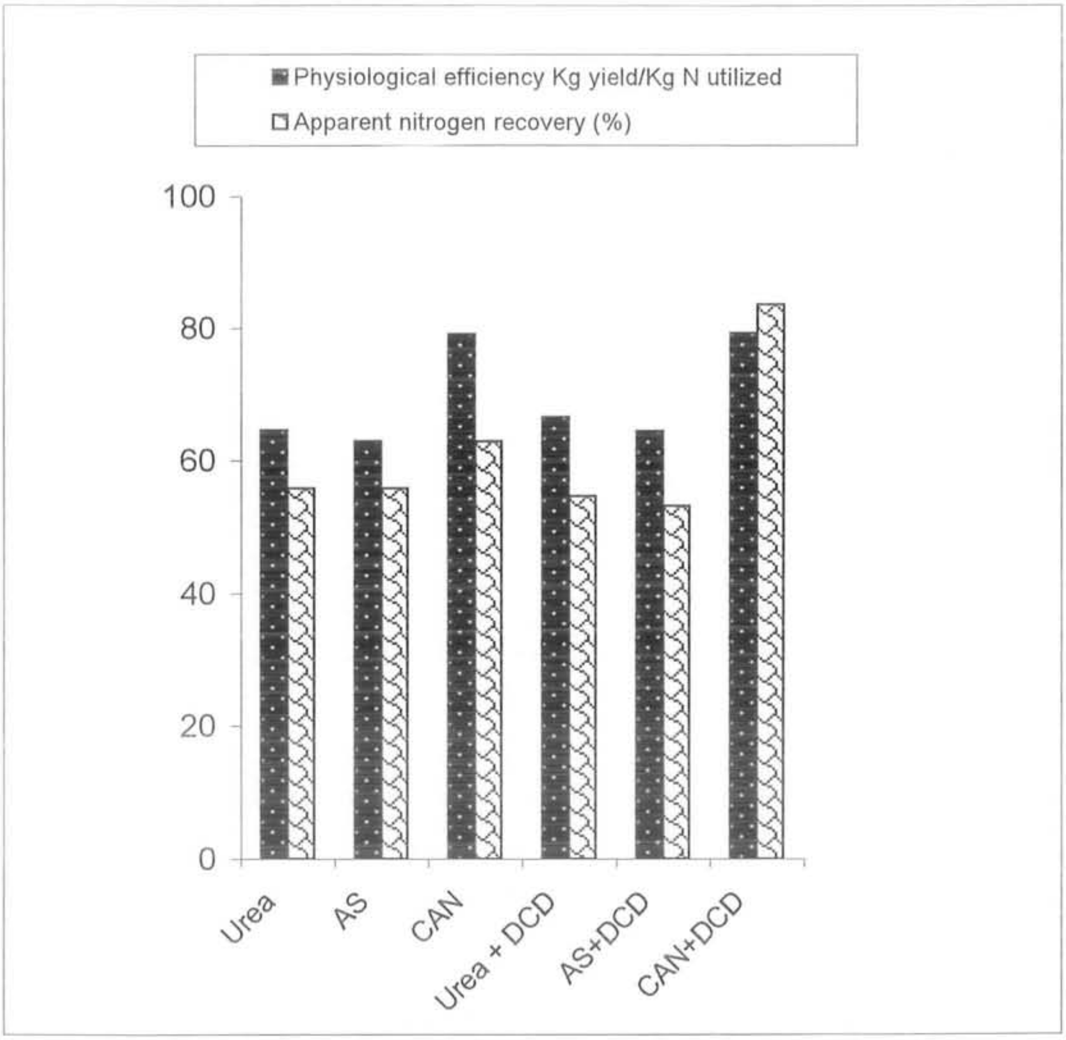


Table 9 **Effect of nitrogen sources and dicyandiamide on nitrogen concentration and uptake by wheat**

Treatments	Nitrogen Conc. (%)		Nitrogen uptake (kg ha^{-1})		Total nitrogen uptake
	Grain	Straw	Grain	Straw	(kg ha^{-1})
Control	0.545 g	0.098 a	7.46 e	1.94 f	9.40 f
Urea	1.185 b	0.278 a	44.65 c	2.57 e	65.21 cd
AS	1.198 a	0.298 a	43.89 c	21.05 cd	64.94 cd
CAN	1.042 e	0.257 a	46.47 b	25.82 b	72.30 b
Urea + DCD	1.145 d	0.292 a	41.98 b	22.07 cd	64.05 d
AS + DCD	1.167 c	0.288 a	41.91 d	20.71 d	62.62 e
CAN + DCD	0.983 f	0.287 a	56.47 a	36.58 a	93.05 a

AS = Ammonium sulphate, CAN = Calcium ammonium nitrate, DCD = dicyandiamide.
Values followed by same letters are statistically non-significant at 5 per cent level of significance.

Table 10 Ratios of NH_4^+–N to NO_3^-–N in soil as calculated from Ammoniacal nitrogen and Nitrate nitrogen values in soil.

Treatments	Days						
	15	30	45	60	75	90	105
Control	35 : 65	29 : 71	46 : 54	28 : 72	35 : 65	35 : 65	40 : 60
Urea	72 : 28	49 : 51	41 : 59	35 : 65	34 : 66	36 : 64	40 : 60
AS	61 : 39	49 : 51	33 : 77	32 : 68	34 : 66	39 : 61	37 : 63
CAN	53 : 47	44 : 56	42 : 58	35 : 65	35 : 65	38 : 62	41 : 59
Urea + DCD	75 : 25	72 : 28	72 : 28	71 : 29	68 : 32	47 : 53	32 : 68
AS + DCD	81 : 19	81 : 29	79 : 21	76 : 24	71 : 29	54 : 46	43 : 57
CAN + DCD	52 : 48	52 : 48	52 : 48	53 : 47	50 : 50	50 : 50	55 : 45

AS = Ammonium sulphate, CAN = Calcium ammonium nitrate, DCD = dicyandiamide.

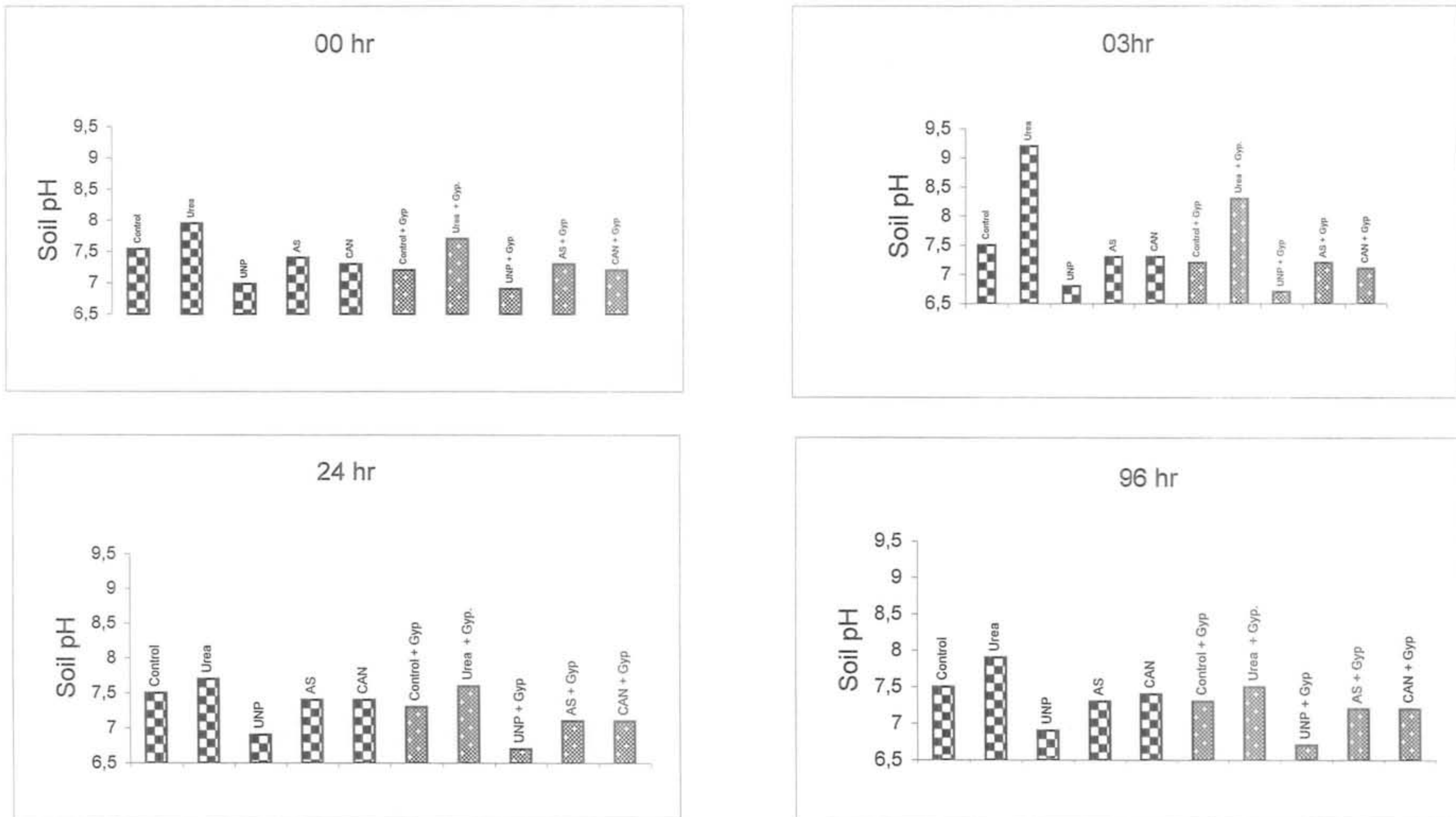
4.4 *Effect of gypsum on NH_3 volatilization losses and efficiency of different nitrogen fertilizers for wheat.*

4.4.1 Effect of nitrogen sources and gypsum application on soil pH.

A laboratory soil incubation experiment was organized to investigate the effect of N-sources and gypsum application on soil pH. Addition of urea fertilizer to soil increased soil pH from 7.54 to 7.95 even immediately after its addition (0-hour). But there was no rise in soil pH due to ammonium sulphate (AS) and calcium ammonium nitrate (CAN). Addition of urea nitrophos (UNP) lowered soil pH from 7.6 in control up to 6.98 (Fig. 8). Maximum rise in pH up to 9.1due to urea was recorded, 3 hours after its addition, thereafter its started declining and attained original soil pH value of 7.5 after 96 hours of fertilizer addition. With addition of UNP the soil pH remained lower than the original soil pH throughout the study period. There was decreasing trend in soil pH due to AS and CAN with passage of time especially more so with AS. Application of gypsum had significant effect on lowering soil pH irrespective of sources of fertilizer used (Fig. 8).

The rise in soil pH due to addition of urea fertilizer is attributed to its conversion to ammonium carbonate which temporarily raised the pH of the soil slightly greater than 9. Similar explanation has been put forth by Fenn and Kissel (1973) and Fenn and Hossner (1985) for rise in pH due to application of urea in the soil. Decreasing trend in soil pH due to ammonium sulphate and calcium ammonium nitrate is attributed to the nitrification of their ammonium component and consequent release of H ions from them (Tisdale *et al.* 1993). Decrease in soil pH due to urea nitrophos (UNP) is attributed to its more acidic nature and it is manufactured by the reaction of HNO_3 with rock phosphate forming H_3PO_4 which is then reacted with urea to form UNP. The decrease in soil pH due to application of gypsum is well known (Shainberg *et al.* 1989) and has also been reported by Patel and Suthar (1993).

Fig.8 Effect of fertilizer sources and gypsum application on soil pH at different timings.



4.4.2 Effect of gypsum on NH_3 volatilization loss.

Cumulative quantities of nitrogen loss through ammonia volatilization was significantly different ($p < 0.01$) from various nitrogen fertilizers applied with or without gypsum incorporation (Fig.9). The loss of nitrogen through ammonia volatilization from various fertilizers as a function of time was described by the Elovich equation (Low 1960) given below

$$Y = a + b \ln t$$

Where Y is the quantity of ammonia volatilized at time t, and a and b are constants. The slope of the Elovich function could be significant for the rate of loss of nitrogen through ammonia volatilization (Table-11). The slope values calculated according to the Elovich equation for different fertilizers correlated significantly ($p<0.01$) with cumulative quantities of ammonia lost (Fig.9) Incorporation of gypsum with different nitrogen fertilizers had a tremendous impact on loss of nitrogen through ammonia volatilization (Fig.9). Gypsum application decreased nitrogen volatilization as ammonia by 51.8 % in control and 76.8 % in ammonium sulphate. Rate of ammonia volatilization, inferred from slope of the Elovich function, was decreased two to three fold by gypsum application. Cumulative ammonia loss for urea was 46.30 mg N, followed by ammonium sulphate 36.62 mg N, calcium ammonium nitrate 33.56 mg N and for urea nitrophos 30.78 mg N (Table-12).

Effect of time of incubation

Overall maximum ammonia volatilization losses occurred 12 hours after (6.55-mg N) fertilizer addition. Losses at 6 hours and 24 hours after fertilizer addition were 3.55 mg N and 5.22 mg N (Table-12) respectively. With increasing time after fertilizer application, losses were significantly reduced being negligible at 192 hours (0.77 mg N) after fertilizer application.

Fig 9 Cummulative ammonia volatiliztion losses from different nitrogen fertilizers with and without gypsum application

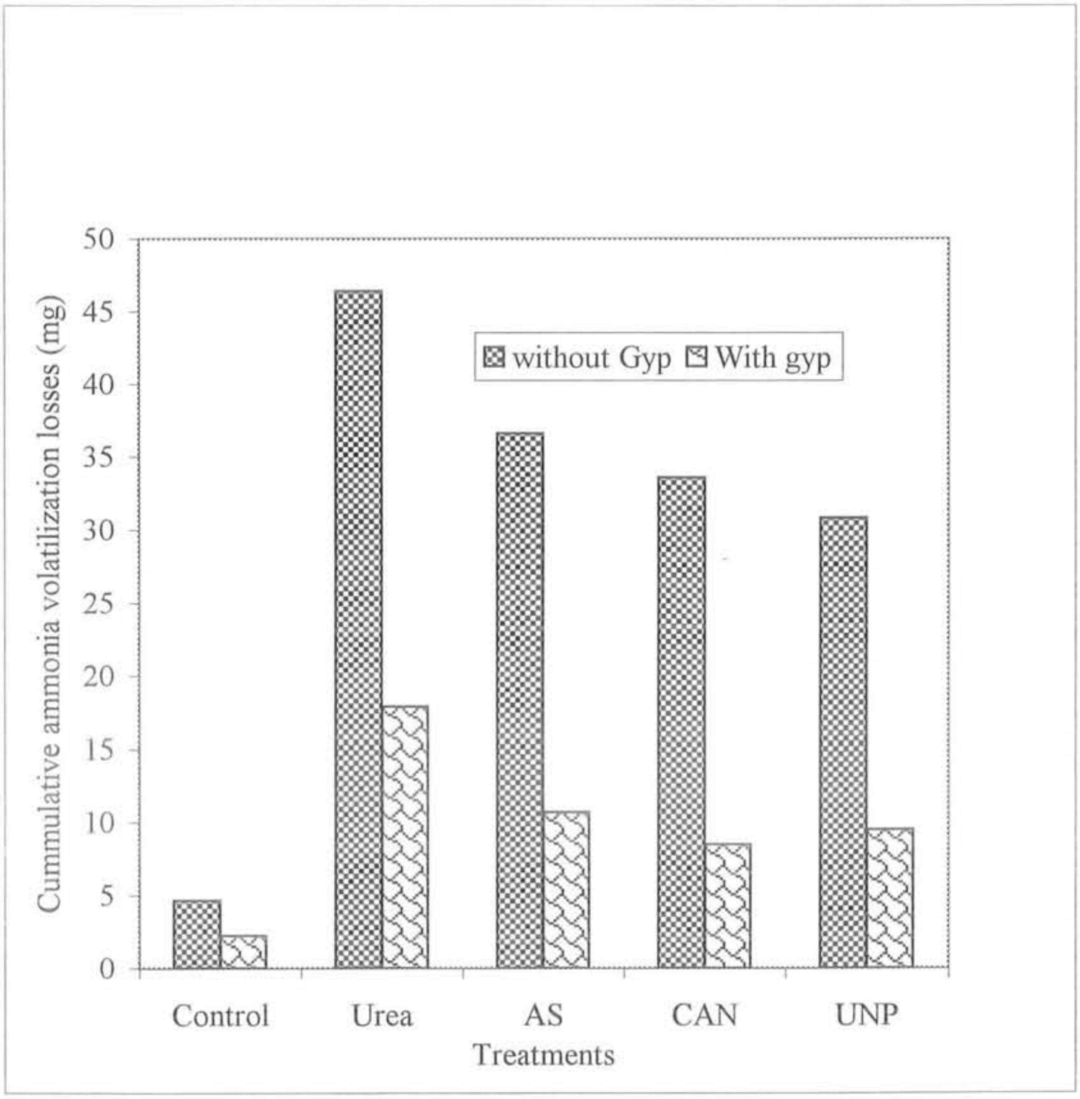


Table 11 Slope and intercept computed by least squares method for the Elovich equation used to describe loss of ammonia through volatilization from different nitrogen fertilizers with and without gypsum incorporation (n=6).

Fertilizer treatment	Slope (mg ammonia / kg / hr)	Intercept (mg ammonia / kg / hr)	R^2
Control	0.72	0.80	0.86
Control + Gypsum	0.22	1.15	0.71
Urea	9.77	-6.85	0.96
Urea + Gypsum	3.90	-2.90	0.92
Ammonium Sulphate (AS)	7.63	-3.90	0.92
AS + Gypsum	2.19	-1.19	0.94
CAN	6.63	-2.49	0.90
CAN + Gypsum	1.76	-1.00	0.94
Urea Nitophos (UNP)	6.13	-2.43	0.92
UNP + Gypsum	1.95	-0.95	0.92

AS = Ammonium sulphate, CAN = Calcium ammonium nitrate, UNP = Urea Nitrophos

Table 12 Effect of gypsum on ammonia volatilization losses (mg N) after different time from different nitrogen* sources.

Treatments	6 hrs	12 hrs	24 hrs	48 hrs	96 hrs	192 hrs	Cummulative NH_3 loss
Control	1.53 g	1.68 c	0.79 g	0.37 g	0.18 e	0.10 d	4.65 g
Urea	7.55 a	13.64 a	12.05 a	7.65 a	3.47 a	2.52 a	46.30 a
UNP	5.47 d	10.27 d	8.44 c	3.40 bc	1.70 c	1.50 c	30.78 c
AS	6.32 b	12.20 b	10.00 b	3.59 b	2.63 b	1.88 b	36.62 b
CAN	5.97 c	11.55 c	8.75 c	3.22 c	2.49 b	1.58 c	33.56 d
Control + Gyp.	1.25 h	0.70 f	0.25 h	0.02 h	0.01 e	0.01 d	2.24 h
Urea + Gyp.	2.28 e	6.20 e	5.28 d	2.58 d	1.50 c	0.04 d	17.88 e
UNP + Gyp.	1.52 g	3.60 f	1.98 f	1.58 f	0.77 d	0.02 d	9.47 f
AS + Gyp.	2.00 f	3.13 g	2.49 c	1.99 c	0.95 d	0.03 d	10.59 f
CAN + Gyp.	1.55 g	2.51 h	2.16 ef	1.48 f	0.77 d	0.01 d	8.48 f
Mean	3.55 c	6.55 a	5.22 b	2.58 d	1.45 e	0.77 f	–

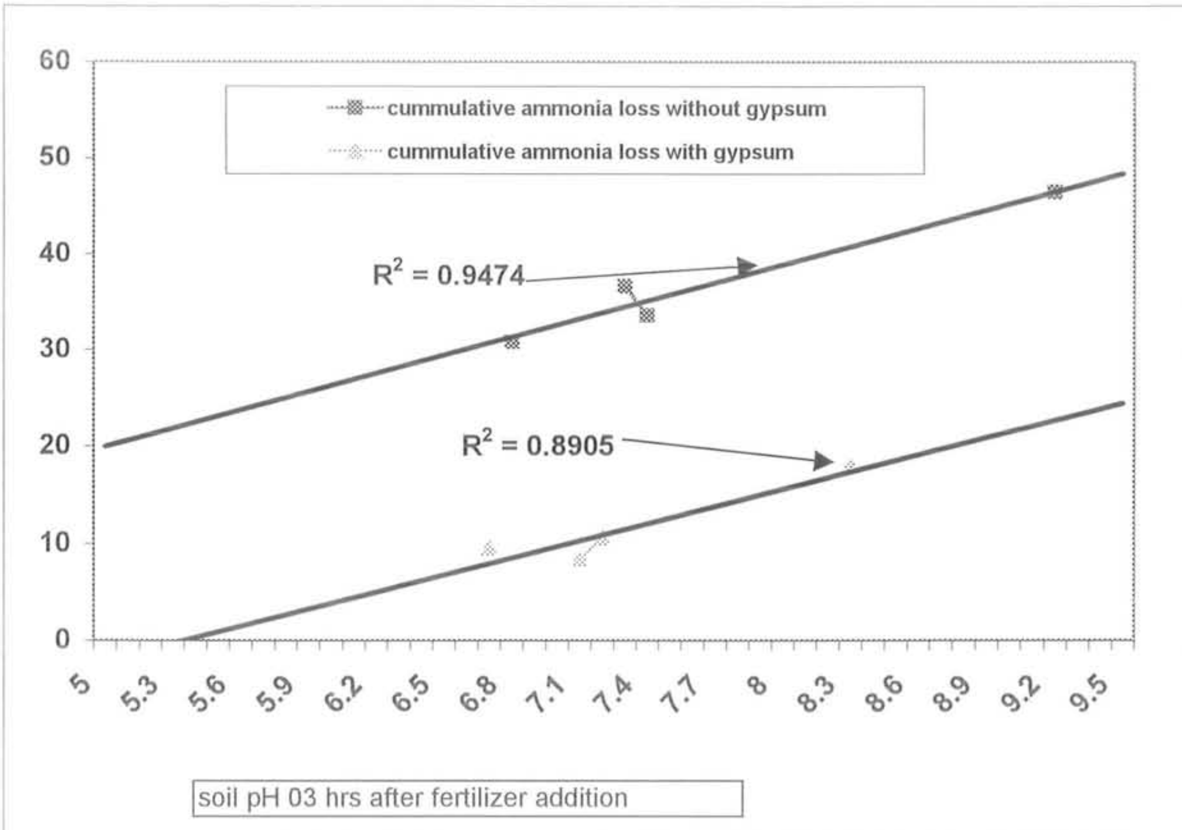
*Nitrogen = 200mg, kg^{-1}, UNP = Urea nitrophos, AS = Ammonium sulphate, CAN = Calcium ammonium nitrate and Gyp. = Gypsum.

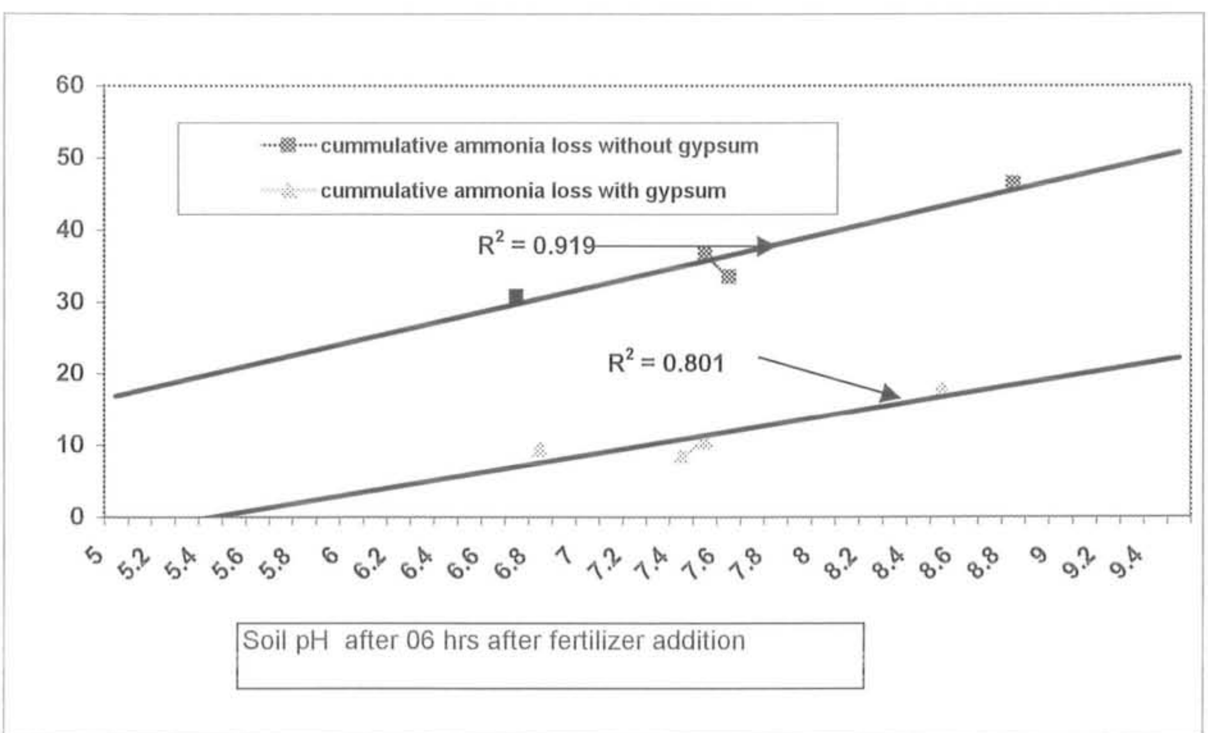
Relationship between soil pH and ammonia volatilization

There was a significant linear relationship ($p<0.01$) between soil pH and loss of nitrogen through volatilization (Fig.10). Ammonia volatilization losses increased with increase in soil pH.

Maximum loss of nitrogen from urea was followed by ammonium sulphate, calcium ammonium nitrate and urea nitrophos in decreasing order. Significantly highest ammonia volatilization losses were recorded due to application of urea. This was followed by ammonium sulphate (AS) calcium ammonium nitrate (CAN) and urea nitrophos (UNP). Similar results have been reported by Zamborlini *et al.* (1995) where losses from urea were greater than ammonium sulphate and ammonium nitrate. Almost the same trend was observed during the entire study period. Higher losses due to application of urea are attributed to the fact that NH_4^+ formed from urea at soil pH > 7.0 is deprotonized to form NH_3 gas, causing significant amounts of NH_3 loss in arid and semi arid regions (Terman 1979). Whereas ammonium sulphate reacts with $CaCO_3$ (in calcareous soil) to form $CaSO_4$ which does not allow to rise soil pH more than 8.5. Therefore, losses due to ammonium sulphate were significantly lower than in case of urea (Feagley and Hossner 1977). Comparatively lower losses due to CAN are attributed to the fact that it contains 50% N in ammoniacal form and 50% in nitrate form, therefore, over all NH_3 volatilization losses from its ammonium component will be lesser. Also CAN which is in fact ammonium nitrate does not produce $(NH_4)_2CO_3$ in calcareous soil, therefore, ammonia losses are consequently controlled by the native soil pH and are normally low in rate and intensity (Feagley and Hossner 1977). The losses were also comparatively lower with newly manufactured fertilizer i.e. urea nitrophos because of the fact that it reduced the soil pH during the course of the study.

Fig 10 Relationship between soil pH and ammonia volatilization losses





Application of gypsum significantly controlled ($P<0.01$) the loss of nitrogen through ammonia volatilization by lowering soil pH raised by urea hydrolysis or by other fertilizer materials. Secondly incorporation of calcium or magnesium salts with urea alters the equilibrium between ammonium carbonate, ammonia and carbon dioxide which retards ammonia losses. Therefore, a satisfactory range 0.25 to 1.0 for the ratio of calcium equivalent to nitrogen had been suggested to reduce ammonia losses from surface applied urea (Fenn *et al.* 1981). On calcareous soils potassium or sodium salts yield comparable results (Gould *et al.* 1986).

A linear and significant correlation exists between the soil pH and ammonia volatilization losses due to different fertilizers (Fig.10). This indicates that ammonia volatilization losses increased with increase in soil pH. Similar close relationship between soil pH and ammonia volatilization has been reported by Bayrakli (1990) and Whitehead and Raistrick (1990). Correlation co-efficient values between soil pH and ammonia volatilization were higher at 3 hours than 6 hours after fertilizer addition. These values were lower when gypsum was applied with these fertilizers.

4.4.3 Effect of gypsum on the efficiency of different nitrogen fertilizer for wheat

The investigations were carried on a normal (non-saline, non-sodic) soil, which was alkaline in reaction (pH 7.8). The soil was low in organic matter, total and mineral N. It was medium in available P and K (Table-1).

- ***Physical Crop Responses***

Data pertaining to tillers, grain and straw yield, 1000-grain weight and harvest index are given in Table-13. Different N sources and rates of gypsum application significantly affected productive tillers. Calcium ammonium nitrate (CAN) produced significantly highest number of tillers followed by ammonium sulphate (AS), urea nitrophos (UNP) and urea. The same pattern of tillers due to N sources was observed at all the rates of gypsum application, however, number of tillers was significantly improved with rate of gypsum application. Highest number of tillers were recorded where gypsum was applied @ 600 kg ha^{-1} (highest rate). Number of tillers at the lower rate (300 kg ha^{-1}) was significantly lower than at the highest rate and was the lowest where no gypsum was applied.(Table 13).

Wheat grain and straw yield exhibited similar pattern under all the fertilizer and gypsum treatments. Grain and straw yields were significantly highest at the higher rate than the lower one and the lowest where no gypsum was applied. With respect to the fertilizers the yields were highest due to CAN, followed by AS, UNP and urea. Urea turned to be the poorest nitrogen source with respect to its effect on wheat yield. Also the 1000 grain weight were significantly improved due to application of nitrogen fertilizers and gypsum. 1000 grain weight in different fertilizers followed the pattern CAN > AS > UNP > urea > control. Again the 1000-grain weights were higher at the higher rate of gypsum than the lower rate and were the lowest where no gypsum was applied. Harvest index was significantly improved by the application of nitrogen. However, there was no significant difference in the harvest index due to different N sources. There was also no significant effect on harvest index due to rates of gypsum application.

Table 13 Effect of nitrogen sources and rates of gypsum on wheat yield.

Treatments	No. of tillers (per m^2)	Grain yield (t ha^{-1})	Thousand Grain Wt. (g)	Straw yield (t ha^{-1})	Harvest Index
G0 + Control	127 l	0.97 l	29.46 i	1.65 o	0.37 d
G0 + Urea	241 I	3.23 i	31.48 g	5.10l	0.39 abc
G0 + UNP	244 hi	3.43 h	31.94 fg	5.47 k	0.38 bcd
G0 + AS	248 h	3.53 g	32.67 e	5.54 j	0.39 abc
G0 + CAN	256 g	3.79 f	34.17 d	5.82 i	0.39 abc
G300+ Control	142 k	1.21 k	30.20 h	2.36 n	0.33 e
G300 + Urea	269 f	3.85 f	34.44 d	5.96 h	0.39 abc
G300 + UNP	276 e	4.12 e	34.08 d	6.46 g	0.39 abc
G300 + AS	280 e	4.29 d	34.28 d	6.55 f	0.39 abc
G300 + CAN	294 d	4.83 b	36.06 b	7.66 b	0.40 a
G600+ Control	153 j	1.81 j	32.38 ef	2.98 m	0.38 cd
G600 + Urea	296 d	4.19 de	35.13 c	6.56 e	0.38 cd
G600 + UNP	303 c	4.61 c	35.32 c	7.43 d	0.38 cd
G600 + AS	326 b	4.64 c	36.28 b	7.53 c	0.38 cd
G600 + CAN	362 a	5.52 a	38.39 a	8.89 a	0.38 cd

UNP = Urea nitrophos, CAN = Calcium ammonium nitrate, AS = Ammonium sulphate, GO = Gypsum @ 0 kg ha^{-1}, G300 = Gypsum @ 300 kg ha^{-1}, G600 = Gypsum @ 600 kg ha^{-1}.

Values followed by same letters are not significantly different from each other at 5 per cent level of significance.

- ***Nitrogen uptake in wheat***

Nitrogen concentration in grain was much higher than in straw. Application of nitrogen fertilizer improved the nitrogen concentration in grain and straw significantly (Table-14). However, differences in N concentration due to nitrogen sources and rates of gypsum application were non-significant.

Nitrogen sources and rates of gypsum (Table-14) significantly affected nitrogen uptake in grain, straw and grain+straw. Nitrogen uptake was significantly higher due to application of CAN and other sources in this respect followed the order AS>UNP>urea. Application of gypsum significantly improved the nitrogen use efficiency. Highest uptake was determined at the higher than at the lower rate. It was the lowest where no gypsum was applied.

- ***Physiological and Agronomic Efficiencies***

Physiological efficiency is actually the nitrogen utilization efficiency for the synthesis of grain, yield. In different treatments it ranged from 49.00 to 54.74 kg grain yields per kg N utilized (Fig.11). There was non-significant difference in physiological efficiencies due to different fertilizer sources especially at G0 (without gypsum) and G 300 (300-kg gypsum ha^{-1}). At the highest rate of gypsum application CAN gave the highest efficiency. UNP and AS, which were at par in this respect, gave significantly higher efficiency than urea (Fig.11).

Gypsum treatments and fertilizer sources significantly affected agronomic efficiency, which is the amount of grain yield produced per unit of nitrogen applied. Over all agronomic efficiency ranged from 22.4 to 37.02 kg grain yield per kg N applied. Agronomic efficiency was generally the highest with CAN. In other treatments it followed the pattern AS>UNP>urea. Agronomic efficiencies were generally lower in treatments without gypsum.

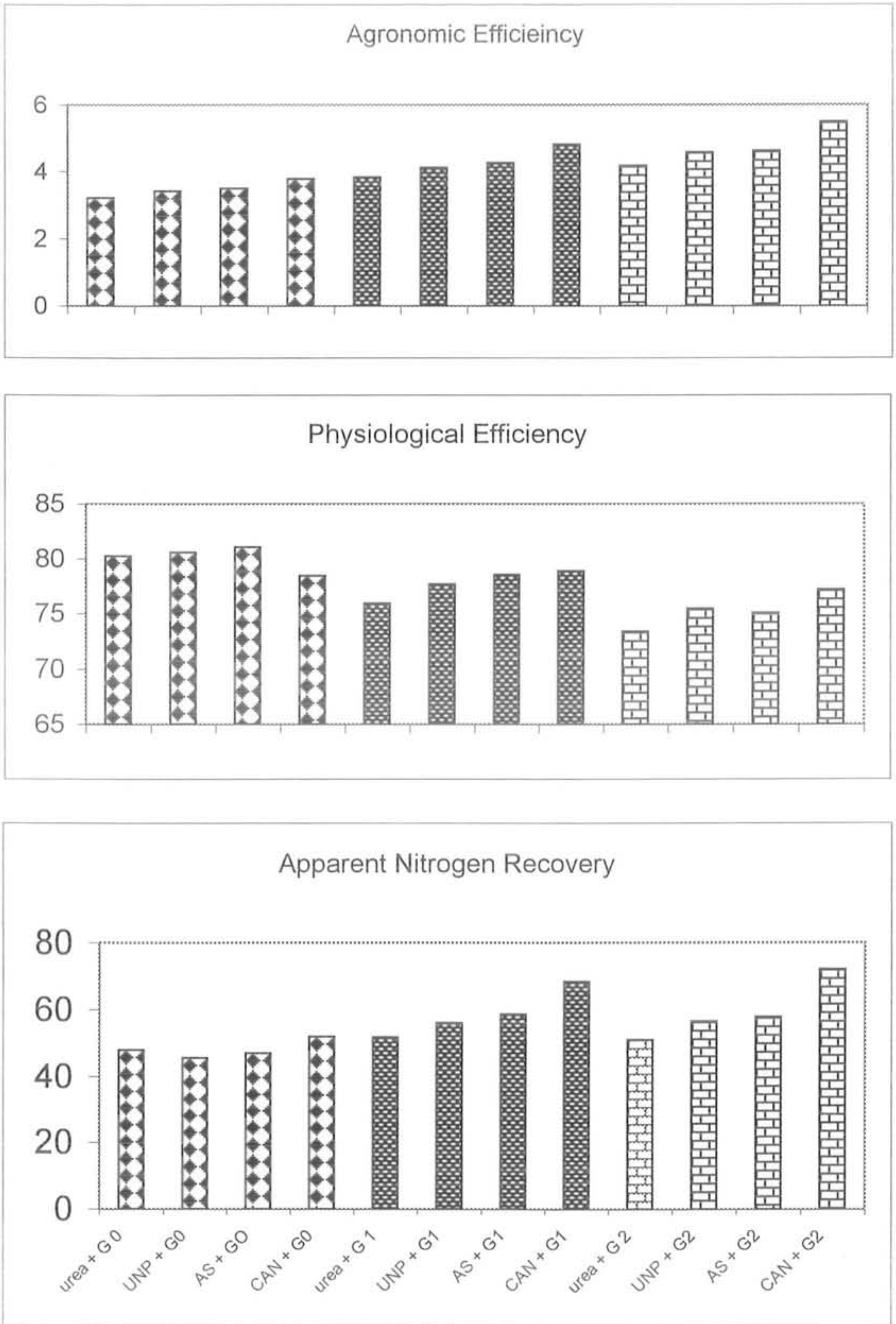
Table 14 Effect of nitrogen sources and gypsum on N uptake by wheat.

Treatments	Nitrogen Conc. (%)		Nitrogen uptake (kg ha^{-1})		Total
	Grain	Straw	Grain	Straw	(Grain+Straw)
G0 + Control	0.843 c	0.137 d	8.310 m	2.252 l	10.562 n
G0 + Urea	1.117 b	0.303 b	36.070 j	15.472 i	51.542 k
G0 + UNP	1.127 b	0.313 ab	38.594 i	17.135 h	56.142 j
G0 + AS	1.133 b	0.323 ab	39.667 h	17.898 h	57.565 i
G0 + CAN	1.137 b	0.333 ab	43.045 g	19.387 g	62.432 h
G300+ Control	1.103 b	0.177 cd	13.387 l	4.175 k	17.562 m
G300 + Urea	1.250 a	0.357 ab	48.066 f	21.261 f	69.327 g
G300 + UNP	1.233 a	0.353 ab	50.857 e	22.829 e	73.686 f
G300 + AS	1.233 a	0.357 ab	52.855 d	23.371 e	76.226 e
G300 + CAN	1.227 a	0.347 ab	59.286 b	25.551 c	85.837 b
G600+ Control	1.117 b	0.227 c	20.254 k	6.755 j	27.009 l
G600 + Urea	1.257 a	0.367 a	52.708 d	24.405 d	78.039 d
G600 + UNP	1.243 a	0.353 ab	57.305 c	26.252 bc	83.556 c
G600 + AS	1.247 a	0.357 ab	57.885 c	26.873 b	84.758 bc
G600 + CAN	1.237 a	0.347 ab	68.211 a	30.821 a	99.032 a

UNP = Urea nitrophos, CAN = Calcium ammonium nitrate, AS = Ammonium sulphate, GO = Gypsum @ 0 kg ha^{-1}, G300 = Gypsum @ 300 kg ha^{-1}, G600 = Gypsum @ 600 kg ha^{-1}.

Values followed by same letters are not significantly different from each other at 5 per cent level of significance.

Fig. 11 Comparative efficiencies of nitrogen sources as affected by gypsum application



- ***Apparent Nitrogen Recovery***

Apparent nitrogen recovery (ANR) is the efficiency of the crop in obtaining fertilizer nitrogen from soil. ANR in different treatments ranged from 40.98 to 72% (Fig. 11). Different fertilizer and gypsum treatments affected ANR significantly. Recoveries were significantly lower in treatments without gypsum. Recoveries due to CAN were significantly greater than all fertilizer sources at all levels of gypsum applications. Differences in recoveries due to AS and UNP were non-significant at all levels of gypsum applications.

Results of the study revealed that significantly highest number of tillers, 1000-grain weight and wheat yield (grain + straw) were recorded due to application of calcium ammonium nitrate (CAN) followed by ammonium sulphate (AS), urea nitrophos (UNP) and urea. CAN, AS, UNP gave significantly higher number of tillers and yield as compared to urea. The highest number of tiller, grain and straw yield due to CAN as compared to other sources can be attributed to balanced NH_4^+-N to NO_3^--N which it contains. On the other hand, other nitrogen sources contained N in NH_4^+-N form, therefore, this form was responsible for low yield due to these fertilizers (Arshad *et al.* 1999). Balanced nitrogen nutrition helped in the balanced uptake of soil nutrients (Ali 1993, Ota and Yamamoto 1987). CAN, AS and UNP gave significantly higher wheat yield than in case of urea due to the fact that ammonia volatilization losses in urea were much higher than these fertilizer sources (Arshad *et al.* 1999). Also the losses in case of ammonium sulphate were slightly higher than in urea nitrophos but it proved to be slightly better than urea nitrophos due to the fact that besides nitrogen it contained 24% sulphur (S), which might have contributed in the S nutrition of the crop. Higher crop yield with CAN than urea has also been reported by (Mello and Arzolla 1984). Gypsum application improved the wheat yield due to the reason that it helped to reduce ammonia volatilization losses by reducing soil pH (Arshad *et al.* 1999). Similar results were also reported by Fenn and Kissel 1973, Fenn *et al.* 1981. They pointed out that addition of calcium salts to urea had reduced ammonia volatilization by as much as 90 %. Gypsum ($CaSO_4$ $2H_2O$) is inexpensive in Pakistan. It reacts with $(NH_4)_2SO_4$ formed during urea hydrolysis to form $CaCO_3$ and $(NH_4)_2SO_4$. Since ammonium sulphate is stable and slightly acidic product, therefore, it lowers ammonia volatilization losses. Ilyas *et al.* (1993) and Patel and Suther (1993) reported that addition of gypsum improved the physical conditions of saline-sodic calcareous soils and it improved the root growth and proliferation, which resulted in uptake of nitrogen and other nutrients more efficiently (Tiwari 1994).

4.5 *Effect of potassium fertilization on the efficiency of different nitrogen fertilizers for rainfed wheat*

- ***Physical Crop Responses***

Data pertaining to tillers, grain and straw yield, 1000-grain weight and harvest index are given in the Table-15. Nitrogen sources and rates of K application significantly affected the number of productive tillers. Calcium ammonium nitrate produced significantly highest number of tillers m^{-1} at all levels of K applications. Ammonium sulphate and urea followed the order. Differences in number of tillers due to ammonium sulphate and urea at medium (50 kg ha^{-1}) and higher (100 kg ha^{-1}) rate of K application were significant but without K it was non-significant.

Wheat grain and straw yield exhibited almost similar pattern under all the fertilizers treatments. At all the levels of K fertilizations, calcium ammonium nitrate produced the highest yield followed by the ammonium

Table 15 Effect of nitrogen sources and potassium on wheat yield.

Treatments	No. of tillers (per m^2)	Grain yield (t ha^{-1})	Thousand grain wt. (g)	Straw yield (t ha^{-1})	Harvest Index
Control + K0	123 f	0.91 j	28.85 j	1.57 k	0.360 defd
Urea + K0	234 f	2.87 g	30.84 h	4.76 h	0.377 bed
AS + K0	238 f	3.13 f	31.64 g	4.93 g	0.387 abc
CAN + K0	251 e	3.55 d	32.66 de	5.57 e	0.393 ab
Control + K50	142 g	1.12 i	29.82 i	2.04 j	0.353 ef
Urea + K50	257 de	3.40 e	32.06 fg	5.17 f	0.393 ab
AS + K50	260 d	3.85 c	32.33 ef	5.93 d	0.398 a
CAN + K50	273 c	4.32 b	33.74 c	6.93 b	0.388 abc
Control + K100	148 g	1.57 h	31.01 h	2.92 i	0.350 f
Urea + K100	269 c	3.96 c	33.00 d	6.68 e	0.370 cdf
AS + K100	291 b	4.33 b	34.86 b	6.72 e	0.388 abc
CAN + K100	335 a	5.13 a	36.92 a	8.16 a	0.388 abc

K0, K50 and K100 are levels of potassium in kg ha^{-1}.

Values followed by same letters are not significantly different from each other at 5 per cent level of significance.

sulphate and urea. Yields were highest at the highest level of K application, lowest without K and in between at the medium level of K application. Also the 1000-grain weight was significantly improved due to application of nitrogenous and potash fertilizers. Thousand grain weight in different treatments followed the order; CAN> AS> urea> control. Again 1000-grain weights were higher at the higher than the lower rate and were the lowest where no K was applied. Values of harvest index were also improved with the application of K fertilizer. Differences in harvest index due to N sources were non-significant due to K fertilizer control and medium level of K application. At the highest level of K application CAN and AS produced significantly greater harvest index values than in case of urea.

- ***Nitrogen Uptake in Wheat***

Nitrogen concentration in grains was much higher than in straw. Application of nitrogen fertilizer improved the concentration significantly. However, differences in N concentration due to nitrogen sources and rates of K application were generally non-significant (Table-16).

Nitrogen uptake in grains, straw and grains + straw was significantly affected by N fertilizers and rates of K applications. Nitrogen uptake was significantly highest due to application of CAN, and AS and urea followed the order. Application of K significantly improved the N uptake. Highest uptake was determined at the higher than at the lower rate. It was the lowest where no K was applied. Highest uptake of N due to K application was found where CAN was the fertilizer source.

Table 16 Effect of nitrogen sources and potassium on nitrogen concentration `and uptake by wheat.

Treatments	Nitrogen conc. (%)		Nitrogen uptake (kg ha^{-1})		Total uptake
	Grain	Straw	Grain	Straw	(kg ha^{-1})
Control + K0	0.743 d	0.137 g	6.77 j	2.14 j	8.92 k
Urea + K0	1.287 a	0.177 fg	36.88 g	8.42 gh	45.30 h
AS + K0	1.290 a	0.190 efg	40.40 f	9.36 g	49.77 g
CAN + K0	1.290 a	0.207 def	45.82 e	11.51 f	57.33 f
Control + K50	1.060 c	0.237 de	11.89 i	4.85 i	16.73 j
Urea + K50	1.327 a	0.350 ab	45.10 e	18.08 e	63.18 e
AS + K50	1.327 a	0.350 ab	51.10 d	21.75 d	72.38 d
CAN + K50	1.313 a	0.310 bc	57.76 b	21.49 d	78.25 c
Control + K100	1.163 b	0.257 cd	18.29 h	7.49 h	25.78 i
Urea + K100	1.327 a	0.370 a	52.77 c	21.72 c	77.48 c
AS + K100	1.337 a	0.380 a	57.97 b	26.16 b	84.09 b
CAN + K100	1.323 a	0.363 ab	67.83 a	29.66 a	97.49 a

K0, K50 and K100 are levels of potassium in kg ha^{-1}.

Values followed by same letters are not significantly different from each other at 5 per cent level of significance.

- ***Physiological and Agronomic Efficiencies***

Physiological efficiency which is actually the nitrogen utilization efficiency for synthesis of grain yield, ranged from 46.13 to 54.55 kg grain yield per kg N utilized in different treatments (Fig.12). Without K application there were non-significant differences in efficiency. With K application CAN gave significantly higher efficiency than the application of AS and urea.

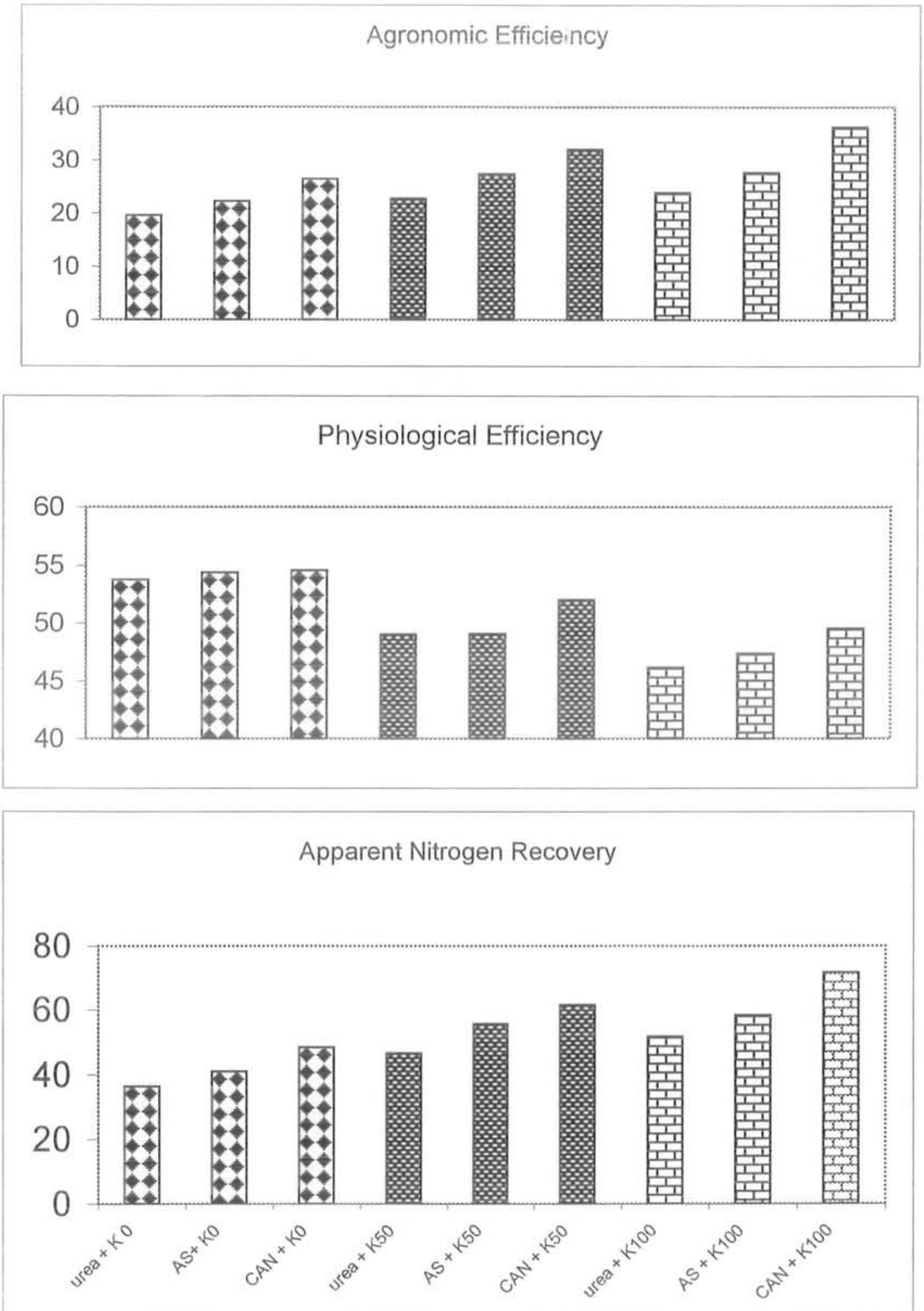
Agronomic efficiency that is the amount of grain yield produced per unit of nitrogen applied was significantly affected due to nitrogen sources and K fertilization. Over all agronomic efficiency ranged from 19.55 to 36.20. It was significantly improved with increase in the rate of K fertilizer application. Significantly the highest efficiencies were recorded with CAN. AS gave significantly higher efficiency than urea.

- ***Apparent Nitrogen Recovery***

Apparent nitrogen recovery (ANR) is the efficiency of the crop in obtaining fertilizer nitrogen from the soil. ANR in different treatments ranged from 36.38 to 71.71% (Fig.12). Different fertilizer and K treatments affected ANR significantly. Recoveries were significantly improved due to K application with highest recoveries being found at the highest rate of K application. Recoveries due to CAN were significantly greater than by the applicaion of AS and urea which followed the order. Urea gave lower recovery than ammonium sulphate.

Wheat yield (grain + straw) and 1000-grain weight were significantly affected by fertilizer sources. All the yield parameters were significantly improved due to the addition of calcium ammonium nitrate (CAN) followed by ammonium sulphate (AS) and urea. Greater yield with CAN can be attributed to the NH_4^+ - N and NO_3^- - N that it contains in 1:1 ratio. Whereas,

Fig. 12 Comparative efficiencies of nitrogen sources for wheat as affected by potassium application



AS and urea contain nitrogen only in NH_4^+ form. Similar results have been reported by Arshad *et al.* (1999). In another study (Goyal and Huffaker 1984) it was reported that applicaion of ammonium sulphate to plant roots along with nitrate resulted in higher plant yield and N content than either form alone. Balanced N nutrition in the form of ammoniacal nitrogen and nitrate nitrogen helped in the balanced uptake of soil nutrients (Ota and Yamamoto 1987, Ali 1993, Ali *et al.* 1995). Maximum amino acid accumulation occurred when both ammonium and nitrate were supplied (Weissman 1964). Urea gave the lowest yield because of greater ammonia volatilization (Arshad *et al.* 1999). Losses from AS were comparatively lower, because its sulphate component might have helped in the S nutrition of the crop, hence it gave more yield than urea. High crop yield with CAN than urea has also been reported by Mello *et al.* (1984).

Potassium application helped to improve the yield especially when the source of N was CAN. Similar results have been reported by Amin *et al.* (1996). They observed significant improvement in the yield of sesame when N was applied along with K as compared to N alone. Higher dose of N alone had depressing effect on yield, on the other hand application of K had significant effect in yield at all levels of applied N. This increase in growth due to application of K along with N is attributed to increase in synthesis of organic acids (Hageman 1984). Adequate concentrations of K favour translocation of amino acids and carbohydrates in plants (Duke and Collins 1985).

The plants can absorb nitrogen either as a cation (NH_4^+) or an anion (NO^-_3). In plant inorganic N must be converted to organic N compounds, amino acids and nucleic acids before they can become a plant protein. Potassium encourages the synthesis of plant protein by stimulating the generation of ATP for the reduction of nitrate to amino compounds. The generation of ATP also increases the active uptake of plant nutrient from the soil. Thus K not only enhances N uptake but also enhances its conversion to yield producing proteins. Studies by the Potash and Phosphate Institute (PPI) show that the addition of K to corn not only increased the yields but increased the N use efficiency also. Nitrogen uptake by grain, straw and total uptake (grain + straw) was significantly affected by N fertilizers and rates of K application. The highest N uptake was observed in CAN followed by AS and urea. Application of K significantly increased N uptake. These results were in accordance with Shaviv and Hagin (1988). They reported that addition of K to soil increased the utilization of N fertilizers, particularly when the ratio of ammonium to nitrate was increased. The highest uptake of N was at 50:50 ammonium-nitrate ratio, when the K was applied. Similarly enhanced N contents through the application of ammonium-nitrate mixture with potassium has been obtained in an other experiment by Shaviv and Hagin (1988).

Higher agronomic and physiological efficiencies and apparent N recovery due to CAN is attributed to better N utilization by wheat from this source. Comparatively lower efficiency of urea than CAN is attributed to the fact that it contained N in ammoniacal form due to which uptake of other cations such as K, Ca and Mg might have been comparatively depressed (Cox and Reisenauer 1978, Ali *et al.* 1995). Also higher volatilization losses from urea (Fenn and Hossner 1985, Arshad *et al.* 1999) lowered its effectiveness. Application of K improved the efficiency of N fertilizer especially due to CAN because it contains both nitrogen forms i.e. NH_4^+ -N and NO_3^- -N in 1:1 ratio. Similar results have been reported by Stromberger *et al.* (1994).

GENERAL DISCUSSION

In general wheat yields in Pakistan are low. These low yields are attributed to insufficient and imbalanced use of fertilizers. Wheat is the major fertilizer consumer and consumes 46 percent of total fertilizer. Also out of the total fertilizers used, the use of nitrogen is about 80 percent. This is because nitrogen plays key role in improving crop yield and quality, but the applied fertilizers are not efficiently utilized. Efficiency of nitrogen fertilizer for wheat with best agronomic practices seldom exceeds 50 percent. This is due to the fact that nitrogen applied to the wheat is lost due to various nitrogen transformations and loss mechanisms. Major nitrogen losses in Pakistan for wheat productions are due to ammonia volatilization and nitrification followed by denitrification. High soil pH and hot climatic conditions in our country are highly favourable for ammonia volatilization. This avoidable nitrogen loss from agricultural system is an expensive waste of resources. Environmentally increasing concentration of ammonia in the atmosphere can cause an aerosol formation of the complex sulphates of ammonia that are component of smog and acid rain. Ample amounts of nitrogen can be lost from the soil by denitrification. This process results in the reduction of nitrate or nitrite to gaseous nitrogen. In our conditions nitrate resulting from fertilizer application is lost due to denitrification, when partially reduced conditions are created due to irrigation or rainfall. Results of various nitrogen management studies regarding their impact on wheat yield and nitrogen efficiency are discussed as under:

Results of the studies have revealed that crop yield and its parameter increased with decreasing NH_4^+-N and increasing NO_3^--N in fertilizer material. The optimum ratio for NH_4^+-N : NO_3^--N was found to be 50:50, as maximum wheat yield was recorded with this mixed nitrogen nutrition. Increased production of biological yield increased the uptake of applied nitrogen, resulting in its increased efficiency. Crop yield, nitrogen uptake and nitrogen utilization were lower with either NH_4^+-N or NO_3^--N. This is due to the fact that with only NH_4^+- N the uptake of sulphate, phosphate and some micronutrients increased and that of K, Ca, and Mg decreased. Whereas with NO_3^--N uptake of cations increased and that of anions decreased (Fen and Barker 1990 & Ali *et al.* 1995). In the field study therefore calcium ammonium nitrate (CAN) having 50% ammoniacal-N and 50% nitrate-N gave the highest wheat yield and nitrogen recovery followed by ammonium sulphate and urea. Gypsum application along with these fertilizers helped to improve the yield and nitrogen utilization due to its effect on soil pH reduction. Similar results were reported by Aslam *et al.* (1992) & Nizami (1995).

In another study drought and salt stress conditions significantly reduced the wheat yield, nitrogen uptake and ultimately nitrogen use efficiency. These results were similar to the results reported by Mitrosuhardjo (1980) & Fardad and Pessarakli (1995) under moisture stress condition. But under salt stress condition these results were in accordance with Pessarakli *et al.* (1991), Ahmed *et al.* (1997) and Naeem *et al.* (1998). Traditionally salt or water stress effects on plant growth were thought to be primarily due to low water potential (high osmotic pressure) of the root environment, therefore, resulting in hampered uptake of water. This reduced uptake of water transported reduced amount of soil nutrients from the soil solution to the plant root, ultimately adversely effecting the plant growth.

In an other study where nitrification inhibitor (Dicyandiamide (DCD) was used again in conjunction with nitrogen sources, CAN gave significantly higher wheat yield and nitrogen recovery than ammonium sulphate and urea, which were at par with each other in this respect. The second reason for the superiority of CAN comes out of this study because of the fact that it contains both the forms of nitrogen NH_4^+-N and NO_3^--N in equal proportion which helped in balanced uptake of the anions and cations. But on the other hand urea and ammonium sulphate contained nitrogen only in ammoniacal form, therefore, proved comparatively less efficient.

DCD in case of CAN was helpful in maintaining NH_4^+–N : NO_3^-–N in 50:50 ratio for the longer period of crop growth by hindering the nitrification of its ammonium component (Amberger 1993, Freney *et al.* 1995) helped in better and balanced uptake of anions and cations (Ali *et al.* 1995). Therefore, it gave significantly higher yield and nitrogen recovery than where CAN alone was used. Serna *et al.* 1994 and Hammam 1995 have reported similar beneficial effects of nitrification inhibition.

On the other hand use of DCD with urea and ammonium sulphate hindered the conversion of NH_4^+-N to NO_3^--N, therefore, NH_4^+-N persisted for longer period for crop growth than when they were used alone (without DCD). Presence of NH_4^+ - N in soil hindered the uptake of cations (Fen & Barker 1990, Ali *et al.* 1995). Therefore, their efficiency was adversely affected with the use of DCD.

In another field study, the effect of potassium and nitrogen on wheat yield and nitrogen utilization was investigated. Wheat yield parameters significantly improved due to application of potassium alongwith nitrogen. Potassium application helped to improve the wheat yield especially when the source of nitrogen was CAN. Greater wheat yield with CAN can be attributed to its NH_4^+- N and NO_3^- -N that it contains in 1:1 ratio. Whereas, Urea and ammonium sulphate contain nitrogen only in NH_4^+ form. Balanced nitrogen nutrition in the form of ammonaical-N and nitrate-N helped in balanced uptake of soil nutrients (Mengal *et al.* 1976, Ali 1993).

Application of potassium significantly improved the nitrogen uptake and use efficiency, especially with CAN. Improvement in nitrogen utilization by wheat with potassium application is attributed to better nitrogen utilization by wheat from this source, because it contains both nitrogen forms i.e. NH_4^+- N and NO_3^--N in 1:1 ratio (Mengal 1989). Comparatively lower efficiency of urea than CAN is attributed to the fact that it contained nitrogen in ammonaical form due to which uptake of other cations such as K, Ca, and Mg might have been depressed (Ali 1993). Also higher volatilization losses from urea (Arshad *et al.* 1999), lower its effectiveness. Application of potassium also improved the translocation of nitrogen compounds from roots towards shoots and grains. Shaviv & Hagin (1988), Mengal (1989) and Stromberger *et al.* (1994) reported similar results.

From the foregoing discussion it is concluded that nitrogen in the form of 50% NH_4^+-N and 50% NO_3^--N helped to overcome the salt and drought stress. Therefore, calcium ammonium nitrate proved to be the efficient nitrogen source than urea and ammonium sulphate. Application of gypsum alongwith nitrogen sources helped in improving their efficiency by reducing ammonia volatilization losses. DCD further helped to improve the efficiency of CAN for wheat production, but its use with urea and ammonium sulphate adversely affected the crop yield. Potassium application also proved useful to improve nitrogen use efficiency for wheat production.

SUMMARY & CONCLUSIONS

Among the major nutrient elements required for crop production, nitrogen is the most abundantly required nutrient in Pakistan due to low inherent nitrogen fertility of its soils. The increased demand of nitrogen fertilizers for crop production, cost of natural gas, the instability of nitrogen in soil through volatilization, denitrification and leaching are such factors which contribute to the increasing cost of nitrogen fertilization. It is therefore, imperative to adopt ways and means effective in increasing the yield per unit of fertilizer applied and also reduce the losses of nitrogen from the root zone. Since the fertilizers are costly inputs, it is essential to enhance their utilization by crops. Keeping in view aforementioned objectives the project was planned and different laboratory studies, green house and field trials were carried out on wheat crop. The results of these studies are summarised below for brevity.

In this connection effect of varying NH_4^+-N:NO_3^--N ratios (100:0, 75:25, 50:50, 0:100) were investigated on wheat yield and nitrogen utilization under different conditions. To maintain the above mentioned NH_4^+-N:NO_3^--N ratio dicyandiamide (DCD) was used as a nitrification inhibitor. Results revealed that the productive tillers, grain, straw and total biomass was the highest with NH_4^+-N:NO_3^--N ratio of 50:50. These growth parameters were the lowest where either NH_4^+-N or NO_3^--N alone was used. Similarly nitrogen uptake and nitrogen recovery in wheat was significantly highest at optimum NH_4^+-N:NO_3^- -N ratio of 50:50 than where NH_4^+-N or NO_3^--N alone was used. Effect of dicyandiamide (DCD) was investigated on the nitrification of nitrogen sources and wheat growth under rainfed ecosystem. DCD effectively inhibited nitrification of nitrogenous fertilizers and maintained favourable NH_4^+-N : NO_3^--N ratio, hence the highest grain yield, agronomic and physiological efficiencies and nitrogen recovery were recorded especially with CAN. In case of ammonium sulphate and urea mostly ammoniacal nitrogen dominated in the soil, due to which it gave significantly lower wheat yield and nitrogen recovery.

From these studies it is concluded that since CAN contains both NH_4^+-N and NO_3^- -N in equal proportion, therefore, it is more efficient than ammonium sulphate and urea. Hence CAN should be the preferred nitrogen fertilizer for wheat production. On the basis of these findings CAN is recommended for large-scale use for wheat production in Pakistan. Also the use of dicyandiamide was helpful in maintaining ideal NH_4^+-N:NO_3^--N ratio of 1:1 through its use with CAN. Therefore, it surely helped to improve nitrogen use efficiency for wheat production. However, economic aspects for use of DCD still needs careful consideration at its large-scale application by the farmers.

Application of gypsum with various nitrogen sources significantly increases the wheat yield and nitrogen utilization. Application of gypsum in fact reduced the soil pH, which consequently helped in reducing the ammonia volatilization losses. It was further observed that increasing drought and salt stress reduced the wheat yield and nitrogen utilization. However, balanced nitrogen nutrition was helpful to ameliorate the adverse effect of drought and salt stress.

Thus gypsum application along with nitrogen fertilizers significantly improved their use efficiency. It is, therefore, recommended that for improving wheat productivity the use of gypsum along with fertilizer may be adopted on large scale. Its use is especially beneficial when the urea is the major nitrogen source. The use of gypsum for this purpose is surely an economic intervention and its large deposits are present in Pakistan. Thus it is available at reasonably low price of Rs. 30 per 50 kg. Along with improving fertilizer use efficiency it also ameliorates soil physical condition. It also takes care of sulphur deficiency in soil if any.

In studies where the effect of potassium fertilizer was investigated on the efficiency of nitrogen sources, it was found that potassium application helped to improve wheat yield, agronomic efficiency and apparent nitrogen recovery significantly especially when the source of nitrogen was CAN. Ammonium sulphate and urea followed the order. Potassium fertilization helped to improve wheat yield and nitrogen use efficiency. Therefore, for enhancing wheat yield and fertilizer use efficiency use of potassium fertilizers is recommended.

REFERENCES

Aamio, T. and P.J. Martikainen. 1995. Mineralization of carbon and nitrogen and nitrification of scots pine forest soil treated with nitrogen fertilizers containing different proportions of urea and its slow releasing derivatives, urea formaldhyde. Soil Biol. Biochem., 27(10): 1325-1331.

Abd-Alla. M.H. and M.A. Wahab. 1995. Response of nitrogen fixation nodule activities and growth on K supply in water stressed broad beans. J. Plant. Nut., 18 (7): 1391-1402.

Abreu, J. P.De. M.E., I. Flores., F. M.G.De. Abreu and M.V. Madeira. 1993. Nitrogen uptake in relation to water availabiltiy in wheat. Plant Soil., 154 (1): 89-96.

Ahmed, Z.I., A.S.Cheema., M.Ashraf., C.M. Azam and N.Ahmed., 1997. Effect of salinity levels on yield components and yield of wheat genotype. Pak. J. Soil Sci., 13: 75-78.

Al-Rawahy, S.A., J.L. Stroehlien and M. Pessarakli. 1990. Effect of salt stress on dry matter production and nitrogen uptake by tomatoes. J. Plant Nut., 13 (5): 567-577.

Alcoz, M.M., F.M. Hons and V.A. Huby. 1993. Nitrogen fertilization timing effect on wheat production, N uptake, efficiency and residual soil nitrogen. Agron. J., 85: 1198-1203.

Ali, A. 1993. Growth and yield of barley. *Hordeum vulgare* L. as affected by salinity and mixed ammonium and nitrate nutrition. Ph.D. Dissertation, Deptt. Soil and Water Sci., Univ. Arizona, U.S.A.

Ali, S., M. Ashraf., M.A. Gill, and A. Faiz 1995. Effect of ammonium and nitrate forms of nitrogen in wheat growth. Pak. J. Soil Sci., 10: 74-77.

Allison, F.E. 1955. The enigma of soil nitrogen balance sheets. Adv. Agron., 7:213-250.

Allison, F.E. 1966. The fate of nitrogen applied to soils. Adv. Agron., 18: 219-258.

Amberger, A . 1991. Dicyandiamide as nitrification inhibitor. German proceedings. Stabilisierte Stickstoffdünger-ein Beitrag zur Verminderung des Nitratproblems. Fachtagung: 15/16. October 1991, Würzburg. Publisher: BASF Aktiengesellschaft, Limburgerhof, SKW Trostberg AG, Germany.

Amberger, A. 1986. Potentials of nitrification inhibitors in modern nitrogen fertilizer management. Pflanzenernhr Bodenkd, 149 (4): 469-484.

Amberger, A . 1993. Potential of the nitrification inhibitor Dicyandiamide to control nitrgoen management and environmental pollution. Proceedings: Dahlia Geidinger Memorial International Workshop on Controlled/Slow Release Fertilizers, Technion. Israel Institute of Technology, Haifa, 7-12 March, 1993.

Amin, M., M.M. Haque., M.A. Akhtaruzzaman., M. Shahjahan and M.N. Anwar. 1996. Effect of NPK and S on sesame under rainfed conditions. Bangladesh J. Agri. Res. 21(2): 306-311.

Arshad, M., T. Ahmad and M. Aslam. 1999. Ammonia volatilization from different nitrogen sources as affected by gypsum application. Science Vision, 4 (4): 40-46.

Ashcroft, W.J. and K.H. Jones. 1993. Response of processing tomatoes to application of nitrogen and potassium in plant nutrition from genetic engineering to field practice. Proceeding of the 12th International Plant Nutrition. Colloquium 21-26 Sep. Perth, Australia.

Aslam, M., M.S. Zia and M.A. Khan. 1992. Effect of combining different nitrogen sources and gypsum application on nitrogen use efficiency for wheat. *In*: Proceeding of Fourth National Congress of Soil Science May, 24-26, Islamabad, Pakistan. p. 483-485.

Asnakew, W., T. Mamo, M. Bekeb and T. Ajenia. 1991. Soil fertility management studies on wheat in Ethiopia. *In:* Hailu Gebre-Marians Tanner D.G. and Mengista Hulluka (eds). *Wheat research in Ethiopia, historical perspective*, p. 137-172. IAR/CINMYT Addis Ababa, Ethiopia.

Awasthi, U.D. and S. Bhan. 1993. Performance of wheat (*Triticum aestivum)* variation with different levels of nitrogen in moisture scarce condition. Ind. J. Agron., 38(2): 200-203.

Baligar, V.C. and O.L. Bennet 1986. Out-look on fertilizer use efficiency in tropics, Fertil. Res., 10: 83-96.

Barber, K.L., L.D. Maddux, D.D. Kissel, G.M. Pierzynski and B.R. Bock. 1991. Grain sorghum responses to ammonium and nitrate nitrogen a free amino acid content. J. Ferti., 8(2): 25-33.

Bayrakli, F. 1990. Ammonia volatilization losses from different fertilizers and effects of several urea inhibitors $CaCl_2$ and Phosphogypsum on losses from urea. Fertil. Res., 23: 147-150.

Below, F.E. and J.A. Heberer. 1990. Time of availability influenced mixed nitrogen induced increase in growth and yield of wheat. J.Plant. Nut., 13(6): 667-676.

Ben-Hayyin, G. and Y. Goffer. 1988. Effect of nitrogen source on salt tolerance of citrus cells in cultivation. Israel Agresearch. 2: 139-152.

Bernstein, L., L.E. Francis and R. A. Clark 1974. Interactive effect of salinity and fertility on yields of grains and vegetables. Agron. J., 66: 412-421.

Biswas, B.E., M. Satish and D.S. Yadav. 1985. Efficiency of different types of fertilisers. *In* Proc. Int. Sem. Fertiliser use efficiency. November 4-6, Lahore, Pakistan. p. 113-135.

Blacquierer, T., F. Voortman and I. Stulen 1988. Ammonium and nitrate nutrition in *Plantago lanceolata* L and *Plantago major* L. SSP majer : 111- Nitrogen metabolism. Plant soil, 106: 23-34.

Blaise, D.T., P.C. Tyagi and O.P.S. Khola. 1996. Ammonia volatilization from urea as affected by addition of iron pyrites and method of application. Nutrient Cycling in Agro-ecosystems. 46: 97-101.

Bloom, A.J. 1988. Ammonium and nitrate as nitrogen sources for plant growth. Atlas of Science. Animal and plant sciences, 55-59.

Bock, B.K. 1986. Increasing cereal yields with higher ammonium/nitrate ratio: Review of potentials and limitations. J. Environ. Sci. Health, 21: 723-758.

Bremner, G.M. and L.A. Douglas. 1971. Decomposition of urea phosphate in soils. Soil Sci. Soc. Amer. Proc., 35: 575-578.

Bremner, J.M. and C.S. Mulvaney. 1982. Regular Kjeldahl nitrogen total. *In:* Page, A.L., R.H. Miller and D.R. Keeny 1982. *Methods of soil analysis.* Part II.

Broadbent, F.E., G.N. Hill and K.B. Tyler. 1958. Transformations and movement of Soil Sci. Soc. Amer. Proc., 22: 303-307.

Campbell, C.A., H.R. Davidson and F.G. Warder 1977. Effect of fertilizer nitrogen and soil moisture on yield components, protein contents and nitrogen accumulation on the above ground pots of spring wheat. Can. J. Soil Sci., 57: 311-327.

Chancy, H.F. and E.J. Kamprath 1982. Effect of nitrapyrine on N response of corn on sandy soil. Agron. J., 74: 565-569. *Chemical and Biological properties* 2nd ed. Madison, Wisconsin, USA. P. 595-622.

Choudhry, T.M. and S.M. Qureshi. 1982. Nitrogen efficiency improvement for wheat production. Transaction 12th International Congress of Soil Science. New Delhi. Abstracts of voluntary paper 104.

Christianson, C.B., G. Carmona, M.O. Klein and R.G. Howard. 1995. Impact on ammonia volatilization losses of mixing KCl of high pH with urea. Fertil. Res., 40: 89-92.

Cochran, V.L., R.L. Warner and R.I. Papendick. 1978. Effect of nitrogen depth and application rate on yield, protein content and quality of winter wheat. Agron. J., 70: 964-968.

Cox, W.J. and H.M. Reisenauer. 1973. Growth and ion uptake of wheat supplied nitrogen as nitrate or ammonium or both. Plant Soil, 38: 363-380.

Cox, W.J. and H.M. Reisenauer. 1978. Absorption and utilization of ammonium nitrogen by plants. Nitrogen in the environment vol. 2. Soil-Plant-Nitrogen relationships. Academic press. New York. p 153-170.

Craswell, E.T. 1987. The efficiency of urea fertilizer under different environmental conditions. Paper presented at the international symposium on urea technology and utilization (FADINAP), held at Kuala Lumpor, 16-18 March, 1987.

Craswell, E.T., and D.C. Gedwin 1984. Efficiency of nitrogen fertilizers applied to cereals in different climates. Advances in Plant Nutrition, 1: 1-54.

Crawford, D.M. and P.M. Chalk. 1993. Sources of nitrogen uptake by wheat (*Triticum aestivum*. L.) and nitrogen transformations in soil treated with a nitrification inhibitor (nitrapyrin). Plant soil, 149 (1): 59-72.

De-Klein, C.A.M. and R.S.R. Van-Lojtestijin. 1994. Denitrification in top soil of managed grassland in the Netherland in relation to soil type and fertiliser level. Plant Soil, 163(1): 33-44.

Delgado, J.A. and A.R. Mosier. 1996. Mitigation alternatives to decrease nitrous oxide emissions and urea-nitrogen loss and their effects on methan flux. J. Environ. Qual., 25(5). Code N: JE VQAA; ISSN: 0047-2425.

Dibb, D. W. and L.F. Welch. 1976. Corn growth as affected by ammonium versus nitrate absorbed from soil. Agron. J., 68: 89-94.

Duke, S.H. and M. Collins. 1985. Role of K in legume nitrogen fixation. P. 443-465. *In*: R.D. Munson (ed) *K in Agriculture*, Am. Soc. Agron. Madison W1.

Ebelhar, S.A., E.J. Kamprath and R.H. Mall. 1987. Effects of nitrogen and potassium on growth and cation composition of corn Genotype differing in average ear number. Agron. J., 79 : 875-881.

Edafologia, C.de. and C.de. Postgraduados. 1992. Effect of NH_4/NO_3 ratio on GS. and PEPcase. Activities and on dry matter production in wheat. J. Plant. Nut., 15 (11): 2545-2557.

Ellen, J. and J. I. J. Spiertz. 1980. Effect of rate and timing of nitrogen dressings on grain yield formation of winter wheat (*Triticum aestivum* L.). Fertil. Res., 1: 177-180.

El-Shafei, Y.Z. and A. Darwesh. 1980. Effect of nitrogen fertilizer on wheat yield as affected by soil moisture stress and rainfall under improved irrigation practices. Agrochemica, 24(1): 69-77.

Ernst, J.W. and H.F. Massey. 1960. The effects of several factors on volatilisation of ammonia formed from urea in the soil. Soil Sci. Soc. Amer. Proc., 24: 87-90.

Errebhi, M. and G.E. Wilcox. 1990. Plant species response to ammonium-nitrate concentration ratios. J. Plant. Nut., 13 (8): 1017-1029.

Estavillo, J.M., M. Rodriguez, M. Lacuesta and C. Gonzales-Munrs. 1997. Effect of cattle slurry and mineral nitrogen fertiliser application on various component of the nitrogen balance of mown grassland. Plant Soil, 188(1): 49-58.

Fardad, H. and M. Pessarakli. 1995. Biomass production and water use efficiency of barley and wheat plants with different irrigation intervals at various water levels. J. Plant Nut., 18 (12): 2643-2654.

Feagley, S.E. and L.R. Hossner. 1977. Ammonia volatilization reaction mechanism between ammonium sulphate and carninate systems. Soil. Sci. Am. J. 2: 364-367.

Feigen, A. 1988. Fertilizer for increasing salt tolerance of agricultural crops. Israel Research, 2 (2): 99-138.

Fen, J. and A.V. Barker. 1990. Responses of different plants to NH_4^+ and NO_3^- as source on nitrogen with application of fungicides J. Plant Nut. 13 (5): 495-512.

Fenn, L.B. and L.R. Hossner 1985. Ammonia volatilization from ammonium and ammonium forming nitrogen fertilizers. Advances in Soil Sci., 1: 123-169.

Fenn, L.B. and D.E. Kissel. 1973. Ammonia volatilization from surface application of ammonium compounds on calcareous soil. 1. General theory. Soil Sci. Soc. Amer. Proc., 37: 855-859.

Fenn, L.B. and D.E. Kissel. 1974. Ammonia volatilization from surface application of ammonium compounds on calcareous soils. II. Effect of temperature and rate of ammonium nitrogen application. Soil Sci. Soc. Amer. Proc., 38: 606-610.

Fenn, L.B. and D.E. Kissel. 1976. The influence of CEC and depths of incorporation on ammonia volatilization from ammonium compounds applied to calcareous soils. Soil Sci. Soc. Amer. J., 40: 394-398.

Fenn, L.B. and R. Escarzaga. 1976. Ammonia volatilization from surface applications of ammonium compounds on calcareous soils. V. Soil water content and method of nitrogen application, Soil Sci. Soc. Amer. J., 45: 537-540.

Fenn, L.B. and S. Miyamoto. 1981. Ammonia loss and associated reactions of urea in calcareous soils. Soil Sci. Soc. Amer. J., 45: 537-340.

Fenn, L.B. and J. Richard. 1984. Ammonia loss from urea-acid adducts surface applied to soils. Soil Sci. Soc. Amer. J., 48.

Fenn, L.B., H.L. Malstorm and E. Wu. 1984. Ammonia losses from surface applied urea as affected by added calcium and fresh plant residues. Soil Sci., 137.

Fenn, L.B., J.E. Matocha and E. Wu. 1982. Soil CEC effects on ammonia loss from surface applied urea in the presence of soluble calcium. Soil Sci. Soc. Amer. J., 46: 78-81.

Fenn, L.B., J.E. Matocha and E. Wu.1981a. Ammonia losses from surface applied urea and ammonium fertilizers as influeced by soluble calcium. Soil Sci. Soc. Amer. J., 45: 883-886.

Fenn, L.B., R.M. Taylor and J.E. Matocha. 1981. Ammonia losses from surface applied nitrogen fertiliser as controlled by soluble calcium and magnesium. General Theory. Soil Sci. Soc. Amer. J., 45: 777-781.

(ed)
Firestone, M.K. 1982. Biological denitrification. *In*: Stevenson, F.J. Nitrogen in agricultural soils, Agronomy Monograph No. 22 Madison, Wisconsin, Amer. Soc. Agron., pp. 289-326.

Fischer, R.A., G.N. Howe and Z. Ibrahim. 1993. Irrigated spring wheat and timing and amount of nitrogen fertilizer. 1 Grain yield and protein contents. Field Crop Res. 33: 37-56.

Focht, D.D. and W. Verstraete. 1977. Biochemical ecology of nitrification and denitrificaiton. Adv. Microbiol. Ecol., 1: 135-214.

Fox, R.H. and L.D. Hoffman. 1981. The effect of nitrogen fertilizer source on grain yield, nitrogen uptake, soil pH and lime requirement in no tillage corn. Agron. J., 73: 891-895.

Francis, D.D. and J.S. Schepers. 1994. Nitrogen uptake efficiency in maize production using irrigation water high in nitrate. Fertil. Res., 39: 239-244.

Francis, G.S., R.J. Haynes., T.W. Speir and P.H. Williams 1995. The effect of nitrification inhibitor on leaching losses and recovery of mineralized nitrogen by a wheat crop after ploughing in temporary leguminous pasture. Fertil. Res., 41: 33-39.

Freney, J.R., C.J. Smith and A.R. Mosier. 1992. Effect of a new nitrification inhibitor (wax coated) carbide on transformation and recovery of fertiliser by irrigated wheat. Fertil. Res., 32: 1-11.

Freney, J.R., D.L. Chen., A.R. Mosier., I.J. Rochesler., G.A. Constable and P.M.Chalk. 1992a. Use of nitrification inhibitors to increase fertiliser nitrogen recovery and lint yield in irrigated cotton. Fertil. Res., 34(1): 37-44.

Freney, J.R., D.G. Keerthisinghe., S. Phongpan., P. Chaiwanakupt and K.J. Harrington 1995. Effect of urease, nitrification and algal inhibitors on ammonia loss and grain yield of flooded rice in Thailand. Fertil. Res., Vol. 40,No, 3. → 40(3): pages ?

Frota, J.N.E. and T.C. Tucker 1978. Salt and water stress influence nitrogen metabolism in red kidney beans. Soil Sci. Soc. Amer. J., 42: 753-756.

Gandhi, A.P. and K.V. Paliwal. 1976. Mineralization and gaseous losses of nitrogen from urea and ammonium sulphate in salt affected soil. Plant Soil. 45: 247-255.

Gartner, J.A. 1969. Effect of fertilizer nitrogen on dense sward of kikuyu Paspalum and carpet grass. To interaction with phosphorus and potassium in savanna zone of Nigeria. Potash. Review, Subject. 16, 57th Suite.

Gashaw, L. and L.M. Mugwira. 1981. Ammonium nitrogen and nitrate nitrogen effects on growth and mineral composition of triticale, wheat and rye. Agron. J., 73: 47-51.

Gass, W.B., G.A. Peterson, R.D. Hauck and R.A. Olson. 1971. Recovery of residual nitrogen by corn (*Zea mays* L.) from various soil depths as measured by N^{15} tracer techniques. Soil Sci. Soc. Amer. Proc., 35: 290-294.

Gee, W. and J.W. Bauder 1986. Particle size analysis. *In:* Klute , A. 1986 *Method of soil analysis*. Part I. Physical and Mineralogical methods 2nd ed. Published by Amer. Soc. Agron. Inc. and Soil Sci. Soc. Amer. Madison, USA. P. 404-408.

Gentry, L.E., X.T. Wang and F.E. Below. 1989. Nutrient uptake by wheat seedling that differ in response to mixed nitrogen nutrition. J. Plant. Nut., 12 (3): 363-373.

Gezgin, S. and F. Bayrakli. 1995. Ammonia volatilisation from ammonium sulphate, ammonium nitrate and urea surface applied to winter wheat on calcareous soil. J. Plant Nut., 18(11): 2483-2494.

Gould, W.D., C. Hagedorn and R.G. McCready. 1986. Urea transformations and fertilizer efficiency in soil. Advan. Agron., 20: 209-238.

Gould, W.D., F.D. Cook and G.R. Webster. 1973. Factors affecting urea hydrolysis in several Alberta soils. Plant Soil, 38: 393-401.

Goyal, S.S. and R.C. Huffaker. 1984. Nitrogen toxicity in plants. p- 97-118. *In*: Hauk, R.D. (ed). *Nitrogen in crop production.* Amer. Soc. Agron., Madison. W-I.

Grant, C.A., S. Jia., K.R. Brown and L.D. Baily. 1996. Volatile losses of ammonia from surface applied urea and urea ammonium nitrate with and without the urease inhibitors NBPT or ammonium thiosulphate. Canadian J. Soil. Sci., 76(3):

Hageman, R.H. 1984. Ammonium versus nitrate nutrition of higher plants P. 67-85. In: Hauck, R.D (ed). *Nitrogen in crop production.* Amer.Soc. Agron., Madison, W.

Hammam, G.Y. 1995. Effect of nitrification inhibitor and nitrogen level on growth and yield of maize (*Zea mays* L.). Ann. Agric. Sci., Moshtober. 33 (2).

Hargrove, W.L. and D.E. Kissel. 1979. Ammonia volatilisation from surface application of urea in the field and laboratory. Soil Sci. Soc. Amer. J., 43: 359-363.

Hargrove, W.L., D.E. Kissel and L.B. Fenn 1977. Field measurement of ammonia volatilization from surface application of ammonium salts to a calcareous soil. Agron. J., 69: 473-476.

Hauck, R.D. 1985. Slow release and bio-inhibition ammended nitrogen fertilizers pp.294-323. In Engelstudt, O.P. (ed) *Fertilizer and Technology*, 3rd ed. Soil. Sci. Soc. Amer., Madison, W.I.

Hauck, R.D. 1980. Mode of action of nitrification inhibitors. P 19-32. *In*: Messinger, J.J. (ed) *Nitrification inhibitors potentials and limitations*. Spec. Publ. 38. Amer. Soc. Agron., Madison. W 1.

Havlin, J.L. 1986. Optimising wheat inputs for profit. SOLUTIONS Nov/Dec. 51-58.

Haynes, R.J. and K.M. Goh. 1978. Ammonium and nitrate nutrirtion of plant. Biol. Rev., 553: 465-510.

Heathcote, R.G. 1972. Fertilization with potassium in savanna zone of Nigeria Potash. Review, Subject, 16,

Hege, U. and M. Munzert. 1991. The effect of stabilised nitrogen fertilizers on the yield of agricultural crops. German Proceeding Stabilisiert Stickstoftdunges. 15-16. Oktober Wurzburg Germany.

Helal, M.H. and K. Mengal 1979. Nitrogen metabolism of young barley plants as affected by NaCl salinity and potassium. Plant Soil, 51: 457-462.

Herberer, J.A. and F.E. Below. 1989. Mixed nitrogen nutrition and productivity of wheat grown in hydroponics. Ann. Bot. 63: 643-649.

Herron, G.M., G.L. Terman., A.F. Dreier and R.A. Olson. 1968. Residual nitrate nitrogen in fertilized deep loess soils. Agron. J., 60: 477-482.

Hira, G.S. and N.T. Singh. 1973. Effect of salinity and water table depth on yield salt uptake and transpiration rate in wheat. Indian J. Agric. Sci. 43: 126-128.

Hoeft, R.G. 1984. Current status of nitrification inhibitors. Use in Agriculture. p 561-570. *In*: Hauk, R.D. (ed). *Nitrogen in crop production.* Amer. Soc. Agron., Madison. W 1.

Hsiao, T.C. 1973. Plant response to water stress. Ann. Rev. Physol., 24: 519-570.

Huffaker, R.C., T. Radin and G.E. Kleinkopf. 1970. Effects of mild winter stress on enzymes of nitrate assimilative and carboxylative phase of photosynthesis in barley. Crop Sci., 10:471-474.

Huffman, R.J. 1989. Effect of enhanced ammonium nitrogen availability for corn. J. Agron., 18: (2) 93-95.

Hummadi, K.B. 1977. Salt and sodium affected soils in relations to nitrogen utilization in wheat. Ph.D. Dissertation. Univ. Arizona, Tueson, U.S.A.

Hussain, F. and M.H. Naqvi. 1998. Ammonia losses from salt affected soils. Pak. J. Soil Sci.,14 (1-2): 1-4.

Hussain, I., I. Haq and M. Sajid. 1997. Effect of nitrogen alone and in combination with constant doses of phosphorus and potassium on yield of radish.Sarhad J. Agri., 12 (1) :39-43.

Hussain, T. and A. Jabbar 1985. Soil and plant analysis. Department of Soil Science, U. Agric., Faisalabad, Pakistan.

IFA, 1992. Fertilizer use manual, Internation fertilizer industry association, Paris.

IFDC. 1984. The vitale role of potassium fertilizers in tropical agriculture. International Fertilizer Development Centre., Technical Bulletin. T. 29, p. 15.

Ilyas, M., R.W. Matler and R.H. Qureshi. 1993. Hydraulic conductivity of saline sodic soil after gypsum application and cropping. Soil.Sci. Soc. Amer. J., 57: 1580-1585.

Jaggi, R.C., R.C. Kanwal and S.P. Dixit. 1998. Effect of fertilizer nitrogen and sulphur interaction on composition and uptake of nutrients by Linseed on acid alfisol. J. Ind. Soc. Soil Sci., 43 (4): 611-615.

Janzen, H.H. and C.W. Lindwall. 1989. Optimum application parameters for point injection of nitrogen in winter wheat. Soil Sci. Soc. Amer. J., 53(6): 1878-1883.

Kaetterer, T., M. Eckersten., O. Andreu and R. Pettersson. 1997. Winter wheat biomass and nitrogen dynamics under different fertilization and water regimes. Application of crop growth model. Ecol. Model 102(2-3): 301-314.

Kafkafi, U., N. Valoras and J. Letez. 1982. Chloride interaction with nitrate and phosphate nutrition in tomato. (*Lycopersicon esculentum* Mills). J. Plant. Nut., 5 : 1369-1385.

Keller, G.D. and D.B. Mengal. 1986. Ammonia volatilisation from nitrogen fertilisers surface applied to no tillage corn. Soil Sci. Soc. Amer. J., 50: 1060-1063.

Khan, H.A. 1993. Prospects and small challenges for enhancing wheat productivity in Pakistan, Presented at the 17th Consultation of FAO fertilizer program (May 9-13, 1993), Islamabad.

Khan, M.G., M. Silberbush and S.H. Lips. 1994. Physiological studies on salinity and nitrogen interaction in alfalfa. 1. Biomass production and root development. J. Plant. Nut., 17 (4) 657-668.

Klute, A. 1986. Water retention: Laboratory methods p. 635-662 *In*:A. Klute (ed) Methods of soil analysis part-I. Soil Sci. Soc. Amer. Madison Wisconsin, USA.

Knowles, R. 1981. Denitrification in terrestrial nitrogen cycle. Processes ecosystem strategies and management impacts. Edited by F.E. Clark and T. Rosswell. Ecol. Bull., (Stockholm). 33: 315-329.

Knudsen, D., G.A. Peterson and E.F. Pratt 1982. Potassium. *In:* Page, A.L., Miller R.H. and D.R. Keeny. *Methods of soil analysis*. Part II. Chemical and Biological properties 2nd ed. Madison, Wisconsin, USA. P. 421-422.

Koch, K. and K. Mengal. 1977. The influence of level of potassium supply to young tobacco plant on short term uptake and utilization of nitrate nitrogen (N^{15}). J. Sci. Fd. Agric., 25: 465-471.

Korentajer, L. and P.R. Berliner. 1988. Effect of moisture stress on nitrogen fertilizer response in dry land wheat. Agron. J., 80 (6): 977-981.

Lamond, R.E. and J.L. Mayer. 1983. Effects of knifed vs broadcast fertiliser placement on yield and nutrient uptake by tall Fescue. Soil Sci. Soc. Amer. J., 47(1): 145-149.

Leidi, E.O., M. Silberbush and S.H. Lips. 1991. Wheat growth as affected by nitrogen type, pH and salinity. 1. Biomass production and mineral composition. J. Plant. Nut., 14 (3): 235-246.

Liang, B.C. and A.F. Mackenzie. 1994. Changes of soil nitrate nitrogen and denitrification as affected by nitrogen fertilizer on two Quebec soils. J. Environ. Qual., 23(3): 521-525.

Low, M.J.D. 1960. Kinetics of chemisorption of gases on soilids. Chemical Review. 60: 267-312.

Mahmood, T., G.R. Tahir, K.A. Malik and S.R.A. Shamsi. 1997. Denitrification losses from irrigated sandy-clay loam under wheat maize cropping system receiving different fertiliser treatments. Biol. Fertil. Soil., 26(1): 35-42.

Mahmood, T., R. Ali, K.A. Malik and S.R.A. Shamsi. 1998. Nitrous oxide emission from irrigated sandy-clay loam cropped to maize and wheat. Biol. Fertil. Soil., 27: 189-196.

Malhi, S.S. and M. Nyborg. 1992. Recovery of nitrogen by spring barley from ammonium nitrate, urea and sulphur coated urea as affected by time and method of application. Fertil. Res., 32(1): 19-25.

Malhi, S.S., M. Nybrog., I.G. Jahn and D.G. Penney 1990. Yield and nitrogen uptake of rapeseed (*Brassica campastris* L) with ammonium and nitrate. Plant Soil, 105:231-239.

Martin, J.P. and H.D. Chapman. 1951. Volatilization of ammonia from surface fertilized soil. Soil Sci. 71: 25-35.

McCarty, G.W and J.M. Bremner.1986. Inhibition of nitrification in soil by acetylenic compounds. Soil Sci. Soc. Amer.J., 50: 1198-1201.

McClung, G. and W.T. Frankenberger Jr. 1985. Soil nitrogen transformations as affected by salinity. Soil Sci. 139: 405-411.

McCrimmon, J.N., H.A. Mills and K.J. Karnok. 1992. Effect of nitrogen form on macronutrient and micronutrient concentration and uptake of creeping Bentgrass. J. Plant. Nut., 15 (8): 1269-1289.

Mehta, K.K. 1983. Reclamation of alkaline soils Indis Oxford. 1 B.4 Pub. Co. New Delhi.

Meisenger, J.J., G.W. Randall and M.L. Vitosh (ed) 1980. Nitrification inhibitors potentials and limitations Spec. Publ. 38 Amer. Soc. Agron. Madison, W.I.

Mello, F.de.A.F.de. and S. Arzolla. 1984. Study to compare nitrogen sources in a greenhouse. Revista-de-Agriculture, Piracicaba, Brazil, 59: 145-148.

Mengal, K. 1989. The role of potassium in improving nitrogen uptakc and nitrogen utilization. P. 111-122. In: *Potassium and fertilizer use efficiency.* National Fertilizer Development Centre, Islamabad.

Mengal, K. and E. A. Kirkby. 1987. Principles of plant nutrtition. International Potash. Inst., Bern, Switzerland.

Mengal, K., M. Viro and G. Hehl. 1976. Effect of Potassium on the uptake and incorportaion of ammonium nitrogen on rice plants. Plant Soil. 44 : 547-558.

Meyer, R.D., R.A. Olson and H.P. Rhodes. 1961. Ammonia losses from fertilised Nebraska soils. Agron. J., 53: 241-244.

Mikkelsen, R.H., W. M. Jarrel., J.Letey and S. Whaley. 1986. Effect of terrazole on nitrogen transformations and movement in irrigated corn. Agron. J., 50: 1471-1478.

MINFAL, 1998. Agricultural statistics of Pakistan, Ministry of Food, Agriculture and Livestock. Food, Agriculture and Livestock Division, Government of Pakistan, Islamabad.

Minhas, P.S., D.R. Sharma and Y.P. Singh. 1995. Response of rice and wheat to applied gypsum and farmyard manure on an alkali winter irrigated soil. J. Ind. Soc. Soil Sci., 43 (3) : 452-455.

Mitrosuhardjo, M. M. 1983. Effect of soil moisture stress on nitrogen uptake and fixation by plants, International Atomic Energy Agency, Vienna, Australia, (Soil Fert. 47 (8) : 8773) p 353-366.

Myers, M. and J.W. McGarity, 1968. The urease activity in profiles of five great soil groups from northern New South Wales, Plant Soil, 28: 25-37.

Naeem, M.A., R.H. Qureshi., M. Aslam and R. Ahmed 1998. Rice growth as influenced by Zn-P ratio of the growth medium. Pak. J.Biol. Sci., 1: 87-91.

Nelson, D.C. and A.D. Halvorson. 1991. Nitrogen fertility influence on water stress and yield of winter wheat. Agron. J., 8: 1065-1070.

Neuman, P.M., E. Van. Volkenburgh and R.E. Cleland. 1988. Salinity stress inhibits leaf expansion by reducing turgor of cell wall extensibility. Plant. Physiol., 88: 233-237.

NFDC, 1996. Annual fertilizer review for the year 1995-96. National Fertilizer Development Centre, Planning and Development Division, Government of Pakistan, Islamabad.

NFDC, 1998. Annual fertilizer review for the year 1997-98. National fertilizer development Centre, Planning and Development, Government of Pakistan, Islamabad.

Nizami, M.M.I. 1995. Results of scan project Land Resources Research Institute, National Agricultural Research Centre, Islamabad, Pakistan.

Olsen, S.R. 1986. The role of organic matter and ammonium in producing higher corn yields. *In*: Chen. Y and Avnimeleck (eds). *The role of organic matter in modern agriculture.* Martinces, Nijhof publisher Dordrecht, The Netherlands. pp. 29-54.

Olsen, S.R. and L.E. Sommers 1982. Phosphorus. *In:* Page, A.L., R.H. Miller and D.R. Keeny. *Methods of soil analysis.* Part II. Chemical and Biological properties 2nd ed. Madison, Wisconsin, USA. P. 421-422.

Ota, K. and Y. Yamamoto. 1987. Effect of N source on growth and chemical constituen ts in radish and carrot plants. J. Japan Soc. Hort. Sci. 56: 193-201.

Overrein, L.M. and P.G. Moe. 1967. Factors affecting urea hydrolysis and ammonia volatilisation in soil. Soil Sci. Soc. Amer. Proc., 31: 57-61.

Page, A.L., R.H. Miller and D.R. Keeny 1982. Methods of soil analysis part II: Chemical and Microbiological properties 2nd ed. Published by Amer. Soc. Agon. Inc. Soil Sci. Soc. Amer. Inc. Madison, Wisconsin, USA.

Patel, M.S. and D.M. Suther. 1993. Effect of gypsum on properties of sodic soils. Infilteration rates and crop yield. J. Ind. Soc. Soil Sci., 41 (4): 802-803.

Park, N., D.W. Hood and H.T. Odum. 1958. Diurnal pH variation in Texas bays and its application to primary production estimates. Ints. Mar. Sci., 5: 47-64.

Patra, A.K., J.R. Burford and T.J. Rego. 1996. Volatilization losses of surface applied urea nitrogen from vertisols in the Indian semi arid tropics. Biol. Fertil. Soil., 22: 345-349.

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

Pearman, I. S. M. Thomas and G. N. Thorne 1977. Effect of nitrogen fertilizer on growth and yield of spring wheat. Ann. Bot., 41: 93-108.

Pessarakli, M. and T.C. Tucker. 1985. Ammonium (N^{15}) metabolism in cotton under salt stress. J. Plant. Nut., 8: 1025-1045.

not cited in thesis

Pessarakli, M. and T.C. Tucker. 1985a. Uptake of N^{15} by cotton under salt stress. Soil Sci. Soc. Amer. J., 49: 149-152.

Pessarakli, M. and T.C. Tucker. 1988. Dry matter yield and N^{15} uptake by tomatoes under sodium chloride stress. Soil Sci. Soc. Amer. J., 52: 698-706.

Pessarakli, M., J.T. Huber and T.C. Tucker. 1989. Dry matter yield, nitrogen absorption and water uptake by sweet corn under salt stress. J. Plant. Nut., 12: 279-290.

Pessarakli, M., T.C. Tucker and K. Nakabayashi. 1991. Growth response of barley and wheat to salt stress. J. Plant Nut. 14 (4) : 331-340.

Prakasha, E.V.S. and K. Puttana. 1994. Evaluation of dicyandiamide (DCD) treated urea in Java citronella. J. Ind. Soc.Soil Sci., 42 (1): 54-59.

Premaratne, K.P. and J.J. Oertli. 1994. The influence of potassium supply on nodulation, nitrogenese activity and nitrogen accumulation of soybean (*Glycine max* (L.) Merrit) grown in nutrient solution. Fertil. Res., 38: 95-99.

Prihar, S.S., K.S. Sandhu., M. Singh., H. N. Vermaand and R. Singh. 1989. Response of dryland wheat to small suplemental irrigation and fertilizer nitrogen in sub mountain Punjab. Fertil. Res., 21:23-28.

Purakayastha, T.J., J.C. Katyal and N.N. Goswami. 1997. Evaluation of ammonia volatilisation from some modified urea fertiliser. J. Amer. Soc. Soil Sci., 45(1): 9-14.

Qayyum, F., A.S. Qureshi and M. Ahmad. 1994. Nitrogen use efficiency in wheat. Pak. J. Sci. Ind. Res., 37(10): 428-430.

Rambe, J., B. Bhalerao and S.R. Oza. 1997. Effect of nitrogen and soil water regimes on soil plant water relationship, yield and water use efficiency of summer sunflower. J. Ind. Soc. Soil. Sci., 45 (4): 701-705.

Rashid, M.T. and M. Saleem. 1992. Relative efficiency of different nitrogen sources and level for wheat crop under rainfed conditions. Pak. J. Agric. Res., 13(2): 227-231.

Rashid, M.T. and M. Yasin. 1993. Effect of irrigation regimes and nitrogen sources on growth and nitrogen uptake by sorghum fodder. Pak. J. Soil Sci., 8(1-2): 30-36.

Rhodes, J.W. 1982. Electrical conductivity. *In:* Page, A.L., R.H. Miller and D.R. Keeny. *Methods of soil analysis*. Part II. Chemical and Biological properties 2nd ed. Madison, Wisconsin, USA. P. 167-178.

Roelcke, M., Y. Han., S.X. Li and J. Richter. 1996. Laboratory measurements and simulation of ammonia volatilization from urea applied to calcareous Chinese loess soils. Plant Soil, 181: 123-129.

Roy, R.N. and S. Chandra 1979. Improving the efficiency of fertilizer use in India. Fertilizer industry, pp. 17-27.

Ryden, J.C. 1983. Denitrification loss from a grassland soil in the field receiving different rates of nitrogen as ammonium nitrate. J. Soil Sci., 34: 355-365.

Sakarvadia, M.L. and B.S. Yadev. 1994. Effect of water stress at different growth phases of ground nut on yield and nutrient absorption. J. Ind. Soc., Soil. Sci. 42 (1): 147-149.

Salim, M.T., A. Nisar and J.G. David. 1986. Fertilizer and their use in Pakistan. National Fertiliser Development Centre, Islamabad, p. 23.

Sandoval, V., M. G. A. Gonzalez, J. T. Torres and A. A. Santelises. 1992. Effect of NH_4/NO_3 ratio on GS. and PEPcase. Activities and on dry matter production in wheat. J. Plant. Nut., 15 (11): 2545-2557.

Sandoval-villa, M., G. Aleantar-Gonzalez and J.L. Tirdo-Torres 1995. Use of ammonium in nutrient solution. J. Plant Nut., 18(7): 1449-1457.

Sanmaneechai, M., F.E. Kochler and S. Roberts. 1984. Nitrogen fertiliser practices for sequential cropping of wheat, turnip and sweet corn. Soil Sci. Soc. Amer. J., 48: 81-86.

Sawyer, J.E. and J.L. Carter. 1993. Urea ammonium nitrate management techniques for winter wheat production. J. Prod. Agric., 6 (1): 62-67.

Scharf, P.C. and M.M. Alley 1988. Nitrogen loss pathways and nitrogen loss inhibitors: A review. J. Fertil. Issues, 5: 109-125.

Schroder, J.J., L. ten. Holte., H.V. Keulen and J.H.A.M. Sleenvoorden. 1993. Effect of nitrification inhibitor and time and rate of slurry and fertilizer nitrogen application on silage maize yield and losses to the environment. Fertil. Res., 34: 267-277.

Serna, M.D., F. Legaz and E. Primo-Millo. 1994. Efficacy of dicynadiamide as a soil nitrification inhibitor in citrus production. Soil Sci. Soc. Amer. J., 58 (6): 1817-1824.

Shah, S.S., Z. Dast and S. Ahmad. 1992. Increasing urea nitrogen efficiency by method and time of application to maize, p. 287-291, *In*: Proceeding of fourth National Congress of Soil Science. May 24-26, Islamabad, Pakistan.

Shainberg, M.E., W.P. Summer., M.P.W. Miller., M.A. Fanna., A. Pavan and M.V. Fey. 1989. Use of gypsum on soils: A Review. Advances in Soil Science. 9: 1-112.

Sharma, B.R. and T.M. Choudhry. 1984. Nitrogen uptake by wheat in relation to water regime and depth of nitrogen placement in a loamy sand, soil measurement and model simulation. J. Soil Sci., 35: 141-148.

Sharma, S.K., V. Kumar and M. Singh. 1992. Effect of different factors on ammonia volatilization losses in soils. J. Indian Soc. Soil Sci. 40: 251-256.

Sharma, S.N. and R. Prasad. 1996. Use of nitrification inhibitors (Neem & DCD) to increase nitrogen use efficiency in maize-wheat cropping system. Fertil. Res., 44 : 169-175.

Shaviv, A. and J. Hagin. 1988. Interaction of ammonium and nitrate nutrition with potassium in wheat. Fertil. Res., 17 : 137-146.

Shaviv, A. and J. Hagin. 1993. Interaction of salinity and enhanced ammonium and potassium nutrition in wheat. Plant. Soil., 154 (1): 133-137.

Shaviv, A., J. Hagin and P. Neumann. 1987. Effect of nitrification inhibitor on efficiency of nitrogen utilization by wheat and millet. Communi. Soil. Sci. Plant. Anal., 18: 815-833.

Shaviv, A., O. Hazan., P.M. Numann and J. Hagin 1990. Increasing salt tolerance of wheat by mixed ammonium-nitrate nutritions. J. Plant Nut., 13(10) 1227-1239.

Shrader, L.E., D. Donska., P.E. Jung and L.A. Peterson. 1972. Uptake and assimilation of NH_4-N and NO_3-N. and their influence on the growth of corn. Agron. J., 64: 690-694.

Silberbush, M. and S.H. Lips. 1991. Potassium, nitrogen, ammonium/nitrate ratio and sodium chloride effects on wheat. 1. Shoot and root growth and mineral composition. J. Plant. Nut., 14 (7): 751-764.

Singh, R., Y. Singh., S. Prihar and P. Singh. 1975. Effect of nitrogen fertilisers on yield and water use efficiency on dry land winter wheat. Agron. J., 67(5): 599-603.

Singh, M., B. Singh. and R.B. Khandelwal. 1993. Response of ground nut to phosphatic fertilizers and their mode of application with and without gypsum on yield quality and phosphorus uptake. J. Ind. Soc. Soil. Sci., 41 (2): 383-384.

Slanger, J.H.G. and P. Kerkhoff 1984. Nitrification inhibitors in agriculture and horticulture. Fertil. Res., 5: 77-98.

Smith, C.J. and D.M. Whitefield. 1990. Nitrogen accumulation and redistribution of late application of N^{15} labelled fertilizer by wheat. Field crops Res. pp. 211-226.

Smith, C.J., J.R. Freney., S.L. Chapman and I.E. Galbally 1989. Fate of urea nitrogen applied to irrigated wheat at Heading. Aust. J. Agric. Res., 40: 951-963.

Smith, R.L., H.A. Mills., C.S. Hoveland and W.W. Hanna. 1990. Inlfuence of ammonium-nitrate ratio on the growth and nitrogen uptake of pearl millet. J. Plant. Nut., 13 (5): 541-553.

Somda, Z.C., H.A. Mills and S.C. Phatak. 1990. Nitrapyrin, Terrazol, Atrazine and Simazine influences on nitrification and corn growth. J. Plant Nut., 13(9): 1179-1193.

Sommer, S.G. and C. Jensen. 1994. Ammonia volatilization from urea and ammoniacal fertilizer surface applied to winter wheat and grassland. Fertil. Res., 37: 85-92.

Spielhaus, G. 1991. Stabilized fertilizer in the production of wheat German proceeding. Stubilisierte Stickstoffdunger. 15-16. Oktober. Wurzburz Germany.

Steel, R.G.D. and J.H. Torrie 1980. *Principles and procedures of statistics*. 2nd ed. McGraw Hill Book Comp. Inc. New York, P. 188-189.

Stephen, G. and D.J. Streeter 1994. Nitrate and ammonium nutrition in rye grass: changes in growth and chemical composition under hydroponic conditions. J. Plant Nut., 17(1) : 71-81.

Stromberger, J.A., C.Y. Tsai and D.M. Huber. 1994. Interaction of potassium with nitrogen and their influence on growth and yield potential in maize. J. Plant Nut., 17(1): 19-37.

Strong, W.M. and J.E. Cooper. 1980. Recovery of nitrogen by wheat from various depths in a cracking clay soil. Aust. J. Exp. Agric. Anim. Husb., 20: 82-87.

Sud, Y.K., R.P. Arora and D.L. Deb. 1990. Nitrogen uptake and its utilization by wheat grown on a typic ustochrept as affected by soil moisture regime and nitrogen management. Annal. Agric. Res., 11(2): 139-148.

Tanner, D.G., A. Gorfu and A. Taa. 1993. Fertilizer effects on sustainability in the wheat based small holders farming system of south eastern Ethiopia. Field Crop Res., 33: 235-248.

Terman, G.L. 1979. Volatilisation losses of nitrogen as ammonia from surface applied fertilisers, organic amendments and crop residue. Advances in Agronomy. 31: 189-223.

Tilahun, G., D.G. Tanner, T. Mamo and G. Gebeyehis. 1996. Response of rainfed bread and durum wheat to source, level and timing of nitrogen fertiliser on two Ethiopian vertisols. II. Nitrogen uptake, recovery and efficiency. Fertil. Res., 14: 195-204.

Tisdale, S.L., W.L. Nelson and J.D. Beaton. 1993. *Soil Fertility and Fertilizers*. 5th edition. Macmillan Publishing Col., *In*: New York and Colloir Macmillan Publisher London.

Tiwari, R.J. 1994. Effect of gypsum on the yield of mustard (*Brassica juncea* L.) cultivars on a salt affected black vertisol of Madhya pradesh. Crop Research, 8 (1): 13-16.

Todd, G. and B. Yoo. 1964. Enzymatic changes in the detached wheat leaves as affected by water stress. Phytone, 21: 61-68.

Touchton, J.T. and W.L. Hargrove. 1982. Nitrogen sources and methods of application for no tillage corn production. Agron. J., 74: 823-826.

Touraim, B. and C. Grignon. 1982. Potassium effect on nitrate secretion into the xylem of corn roots. Physiol. Veg., 20: 23-31.

Tripathi, P.N. and N.L. Sharma. 1994. Evaluation of pyrite and gypsum as a source of sulphur in Indian mustard (*Brassica juncea* L. Rice (*Oryza sativa*) cropping sequence. Ind. J. Agri. Sci., 64 (8): 536-539.

Tripathi, A.K., T.A. Singh and M. Singh. 1997. Leaching losses and use efficiency of nitrogen in rice as influenced by modified gypsum urea. J. Ind. Soc. Soil. Sci., 45 (4): 750-752.

Urban, W.J., W.L. Hargrove., B.R. Bock and R.A. Raunkeir. 1987. Evaluation of urea phosphate as a nitrogen source for no tillage production soil. Soil Sci. Soc. Amer. J., 51: 242-246.

Vaughan, B., D.G. Westfall and K.A. Barbarick. 1990. Nitrogen rate and timing effect on winter wheat grain yield, grain protein and economics. J. Prod. Agric.,3: 324-328.

Vlek, P.L.G. and M.F. Carter. 1983. The effect of soil environment and fertilizer modification on the rate of urea hydrolysis. Soil Sci., 136: 56-63.

Vos, G.J.M., B. Duquet., J.C. Vedy and J.A. Neyroud. 1993. The course of N^{15} ammonium nitrate in a spring barley cropping system. Plant Soil., 150(2): 167-175.

Walter, D. T. and G.L. Malzer. 1990. Nitrification inhibitor effects on nitrogen-15. Urea : yield Amer. J., 54:115-122.

Watson, C. J., P. Poland., H. Muller., M.B.D. Allen., M.K. Garrett. and C.B. Christianson. 1994. Agronomic assessment and N^{15} recovery of urea amended with the urease inhibitors on BTPT (N-(n-butyl) thiophosporic triamide) for temperate grass land. Plant Soil., 161(2): 167-177.

Watson, C.J. 1987. The comparative effect of ammonium nitrate, urea or combined ammonium nitrate urea granular fertilizer on the efficiency of nitrogen and recovery by perennial rye grass. Fertil. Res., 11: 69-78.

Weissman, G.S. 1964. Effect of ammonium and nitrate nitrogen on protein level and exudate composition. Pt. Physiol. 39: 947-952.

Wetselaar, R. 1962. Nitrate distribution in tropical soil III Downward movement and accumulation of nitrate in this sub soil. Plant Soil., 16: 19-31.

Wetselarr, R. and M.J.T. Norman. 1960. Soil and crop nitrogen at Katherine, N.T. CS, RO Aust. Div. Land Res. Reg. Surv. Tech. Pap., No. 10.

Whitehead, D.C. and N. Raistrick. 1990. Ammonia volatilization from five nitrogen compounds used as fertilizer following surface application to soils. J. Soil Sci., 41: 387-394.

Winkleman, G.E., R. Amin., W.A. Rice and M.B. Tahir. 1990. Sample processing. *In: Methods manual soils laboratory,* Barani Agric. Res. Development Project. 27-92.

Zamborlini, M., F. Franzin and S. Facco. 1995. Ammonia volatilization losses from nitrogen fertilzer applied to some alkaline soils. Agricoltora Mediterranes 125 (4): 305- 319.

Zhang, S.L., G.X. Cai., X.Z. Wang., Y.H. Xu., Z.L. Zhu., and J.R. Freney. 1992. Losses of urea nitrogen applied to maize grown on calcareous fluvo-aquic soil in north china. Plan. Pedosphere, 2: 171-178.

Zia, M.S., A. Ali., M. Aslam., F. Hussain and M. Yasin. 1996. Annual report of fertilizer use efficiency project, Land Resources Research Institute, National Agricultural Research Centre, Islamabad, Pakistan.

Zerulla, W. and B.A.S.F. Aktiengesellschaft. 1996. Reply to the request on nitrification inhibitors. Personal communication.