

**EFFECT OF TILLAGE AND NITROGEN UNDER
DIFFERENT WATER REGIMES ON RICE AND WHEAT
CULTIVATION**



A DISSERTATION

Submitted to the Department of Soil Science
The University of Dhaka, Bangladesh
in fulfillment of the requirements
for the degree of

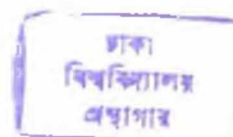
DOCTOR OF PHILOSOPHY

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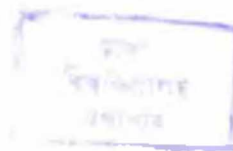
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*Bowing down most humbly to
Almighty Allah, the
Beneficent, the Merciful.....*

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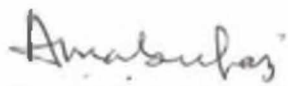
CERTIFICATE

Certified that Mr. Md. Abdul Mazid Miah has submitted this thesis entitled "**Effect of tillage and nitrogen under different water regimes on rice and wheat cultivation**" in fulfillment of the requirements for the award of the degree of Doctor of Philosophy in Soil Science, University of Dhaka, Bangladesh. This thesis has been prepared on the basis of original research work carried out by Mr. Md. Abdul Mazid Miah himself under our supervision. So far as our knowledge goes, no part of this thesis has been submitted elsewhere for any other degree or diploma.

It is further certified that while resubmitting the thesis the researcher has corrected and duly incorporated new data and other information generated through repeated experiments where necessary, in the light of the suggestions and recommendations made by the Examiners.

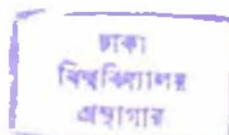
The title of the thesis was approved by the Departmental Academic Committee, Faculty of Biological Sciences, and finally by the Academic Council of the University and therefore, no change in the title has been made.

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***DEDICATED TO MARTYRS WHO HAVE
SACRIFICED THEIR LIVES FOR
THE FREEDOM OF THEIR
MOTHER LANDS***

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MD. ABDUL MAZID MIAH

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1. Introduction

Soil puddling is, to date, an inevitable part of land preparation for wetland transplanted rice. It has certain advantages in terms of weed control, ease of transplanting, and minimization of loss of water and nutrients from the soil through percolation and leaching. Nonetheless, puddling is time-, energy-, and capital-intensive. In addition, it creates soil physical conditions that are not suitable for crops following wetland rice, and hence, may not be desirable in wetland rice-dryland cropping systems (Sharma *et al.*, 1988).

The physico-chemical environment of a flooded, puddled soil, although favorable for rice, is in many ways unsuitable for upland crops. Puddling deteriorates soil structure, decreases soil aeration and water permeability, increases soil strength, and accelerates the formation of plowpans resulting in restricted root development (Hundal and De Datta, 1981). The changes in soil physical conditions create an environment which is unfavorable for a dryland crop following wetland transplanted rice. High moisture content and more compact soil after puddled flooded rice resulted in a poorer establishment, growth and yield of corn compared to corn grown after unpuddled flooded rice (Syarifuddin and Zandstra, 1978).

No-till and minimum-till systems were found to produce rice grain yields similar as those with conventional puddling (De Datta *et al.*, 1979; Rodriguez and Lal, 1979). Minimum tillage may substantially reduce the land preparation period for rice (Brown and Quantrill, 1973). Reduced tillage may increase grain yields of wheat by increasing the infiltration of water into the soil (Hamblin and Tennant, 1979) while at the same time decreasing the mineralization of N (Dowdell and Cannell, 1975). In some cases, however, puddling was found to be essential for higher rice yields (Dayanand and Singh, 1980; Sharma and De Datta, 1986). These contradictions arose because of variations in weed and crop management and in soil physical properties.

Rice may be grown under continuous submergence or rainfed conditions. Under continuous submergence, about 60 to 70% of the total water applied is lost through deep percolation and only a small proportion, 30%-40%, is utilized consumptively (Hukkeri and Pandey, 1977). The utility of keeping the field continuously submerged has been questioned by several workers (Hukkeri and Sharma, 1980; Jha *et al.*, 1981 and Mishra *et al.*, 1990). Water

being a costly input, its economic use is of utmost importance. Intermittent irrigation may be more practical than continuous submergence in this respect.

Physical properties play an important role in soil productivity. The selection of efficient soil cultivation practices and determination of the conditions of their use require a thorough study of the physical properties of soils and their dependence on the conditions and the changes arising under cultivation. Development of appropriate tillage practices can play a critical role in energy and time savings and in making the best use of available water stored in the soil profile at the end of the wet season (Hundal and De Datta, 1981). For a better understanding of soil-water-plant relations under the rainfed situation, there is a need to characterize drying patterns in paddy soils in the presence of an actively growing crop. Such information provides the basis for the selection of suitable post-rice crops that are of appropriate growth duration and that can tolerate the expected moisture stress conditions.

Along with the maintenance of proper soil moisture, proper fertilizer management is also desirable as it is one of the most important factors in rice cultivation. Ever increasing costs of inorganic fertilizers necessitates the improvement of the efficiency of utilization of the applied fertilizers by rice. Since N is the major limiting element in soils of Bangladesh, it is important to determine the most appropriate N rate for rice under given water regimes.

Tillage has a considerable impact on the level of N nutrition derived from the soil by the crop. Some studies indicated a reduction in N availability with minimum tillage (Phillips *et al.*, 1980). This reduction was attributed to leaching loss and retarded decomposition and N release from organic residues accumulating on or near the soil surface. Denitrification (Dora, 1980) and immobilization (Rice and Smith, 1982) also have been identified as instrumental in depressing N availability in minimum tillage soils. On the other hand, a greater response of wheat to N with minimum tillage has been observed under drought than under normal weather conditions (Read and Warder, 1974).

Tillage, irrigation and fertilizer constitute the major components of energy input in a crop production system. With increasing energy costs it becomes imperative to evolve energy efficient crop management systems. There are some reports that within certain limits water and nutrients substitute for each other (Prihar *et al.*, 1989) and tillage increases efficiency of water and fertilizer use (Sharma, 1985). In spite of the importance of the interactions of moisture regime, tillage and N fertilization in the production of rice and non-rice crops, little research has

been done in Bangladesh addressing these issues although the existing cropping systems in the country are essentially wetland rice-based cropping systems. In view of this, the present research work was designed to study:

1. the effects of varying combinations of tillage practices, moisture regimes and N fertilizer rates on some soil physico-chemical properties and N availability in soils;
2. the effects of the interactions of tillage, N fertilization and moisture regimes on the growth, yield and mineral nutrition of transplanted rice and post rice wheat.

2. Review of Literature

2.1. Scope and limitation of tillage systems

Tillage implies mechanical disturbance of the soil in preparation for crop production. The Soil Conservation Society of America (1982) defined various tillage practices as follows:

- a. *Conventional tillage*: The combined primary and secondary tillage operations normally performed in preparing a seedbed for a given crop in a given geographical area.
- b. *Reduced tillage*: System in which the primary tillage operation is performed in conjunction with special planting procedure to reduce or eliminate secondary tillage operations; less mechanical disturbance of soil than is done in conventional tillage.
- c. *Minimum tillage*: The minimum soil manipulation necessary for crop production or meeting the necessary tillage requirements under the existing soil and climatic conditions.
- d. *No-tillage*: A method of planting crops that involves no seed bed preparation other than opening of the soil for planting the seed at the intended depth; usually involves opening a narrow slit or punching a hole into the soil; chemical weed control is normally used; also called slot planting or zero tillage.

The reason for tillage usually centered around the need to control weeds more than anything else (Russel, 1965). Other important reasons include creation of a suitable soil structure for crop establishment, incorporation of surface crop/weed residues and fertilizers, aeration of the soil, pest control, and stimulation of root growth. On the other hand, tillage is time, energy and capital intensive.

During the late 1940's attempts were made to use chemicals in place of cultivation to eliminate or severely suppress the existing vegetation and this facilitated the establishment of crops without resorting to traditional tillage operations (Blevins, 1986). From the early 1960's researchers have given more attention to no-tillage or reduced tillage techniques for the following reasons:-

- a. No-tillage systems reduce labor/energy cost and eliminate moisture loss that are associated with conventional tillage at planting.
- b. No-tillage ensures stands of second or third crops under restricted rainfall patterns.

- c. Delayed seedling/planting with conventional tillage causes considerable reduction in yield
- d. No-tillage can maintain better soil structure and reduce soil erosion.

There were no-till farming long before the discovery of tillage tools. Forms of reduced or minimum tillage have been used for centuries and are still practiced today. No tillage contributes to the success of double cropping by enabling the second crop to be established with the least delay. No-tillage culture not only minimizes time but also minimizes labor and cost of land preparation. Phillips (1984) showed a 50% labor reduction in land preparation and planting in favor of no-tillage. However, in other areas zero tillage produce similar and often lower crop yields than conventional tillage (Koehler *et al.*, 1983; and Malhi *et al.*, 1988). Minimum tillage has been shown to be an effective means of controlling erosion, reducing evaporation and in some cases, increasing infiltration and soil moisture storage (Johnson *et al.*, 1984; Andraski *et al.*, 1985).

As with most systems, no-tillage has some limitations which include its needs for a higher level of management practices. Fertilizer usage and timing may vary from that of conventional systems. Technologies that provide a sound planting depth, seed-to-soil contact, and seed cover in the absence of loose pulverized soil delivered by tillage need to be used. Weed control is considered as a major problem in no-tillage crop culture and shifts in weed population may be more pronounced. More herbicides needed in NT. Plant pests tend to be of more consequence in untilled soils with crop residue at the surface than in conventionally tilled soil (Lal, 1981).

Sanchez (1973b) emphasized that puddling or wet tillage of the soil is done exclusively for the cultivation of wetland rice. It is the transformation of soil aggregates into a uniform mass accomplished by applying mechanical force to the soil at a high moisture content. Puddling of the soil facilitates easy transplanting, control of weeds, prevention of excessive percolation, increase the capacity of the soil for supplying nutrients to the rice plant, and reduction of losses of applied N. This process frequently results in the creation of semipervious sub soil layers or pans. These not only restrict internal soil drainage and create difficulties for the establishment of subsequent crops but also limit the depth of root penetration of the subsequent crop. It increases the water requirement at the planting stage. It is a labor and energy consuming practice, and it also reduces the effective growing time left for the non-rice crops in a multiple cropping system.

The limitations of puddling rice soils are in restricting root development when the soil shrinks and cracks at the early stage of rice growth in rainfed systems, and a slow water loss pattern after rice harvest which may limit rotation with other crops.

2.2. Effect of tillage and moisture on soil physical properties

Physical properties play an important role in soil productivity. Soil physical properties are described by many characteristics which are sometimes difficult to determine. The characteristics most suited for large scale determinations are bulk density, porosity, and moisture retention capacity of the soil (Gordiyenko and Kostogryz, 1990).

Tillage operations are aimed at improving the soil physical conditions for seed germination, seedling establishment and support through the growth and yield production periods. Tillage should produce a soil tilth that provides crops with air and water, and produces low mechanical resistance to crop roots. Soil properties most commonly affected by the tillage systems are soil water retention and movement, soil density and porosity, infiltration, structure, organic matter, pH, microbial activity and nutrient distribution and availability (Blevins, 1986).

Soil density and porosity have a profound influence on air and water movement and the potential productivity of a given soil. Past research on this subject gave contrasting results when compared over a wide range of soil types and climatic conditions. In Bangladesh Matin and Uddin (1994) reported increased soil bulk density with ploughing and soil depth while Rahman (1991) found little influence of tillage on soil bulk density on a grey flood plain soil. In the humid temperate zone of U.S.A., long-term cropping systems showed no net change in bulk density resulting from the lack of tillage in a medium textured soil (Blevins *et al.*, 1984). In contrast, a comparison of the effects of no-tillage with conventional fall plow tillage in Minnesota on a clay loam soil produced a different picture (Gantzer and Blake, 1978). This finer textured soil had significantly greater bulk density in spring and fall in no-tillage treated plots than that in conventionally tilled plots. At a number of sites in Great Britain, under direct drilling of grain crops, a pronounced increase in bulk density was developed at 0-15 cm soil depth (Cannell *et al.*, 1980). Studies of soil properties of a latosol influenced by tillage versus direct drilling in Parana', Brazil (Vieira, 1981) showed higher bulk density and slightly lower porosity in the direct drilled plots than in the conventionally tilled plots. Hallowang and Dexter (1991) reported reduced soil strength and bulk density by tillage. Yoshida *et al.* (1991) observed greater bulk density, soil hardness and proportion of the solid phase in the superficial layer of

the no tillage plots. The physical properties of the soil were not influenced by tillage below the 15 cm soil depth.

Narang *et al.*, (1992) found higher soil strength in top layers in no-till plots than the conventional tillage plots of wheat crop at 3 weeks after sowing. The higher soil strength in the top layers in no- till plots occurred primarily due to undisturbed condition obtained after the harvest of rice crop in puddled field. Rahman (1991) working with wheat and rice in Bangladesh reported the influence of tillage depth on soil penetration resistance (SPR) and found greater SPR values just bellow each tillage depth . Greater SPR values just below each tillage depth indicated that tillage caused a dense layer due to the combined effect of tillage and puddling. Formation of these dense layer enables the top soil to store more water thus obtaining better yields with dry season crops and better utilization of limited irrigation. Matin and Uddin (1994) found the largest resistance values at 18 - 24 cm depth indicating the presence of a ploughpan. In Bangladesh, development of a plough pan is particularly prominent in soils which are puddled for transplanted rice cultivation (Brammer , 1980 ; and Rahman and Islam ,1987)

Cannell and Ellis (1977) working with wheat in Great Britain, concluded that no-tillage (direct drilling) compared with conventional tillage resulted in a reduction in total pore space and that a large portion of the remaining pores were filled with water. Similar studies by Douglas *et al.* (1980) showed lower total porosity and less volume of transmission pores in direct drilled plots on a clay soil. Zero tillage experiments in Netherlands (van Ouwerkerk and Boone, 1970) showed that untilled soils were usually denser than plowed soils and that the mean soil pore space was lower in untilled plots. According to Hamblin (1987) tillage generally tends to decrease the bulk density and increase the total porosity of the surface soil. Porosity increases as aggregates are broken up into smaller sizes by tillage. Ike and Arena (1990) reported less aggregate stability and soil porosity and greater bulk density under tractor plowed cultivation.

Generally, in moisture retention curves, as the tension is increased from zero, the moisture content of soil decrease due the draining of the large pores initially and progressively followed by the smaller pores. The amount of moisture release for each increment of the tension also gives the proportion of pores with in a given size range. The moisture retention curves of the soils of Ganges river flood plain remained near saturation having about 50 percent volumetric moisture content up to a tension of 50 cm of water (Joshua and Rahman , 1983). According to Hannan (1995) and Mollah, (1995), the moisture retention curves of all the soil

profiles of Modhupur Tract remained near saturation up to 0.1 kPa metric potential. Lal (1986) found that soil moisture retention for the 0-1 cm and 1-2 cm layer was influenced by tillage method, while that of the 2-5 cm layer was not. In the 0-1 cm depth, the soil from no-till plots retained more water than puddled treatments at all suctions. In the 2-5 cm layer there was slight or no effect of tillage on moisture retention.

The physical properties related to the storage of soil water and movement play a significant role in determining soil management for better production (Scotter *et al.* ,1979) Soil physical properties such as sand , silt, clay, gravel contents, and bulk density resulted in a high variability in soil water conductivity (Babalola , 1978). Nyborg and Malhi (1989) observed greater water content in zero tillage compared with conventional tillage plots. In spite of lower airfilled porosity and higher bulk density values, the no-tillage treatments still had higher volumetric water contents and higher number of bio-channels (Blevins *et al.*, 1984). In growing corn and soybean after puddled flooded rice it was observed that during planting, soil moisture content decreased as tillage intensity increased and zero tillage maintained a higher moisture content (45%) than did medium tillage (39%) and complete tillage (36%). But at 50 days after sowing, soil moisture content was found similar in all treatments in both crops regardless of tillage method (IRRI, 1979). On the contrary, by planting soybean after rice, Syarifuddin and Zandstra (1978) reported the lowest soil moisture content with zero tillage and relay planting at 40 days after sowing. Rahman and Islam (1987) observed higher water storage in clay loam soil of Modhupur Tract in deep tilled plots compared to no tilled ones at the end of 70 days drainage period. Higher moisture content in zero tillage was also reported by Saputro (1987) for soybean and mungbean grown after wetland rice. Mondal , (1986) reported no effect of tillage practices on soil moisture content in a silty clay soil cropped to grain. A higher water use efficiency of wheat in deep tillage than conventional tillage was reported by Gerik and Morrison Jr. (1984)

Soil temperature is an important environmental factor in influencing plant growth. Surface residues in a reduced tillage system decrease soil water evaporation thus furnishing a more moist and cooler environment. In general, soils are cooler in no- tillage fields during early spring resulting in slower wheat growth rates than in plowed fields (Dao and Nguyen, 1989). Bhagat *et al.*,(1994) found higher soil temperature with puddled soil. Ojcnayi (1986) reported no significant differences in soil temperature due to soil tillage. However, Blevins (1986)

observed a lower soil temperature in reduced tillage systems- an advantage in the tropics where surface temperatures commonly exceed the optimum.

Alternate wetting and drying also influences soil properties. Aragon *et al.* (1990) reported that at the end of a water stress period, bulk density in the upper 2 cm of soil increased from about 0.62 g/cc in continuously flooded plots to about 1.23g/cc in stress plots. Bulk density was relatively lower at deeper soil layers. Reflooding reduced the bulk density at a shallower depth but not to the level of continuous flooding. Wet tillage or puddling is one of the most characteristic features of wetland rice cultivation and is widely assumed to be essential for rice production. Soil puddling lowers soil permeability and substantially increases the water retention capacity of soil (Sanchez, 1976; De Datta and Karim 1979; and Wickham and Singh, 1978). During puddling coarser aggregates are broken down, no capillary pore space is destroyed, microvoids increase and apparent specific volume decreases. A puddled soil holds more water at a given soil moisture tension than its natural status due to the decrease of hydraulic conductivity and free percolation of water (Gildyal, 1977). Mishra *et al.* (1991) reported an increased bulk density and enhanced microporosity due to puddling. He also pointed out an increased soil moisture retention capacity at all suctions up to 15 bars except at saturation (0 bar) under puddling.

Percolation of the soil is one of the most important physical properties (Parr and Bertrand, 1960). Percolation has been reported to vary from 0.1 to several hundred mm d⁻¹ (Sharma and De Datta 1992) and is influenced by a variety of environment and soil related factors (Wickham and Singh, 1978). The magnitude of the decline in percolation depends on soil texture, structure, clay mineralogy and organic matter content. Lal (1986) observed that percolation of water through rice soil is essential. Percolation rate 5.0 to 20.0 mm day⁻¹ is necessary for high yield (De Datta, 1981, and Hasegawa *et al.*,1985). The Possible benefit of higher percolation rates to rice growth are thought to be due to the removal of phytotoxin from the root zone (Govindasamy and Chandrasekaran, 1979 and, Patel and Ghildyal, 1980), increase in the oxygen concentration in the rhizosphere, and an increase in the root activity (Alva and Peterson, 1979). Higher percolation rate also decrease the redox potential by enhancing soil microbial activity (Takai *et al.*,1974). Puddling of rice fields reduces percolation losses (Sharma and De Datta,1985; and Aggarwal *et al.*,1995). Ghani (1978) reported a mean seepage and percolation rate of 1.7 mm day⁻¹ in a silty clay soil during rice growing period in

dry season. Puddling eliminates large soil pores and therefore decrease the hydraulic conductivity of soil (Sharma and De Datta, 1985). Compaction and shearing by farm implements may create a compact zone often called plowpan (Moorman and Vanbreeman, 1978). In addition settling and consolidation of dispersed clay particles may occur (Sharma and De Datta, 1985 ; and Adachi 1992). Both compaction and clay translocation reduce the percolation rate. The scaling of macro pores with fine particles translocated during puddling predominantly caused the formation of a semi-impermeable layer just beneath the puddled top soil. This semi-impermeable layer is the single most important layer and is responsible for the low percolation rate of well puddled soil (Toung *et al.*, 1994). A reduction of percolation rate through puddling by a factor of 500 in a silty clay loam soil was reported by Woperies *et al.* (1992b). Osari (1988) found a reduction factor of around 500 to 700 times in a volcanic ash paddy soil. Singh *et al.*, (1993) also reported a decreased percolation rate by up to 61.7% in clayey soil.

In growing wheat after puddled flooded rice Karim *et al.* (1983) found a faster rate of infiltration through the soil profile in deep tillage treatment and Shaha *et al.* (1991) reported an increased infiltration rate with the increase in tillage intensity. Reddy *et al.*, (1983) observed that deep ploughing increased water intake, which in turn enhanced root growth and enhanced yields. Rahman and Islam (1987) noticed that deep tillage to 15 cm or more resulted in increased infiltration. Infiltration rate was increased with deep ploughing as compared with shallow tillage and this increase was possible due to decementation of the profile by deep cultivation (Vital *et al.*, 1983). Maurya (1986) observed a higher infiltration rate in the minimum tillage than conventional tillage. Several workers have also reported higher infiltration rate and cumulative intake of water under zero tillage as compared to normal cultivation (Brai *et al.*, 1983; Mishra and Singh, 1985). Goss *et al.* (1978) observed rapid infiltration of water to a depth between 0.5 and 1.0 m in direct drilled (no-tillage) cereal cropped soil, whereas in ploughed soil, movement was restricted to the tilled zone. Radcliffe *et al.* (1988) measured significantly higher infiltration rate in no-tillage. Ghuman and Lal (1984) observed that depending on initial soil moisture contents, infiltration rate changed from 4.6 to 42.9 cm hour⁻¹ for tilled plots compared to 15.0 to 120.0 cm hour⁻¹ for no-tilled treatments might be due to higher porosity and more intensive microflora activity.

In a field study with a clay soil, Mambani *et al.* (1990) found that puddled soils had more cracks and dried up at the surface more rapidly than did the untilled soils. But, Sharina *et al.* (1988) reported that zero and minimum tillage plots dried faster than puddled plots after they were drained at harvest and also the higher surface cracking in puddled plots.

2.3. Effect of tillage and moisture on nutrient availability

Puddling is the transformation of soil aggregates into a uniform mass accomplished by applying mechanical force to the soil at high moisture content. Under these condition the availability of N, P, K, Ca, Mg, Fe, Mn and S is higher, the supply of Cu, Zn and Mo is adequate and injurious concentration of Al, Mn, Fe, CO_2 and organic acids are absent (Ponnamperuma, 1977).

Saroj and Thakur (1991) pointed out that puddling of chemically weeded plots increased the available N and puddling of hand weeded plots increased the available P content of soil. The calcium level of west African soil tended to increase over that found in conventional tilled soils (Lal, 1981). Similar results have been observed in Southern Brazil by Muzilli (1981). Hargrove *et al.* (1982) also reported higher calcium content at the surface soil with no tillage than with conventional tillage. Minimum tillage can result in larger concentrations of P and K in the surface layer than are present following moldboard ploughing (Moschler *et al.*, 1975). With no-tillage the surface applied fertilizer is not moved except by water and by diffusion. Hence the concentration of P and K are highest in the upper 5 cm of soil and then decline rapidly with soil depth. Magnesium is not affected appreciably by tillage.

The upper soil under no tillage generally is wetter, cooler, higher in organic matter, microorganisms, P and K and somewhat higher in acids than in a comparable soil that is tilled (Thomas and Frye, 1984). Under these conditions the mineralization rate tends to be lower because the soil is not disturbed and the organic residues remain on the surface where decomposition is slower. Hence especially in the spring, there is usually less nitrate in the soil in unfertilized no tillage soils than in similar tilled soil (Rice and Smith, 1982). Reduction in N availability with minimum tillage was reported by Gordon and Rickerl (1992). This reduction was attributed to leaching loss and retarded decomposition and N release from residue accumulating on or near the soil surface. Denitrification and immobilization also have been identified as depressing N availability in minimum tillage soils. On the other hand, greater

response to N with minimum tillage have been observed under drought than under normal weather condition.

According to Thomas and Frye (1984) N efficiency is less, the amount of leaching of nitrate and the basic cations accompanying it is apt to be slightly higher in no-tillage than in conventional tillage. When soil is tilled, the breakdown rate of organic matter is increased tremendously for a short time. As organic matter is decomposed, N, P and S are mineralized at a rate which roughly corresponds to the relative quantities present. There have been reports of S deficiency in no-tillage when no deficiency was observed in conventional tillage (Koehler *et al.*, 1977). The extent of S deficiency due to no-tillage is not known but in areas where S deficiency is suspected it would very likely be worse under no-tillage just as N deficiency (with no N applied) is usually worse with no-tillage. Lal *et al.* (1990) observed lower pH, but higher concentration of P, exchangeable K and Mg in the surface layer of no-tillage plots than plow till treatments.

Higher organic matter and reduced erosion under no-tillage favor the availability of Zn. Micronutrient availability under no-tillage is less of a problem than it is under conventional tillage (Thomas and Frye, 1984). In soil that undergoes wetting and drying, the reduction and oxidation of Fe and Mn compounds is cyclic (Patrick and Reddy, 1978). Higher denitrification losses under alternate wetting and drying indicates that N compounds may also undergo the oxidation-reduction cycle, particularly in the presence of crop residues as the energy sources for microorganisms (Buresh *et al.*, 1976).

2.4. Tillage levels, moisture regimes, N fertilization and their interactions on rice crop performance.

2.4.1. Tillage practices

Effects of tillage on rice yield are unclear. Some investigators reported increased yield while others found insignificant or no increase in yield with tillage. In tropical Asia where most rice is grown rainfed, it is believed that puddling minimizes the risk of yield reduction due to drought (De Datta, 1981). Satter (1978) reported an increase in grain yield of rice with increasing number of ploughing from 2 to 3 in Bangladesh. Ogunremi *et al.* (1986) observed more leaves, productive tillers and dry matter yield of upland rice in ploughed plots. In a field with clay loam soil, Mambani *et al.* (1990) found increased grain yield with tillage. Panda *et al.*

(1994) and Bhagat *et al.* (1994) also reported increased grain yield with puddling. On the other hand, Mabbayad *et al.* (1968) demonstrated that yield, panicle number and percent of sterile spikelets of rice were not significantly different from soil prepared by zero, minimum and conventional tillage. Rodrigues and Lal (1985) observed no effect of tillage on grain yield of rice in four out of five experiments. Griffith *et al.* (1986); Lal (1986) and Aggarwal *et al.* (1995) also reported no effect of tillage on crop yield. Sharma *et al.* (1995) found reduced tillage as more cost effective than conventional tillage.

Rodriguez and Lal (1985) and Lal (1986) reported lower root density of rice in no-till plots compared to conventional tillage. Sharma *et al.* (1988) stated increased root length density of rice with increasing intensity of tillage. On the contrary, Mambani *et al.* (1990) reported a decreased root length density with dry and wet tillage compared with zero tillage. Lee and Jung (1993) reported higher root density of rice in the upper 10 cm of soil in the no tillage treatment. Lower root density of rice at 18–24 cm depth of soil was reported by Matin and Uddin (1994). Gajri *et al.* (1992) pointed out that puddling coarse textured soil in rice culture induces high bulk density in sub surface layers which impedes root growth of the subsequent crop and cause nutrient and water stresses.

2.4.2. Moisture regimes

Water is the most important single factor in production of rice and wheat. Sene Wiratne and Mikkelsen (1961) compared growth of rice plants in submerged and upland soils. At the early growth stage of rice, plants grew larger in the non submerged upland soils than in the submerged soil. But later, there were more increases in tiller number, plant height, and leaf area in the submerged soil than in the upland soil. De Datta (1981) showed that most rice varieties maintained better growth and produced higher grain yields when grown in flooded soils.

It is believed that the peak water demand of rice is between maximum tillering and the grain filling stages. Moisture stress throughout the entire growth period reduced the grain yield to 20-25% of the yield of the continuous flooded plot (De Datta, *et al.* 1973a). When moisture stress was allowed to develop only between the maximum tillering and heading stage, the grain yield remained relatively high. The reduction in grain yield was more related to the duration of moisture stress than to the stage of plant growth at which the stress occurred. Castillo *et al.* (1992) reported significant reductions in straw and grain yields of rice with water deficit at 15 to 35 days after transplanting (DT). Aragon *et al.* (1990) observed decreased plant height and dry

matter production of rice at 65 DT with decrease in total water applied during the stress period. Perhaps this was a consequence of poorer root and shoot growth and reduced N fertilizer efficiency under limited water supply.

Continuous submergence produced significantly higher straw and grain yield of rice followed by irrigation given immediately after the disappearance of ponded water (Saikia and Dutta 1989; Wahab and Danel, 1992). Increasing soil water stress from continuous submergence to rainfed decreased the straw and grain yields of rice (Mishra *et al.*, 1991). Continuous submergence and irrigation a day after infiltration of ponded water gave comparable grain yields of rice and the increase of interval between infiltration and irrigation from 1 to 3 days or more declined the yield by 9 to 12q/ha (Sandhu *et al.*, 1980). Grain yields did not vary greatly with 4-8 days interval between irrigation (De Datta *et al.*, 1973b). Grain yield however, dropped to 1 t/ha, or more when the irrigation interval is increased to 10 days. Singandhupe and Rajput (1990) observed that maintenance of 7 cm irrigation water after 1 day drainage, increased grain and straw yield compared with 6 days drainage.

According to Aragon *et al.* (1984) grain:straw ratio tended to decrease and percent sterility tended to increase with increasing stress treatment; 1000 grain weight decreased with an increase in moisture stress. Saleh (1991) reported that with the use of supplementary irrigation, rice yield in the Aman season could be increased by upto 70% depending upon the amount, distribution and intensity of rainfall. The need for supplemental irrigation was much higher during the latter part of the growing season than earlier as the probability of rainfall meeting the crop water requirement decreased from 85% at the vegetative to 21% at the ripening stage. Mambani *et al.* (1990) found increased grain yield of rice with tillage in the field experiment with clay loam soil where moderate moisture stress occurred.

In dry soil, mechanical impedance is the dominant stress factor, such as a loss of soil-root contact, roots and soil particles shrinks as they dry, which may lower the supply of mineral nutrients (Faiz and Weatherly, 1982). Yellamanda Reddy and Kuladaivelu (1992) reported higher root volume and root dry weight under continuous submergence than under drier moisture regimes. In addition, root growth might have been inhibited by decreased N efficiency due to alternate wetting and drying. In medium textured soil, tillage do not affect rice root growth under and adequate moisture regime. While in stress condition, high intensity tillage

methods increased root length density where zero tillage and one rototilling produced contrary effect (IRRI, 1986).

2.4.3. Nitrogen fertilization

Nitrogen fertilization is highly correlated with yields and is a major factor in world crop production. A considerable body of research has indicated the positive response of rice, wheat and sorghum to N fertilization (Locke and Hons, 1988; Saikia and Dutta, 1989; Castillo *et al.*, 1992; Malhi *et al.*, 1992). In general, grain yield increases with N addition upto a certain level. The response of a crop to added N is largely influenced by variety, soil fertility, environmental factors, and management practices. However, because rice is grown in diverse land and water management systems, tillage practices for land preparation vary with the system. The traditional method of tillage for lowland rice is plowing and puddling. De Datta (1981) pointed out that in rice growing areas of temperate regions, where soils are not puddled, grain yields are consistently high.

Davis and Cannell (1975) and Buchholz and Hanson (1982) reported significant interactions between tillage and fertilizer N in crop production. According to them zero tillage may require more fertilizer N to produce crop yields similar to those under conventional tillage. Lal (1986) observed that puddling treatments yielded more rice at a low level of N than no-till treatment, while, Syarifuddin and Zandstra (1978) observed higher corn yield on unpuddled flooded soil than on puddled flooded soil under complete tillage in absence of fertilizer.

A survey made by a group of agricultural economists (Auden and Barker, 1973) reported that N and water level were the two major factors constraining yield of rice in some Asian countries. Sheik Dawood *et al.* (1990) reported significant influence of irrigation and N on grain yield of rice. Higher grain yield was obtained at higher level of N when the field was irrigated to 5cm depth of water immediately after disappearance of ponded water followed by irrigating once in 2 days. Nageswara and Raju (1987) also found that flooding 1 or 2 days after disappearance of ponded water increased the grain yield of rice over flooding 4 days after disappearance of water at a higher rate of N fertilizer, while, Aragon *et al.* (1990) found no significant interactions between N and water management in terms of plant height and tiller and panicle numbers of rice. Castillo *et al.* (1992) also reported no significant interactions between N and water levels on straw and grain yield of rice. On the other hand Khan *et al.*, (1992) found

optimum rice yield with medium fertilizer dose and keeping soil moisture regimes from field capacity to saturation. Nitrogen application aggravated the effects of severe moisture stress (Aragon *et al.*, 1990). Root mass density increase several fold in zones where concentration of nutrients, especially N are high (Marshner, 1986).

2.4.4. Nitrogen availability in soils

Various fractions are present in the inorganic N pool of a wetland soil. These forms, however, constitute an extremely dynamic N system in the soil, which is affected by physical, chemical and microbial reactions. The predominant form of inorganic N in wetland soils is NH_4^+ . Although the rice plant absorbs N from the soil both as NH_4^+ and NO_3^- , the contents of these ions in a soil sample frequently do not reflect the soil N supplying capacity throughout the growing period. The available N status in wetland rice soils is influenced by many chemical and biological processes. Flood water impedes oxygen diffusion, creating an aerobic-anaerobic system within which nitrification-denitrification occurs (Ponnamperuma, 1977). Nitrification takes place only in the surface oxidized layer or the rhizosphere in a continuously flooded soil. The differentiation of oxidized and reduced soil layers was first reported by Pearsall (1938). The surface oxidized layer can vary from 0 to 2-3 cm. in thickness, depending on the oxygen concentration in the flood water and oxygen consumption (Howeler and Bouldin, 1971). For simplification, the oxidized rhizosphere of the rice plant is included with the aerobic soil and flood water (Bouldin, 1966). In flooded soils, the product of mineralization is mainly NH_4^+ . The reaction, however, proceeds to form NO_3^- -N when oxygen is adequate. Accumulated NO_3^- is prone to loss by denitrification and leaching upon soil flooding. The determination of NH_4^+ -N mineralized in anaerobic conditions may give a good estimate of the amount of N available to the wetland rice crop (De Datta and Craswell, 1982).

Fertilized rice obtains 50-80% of its N requirement from the soil; unfertilized rice obtains an even larger proportion, mainly through mineralization of organic sources. Thus, rice depends primarily on the mineralization of organic sources for its N (Broadbent, 1979). De Datta *et al.* (1968) reported higher ^{15}N recovery in pots than in the field. Basal, surface application in general, produced the lowest values for ^{15}N recovery (7-38%). Recovery is improved with split application (35-61%), delayed application (27-77%), or deep placement (18-68%). Even with good management practices, only 30-50% of the fertilizer nitrogen recovery by rice was reported by Prasad and De datta (1979). The breakdown of organic matter

that leads to the liberation of ammonium ions into the solution phase proceeds at a much slower rate in a flooded soil than in an aerobic soil. The quantity of N mineralized from organic sources during the growing period of a lowland rice crop is larger than that for a similar period of an upland crop. The greater part of the N mineralized during a season appears as $\text{NH}_4\text{-N}$ within two weeks of submergence if the temperature is favorable and the soil is not strongly acid or very deficient in available P (De Datta, 1981).

Cultivation accelerates the oxidation of organic matter in soils and generally results in higher $\text{NO}_3\text{-N}$ in the profile. Cultivation may also decrease the rates of denitrification, immobilization and leaching of $\text{NO}_3\text{-N}$ (Rice and Smith, 1982). Data from Sanchez (1973 a) indicate that puddling decrease losses of applied N from soil.

The moisture regime of a soil is critical for the mineralization of organic N. Soil drying prior to flooding changes the pattern of soil mineral N release. Studies by Sahrwat (1983) have shown that soil drying enhances soil N mineralization and thus its availability to rice. Thus, careful water management is necessary to avoid either N deficiency or excessive loss of organic matter accompanying rapid mineralization. Under flooded soil conditions, $\text{NO}_3\text{-N}$ was reduced to $\text{NH}_4\text{-N}$ and consequently resulted in higher concentration of $\text{NH}_4\text{-N}$ as a result of the reducing environment (Sarker *et al.* 1991). In a saturated soil water regime, when the soil environment was relatively oxidized, the domination of $\text{NO}_3\text{-N}$ over $\text{NH}_4\text{-N}$ occurred. George *et al.* (1993) reported that in tropical rice lowlands, soil NO_3 is lost during the transition from the dry to the wet season. After soil flooding, NO_3^- is lost by leaching or by denitrification to N_2 and N_2O gases (Muskina *et al.*, 1993). Severe N losses have been shown to occur in soils subjected to periods of alternate drained and flooded conditions. Increasing the frequency of changing from aerobic to anaerobic conditions will increase the loss of N. Repeated cycles of flooding and drying to field moisture caused N losses up to 20% of the total (Reddy and Patrick, 1975).

Because of its relative immobility in soil, $\text{NH}_4\text{-N}$ is retained in the soil surface layer and can become temporarily unavailable for plant use when the soil surface dries out (Mason, 1992). Buresh *et al.* (1993) pointed out that water deficit at 15 to 35 DT and 41 to 63 DT in a rice growing season compared with continuous flooding, significantly reduced extractable NH_4^+ in the top 30 cm soil layer and resulted in a small NO_3^- accumulation. Soil NO_3^- which accumulated during the water deficit, rapidly disappeared after flooding. The N loss due to soil drying and flooding decreases with increasing crop age apparently because of increased

competition by rice with soil micro-organisms for NH_4^+ and NO_3^- . The NH_4^+ fixing capacity of the soil increased as the rate of NH_4^+ application was increased but the percentage of recovery of NH_4^+ remained more or less constant (Sahrawat, 1978). The results may vary depending on mineralogical make up of the soil.

The denitrification rate in undisturbed soil is linearly related to soil water content (Rice and Smith, 1982). Because the water content of untilled soil is higher, the rate of biological denitrification can be expected to be higher than that in tilled soil. The effect can be small in well drained soils or very large in poorly drained soils. Gordon and Rickerl (1992) reported that the tillage system employed has a considerable impact on the level of N nutrition derived from the soil by the crop. Some studies have shown a reduction in N availability with minimum tillage. This reduction was attributed to leaching loss and residues accumulating on or near the soil surface. Denitrification and immobilization also have been identified as depressing N availability in minimum tillage soils. On the other hand, a greater response to N with minimum tillage have been observed under drought than under normal weather conditions. This was due mainly to a greater moisture storage in minimum tillage soils. The slow release of nutrients, ion leaching, accumulation of organic residues and lessened disturbance of the plow layer all decrease N availability under reduced tillage (Dick, 1983).

According to Rice and Smith (1982) and Murdock (1986), N in a minimum tillage system tends to be less available. There is slower mineralization, higher denitrification and greater leaching which decreases the availability of N. The N mineralization tends to be slower because the soil is not as greatly disturbed and the organic residues remain on the surface where decomposition is slower. Hence there is usually less NO_3^- in unfertilized soil under reduced tillage as compared to similar conventionally tilled soils. Leaching of NO_3^- is also favored under reduced tillage due to a higher soil water content and more rapid water infiltration. Leaching of NO_3^- occurs when evaporation is exceeded by rainfall. Sahrawat (1983) found that the N availability of unfertilized soils was not affected by continuous flooding or soil drying and flooding one or more times during the growing season as judged by crop growth and N uptake. Perhaps soil drying compensated for small N losses that occurred because of nitrification-denitrification by enhanced mineralization.

De Datta and Craswell (1982) reported that in wetland soils a distinct concentration gradient of $\text{NH}_4\text{-N}$ following deep placement of urea may exist for 4 weeks or more. During the

first 2-3 weeks after transplanting, when the rice plant's N requirement is low, it may be adequately met from the native N pool or from the outer defused zone of soil-urea reaction having low $\text{NH}_4\text{-N}$ concentration or from both. This is because the rice roots generally avoid proliferation through the soil-urea reaction zone of steep $\text{NH}_4\text{-N}$ concentration gradient.

Sarker *et al* (1991) found significantly higher amount of $\text{NH}_4\text{-N}$ under flooded soil than the saturated soil water regime throughout the growing period of rice. They also reported an increase in $\text{NH}_4\text{-N}$ concentration upto 40 DT and then decreased. They also reported a decrease in NO_3 content from 20 to 40 DT and then an increasing tendency upto harvest. According to Bhardwaj and Singh (1992) the $\text{NH}_4\text{-N}$ content in soil was the highest at tillering stage of the crop and it declined subsequently upto crop maturity. Its content increased with an increase in the N level. The decrease in $\text{NH}_4\text{-N}$ content after tillering stage was attributed to its uptake by plants, gaseous losses as NH_3 or incorporation of $\text{NH}_4\text{-N}$ into microbial tissues. The $\text{NO}_3\text{-N}$ content in soil was quite low varying from 2.5-5.9 ppm at tillering stage and it decreased with time. Nitrogen application enhanced $\text{NO}_3\text{-N}$ content at initial stages, but at maturity, treatment differences leveled off.

George *et al.* (1993) reported that $\text{NH}_4\text{-N}$ release from recycled residues peaked within three to four weeks of incorporation *i.e.* land preparation. Although rice responded to increased $\text{NH}_4\text{-N}$ levels, rice N requirement was small at this early stage to substantially benefit from the higher amount of $\text{NH}_4\text{-N}$ released. Availability of fertilizer N to rice decreased rapidly following flooding, usually dropping to a very low level within 30-40 days (Mikkelsen, 1987). After that the crop is dependent on $\text{NH}_4\text{-N}$ released by mineralization of soil organic matter and to a lesser extent, on clay fixed $\text{NH}_4\text{-N}$. Ammonium is reported to be less variable than NO_3^- in cultivated soil (McIntyre, 1967).

2.4.5. Nitrogen nutrition of crops

Nitrogen absorption from soil by rice is greatly influenced by varietal type, availability of N and climatic factors (Murayama, 1979). Syarifuddin and Zandstra (1978) reported increased growth and accompanying high absorption of N by rice from soil where N availability was high. They also reported an increased concentration of K and decreased P, Mn and Zn concentrations in corn with N fertilizer application. A linear relationship between N accumulation and N fertilizer rate was observed by Locke and Hons (1988) in both stover and grain of sorghum. The increase in fertility level increased the N and P uptake both in seed and

stover, because the increase in the supply of these nutrients not only increased their concentration in plant but also resulted in higher dry matter accumulation and seed yield. The results are in consonance with those of Narang and Singh (1985). Application of fertilizer N increased the N uptake of wheat due to increase in crop yield (Flower *et al.*, 1990; Gauer *et al.*, 1992). Good relations between total N uptake and applied N were also reported by Gordon and Rickerl (1992) and the response was found linear in different tillage systems.

According to Viets (1972) the quantity of soil water affects the nutrient concentration in soil solution and rate of nutrient movement to the root by diffusion and mass flow. A positive influence of increasing irrigation level on N concentration in seed, flower head, leaf and stem of safflower was observed by Zaman and Das (1991) while Virendar and Agarwal (1991) reported a depressive effect of irrigation on N concentration in barley. Syarifuddin and Zandstra (1978) reported increased Fe and Mn concentrations and decreased Zn concentration in rice under flooded soil conditions. Increasing irrigation level increased N and P contents in seed and stover of mustard (Tommer and singh., 1992), while a decreased N content of wheat due to increased water supply was reported by Gauer *et al.* (1992). The effect of cyclic submergence produced a significantly higher N content in grain of rice over continuous submergence (Saikia and Dutta, 1989).

Among the water regimes, alternate wetting and drying cycles had the lowest N uptake owing to N loss through sequential nitrification and denitrification (Pillai and De 1979; Aragon *et al.* 1990). Total N uptake was found higher in 1-day drainage compared to 6-day drainage by Sigandhupe and Rajput (1990). More N uptake under 1-d drainage may be due to higher mobility of inorganic nitrogen in soil solution and hence facilitated absorption by plant roots. Whereas under 6-day drainage, increased moisture stress might have resulted the plant roots to spend more energy to extract an unit amount of N. Similar trend was also observed by Biswas and Mohapatra (1980) and De Datta (1981).

Significant influence of water regime by N fertilizer interaction on grain nitrogen concentration of rice was reported by Castillo *et al.* (1992). In the absence of applied N, grain N concentration was similar for continuously flooded and at 15 to 35DT water deficit treatment while in the presence of applied N water deficit at 15 to 35DT significantly reduced grain N concentration. Campbell *et al.* (1977) reported a higher N concentration in wheat with increase N fertilizer under irrigated condition. Sharma *et al.* (1992) found maximum N uptake at the

highest irrigation frequency coupled with the highest nitrogen rate and a linear positive relation between water use and nitrogen uptake.

Nutrient uptake is a function of soil water availability and root proliferation, both of which are influenced by tillage. Crops whether grown under conventional or reduced tillage usually do not vary in N uptake (Terman 1979). Low yield and reduced N may occur in no-tillage system if the soils are too heavy (Baryeh, 1983). Higher concentration and uptake of N by rice and wheat were observed in deep tillage treatment by Rahman and Islam (1987). Crops whether grown under conventional or reduced tillage usually do not vary in nitrogen uptake if the yields are identical (Ellis and Howse, 1981). Nitrogen uptake by soybean as well as sesame were not significantly different under different tillage levels (Sarder, 1990). A higher total and slightly low P concentration in barley was reported by Malhi *et al.* (1992) under conventional tillage than zero tillage while Ellis and Howse (1981) reported no effect of tillage on P concentration in spring barley and winter wheat. There was no consistent pattern in the N P and K contents of maize grown under the zero, minimum and conventional tillage methods (Lindsay *et al.*, 1983). Cannell and Graham (1977) also reported no significant effect of tillage on NP or K concentration in growing shoots or grain of winter wheat. On the other hand Ogunremi *et al.* (1986) reported higher uptake of nutrients in upland rice with ploughed plots. Higher uptake of N, P and K of puddled flooded rice than that of unpuddled flooded and non-flooded rice was observed by Syarifuddin and Zandstra (1978). They also reported significantly reduced concentration of Ca, Mg, Fe, Zn, Mo, B and Al and increased concentration of K in corn leaf tissue under no-tillage condition. Conventional tillage treatments had generally higher N P and K levels in plants than either zero or minimum tillage treatments (Lindsay *et al.*, 1983).

2.4.6. Nitrogen use efficiency

Nitrogen utilization by rice at the farm level is affected by soil, crop, environmental and management factors (De Datta, 1978). Numerous experiments have shown that the efficiency at which the N is utilized by wetland rice is only about 30-50% of the applied fertilizer N and in many cases even less (Prasad *et al.*, 1970; Sanchez *et al.*, 1973; De Datta, 1978). Two aspects, such as recovery rate of the applied N in the rice plant and the efficiency of absorbed N for grain production should be considered in increasing the productive efficiency of the applied N (Murayama, 1979). Increasing N level decreased N use efficiency of wheat (Clarke *et al.*, 1990; Guer *et al.*, 1992). Virendar and Agarwal (1991) reported a decreased %N recovery with an

increase in fertilizer N level and found maximum production efficiency of barley with lower level of applied N.

The physiological efficiency (kg grain produced/kg absorbed N) and agronomic efficiency (kg grain produced/kg applied N) are significantly influenced by water regime. As a result of reduced grain yield agronomic efficiency declined with water deficit (Castillo *et al.*, 1992; Bharmbe *et al.*, 1992). Improved moisture condition increased N use efficiency (NUE) both through increased yield potential and improved N mobility in the soil (Black, 1966; Marshall and Holmes, 1979; Gauer *et al.*, 1992).

In upland rice, Olofintaye (1980) found better N use efficiency under zero tillage than under minimum or conventional tillage when split application was done. Nitrogen fertilizer was used more efficiently in no-tillage than conventional tillage corn, when evaluated on the basis of yield response in fertilized plots (Phillips *et al.*, 1980; Frye *et al.*, 1981). Greater fertilizer use efficiency for no-tillage maize production than with conventional tillage was also reported by Lal (1981). Welles (1984) stated that at the highest rate of fertilizer N, and at all rates of P and K, no-till increased the efficiency of applied fertilizer. On the other hand IRRI (1977) and De Datta *et al.* (1979) reported considerably lower nitrogen fertilizer efficiency with zero tillage than with conventional tillage as measured by increase in grain yield of rice. No-till systems were found less efficient in utilization of N as these systems were more vulnerable to denitrification (Aulakh *et al.*, 1984 and Bhuiyan, 1986), leaching (Thomas *et al.*, 1980) and possible volatilization (Mengel *et al.*, 1982) compared to conventional tillage.

2.5. Evapotranspiration

The combined losses of water resulting from plant transpiration and surface evaporation lead to what is known as evapotranspiration (ET). It is also commonly referred to consumptive water use (Michael, 1978). The amount of water available to the roots of rice plants depends on the balance between rainfall and evaporation and the relationship between soil moisture content, water potential conductivity, effective rooting depth and water table (Yoshida, 1979). The Food and Agriculture Organization (Doorenbos and Pruitt, 1977) suggested Blaney-criddle, radiation, Penman, and Pan evaporation methods to calculate potential or reference crop evapotranspiration (ET_0) from available climatological data. ET_0 is defined as the rate of evapotranspiration from an extensive surface of 8-15 cm tall, green grass cover of uniform height, actively growing, completely shading the ground and not short of water (Michael,

1978). The effect of crop characteristics on crop water requirements is given by the crop coefficient (K_C), which presents the relationship between reference crop evapotranspiration (ET_0) and actual crop evapotranspiration, or $ET = K_C \cdot ET_0$ (Dorenbos and Pruitt, 1977).

In several countries, U.S. weather Bureau class A pan or sunken pan (installed in the rice field) data have been correlated with actually measured ET. Evaporation pan provides measurement that integrates the effect of solar radiation, wind, temperature, and humidity on evaporation from a specific open water surface. To eliminate the effect of these meteorological factors, the values of potential evapotranspiration and ET have been divided by the value of pan evaporation (PE). These ratios can then be used to compare the difference between variety, cropping season, and latitude (Tomar and O' Toole, 1979). The ET-PE ratio in rice starts around 1: 0 after transplanting, shows a first peak (1.1 and 1.3) at the maximum tillering stage, and a maximum value at about heading stage. The value at heading time become 1.4 -1.5 in Malaysia and 1.7 in the Philippines (Tomar and O' Toole, 1979). On the average this value is 1.43 for tropical countries. It is 1.33 for Japan and 1.37 for Australia (Evans , 1971). Thus, on the average this ratio is 1.0 at the time of transplanting, reaches 1.15 after 15-20 days, and attain a maximum of 1.3-1.4 at about heading (De Datta, 1981). Tomar and O' Toole (1979) concluded that over the whole rice crop growth period, ET from low land rice fields is more than open pan evaporation during that period. They suggested the relationship: $ET = 1.2 PE$.

Karim and Akhand (1982) computed the ET_0 and ET for rice, wheat and Potato from available 10 years meteorological data of Bangladesh for different season and location using modified Penman method. The variations among the locations in a specified month are not wide. Generally maximum values of ET_0 were obtained during the month of April and May and the minimum values were in the month of December and January.

2.6. Wheat after Rice

2.6.1. Scope and limitation

Rice – Wheat is the main cropping system of the sub-tropical agro – ecozones where assured irrigation is available . This system is practiced on about 23 million hectares comprising 10.3 million hectares in China, 10.5 million hectares in India, 1.5 million hectare in Pakistan, 0.5 million hectare each in Nepal and Bangladesh and 0.05 million hectare in Bhutan (Singh and Abrol ,1995). In Bangladesh , rice alone covers about 80% and rice - wheat together occupied

over 83% of the total cropped area . Over 80% of the total wheat area preceded by transplanted Aman (Saunders 1991). In several parts of Bangladesh, rice and wheat are grown sequentially in the same field in the same farming year, in one or another of several distinct cropping pattern. Yield in this sequence in several years , and averaged over all Bangladesh have been about 3.4 t/ha of rough T.Aman rice, and 2.6 t/ha of unmilled wheat grain (Huke *et al.*,1993) Wheat yield in this cropping pattern are also some of the poorest in the region. The physical limitations imposed by puddled soil have been recognized as the major cause of poor establishment and yield of post rice crops in Asia (Woodhead, 1990)

Puddling is associated with the breakdown of soil aggregates during wet cultivation (Adachi ,1990). After drainage of the surface water prior to rice harvest, the water content of the surface soil decreases, which is accompanied by a relatively rapid increase in redox potential (Maghari,1990) and a slower increase in soil strength (IRRI, 1988).The structure of the puddled layer becomes massive as the soil dries. Puddling also results in the formation of compacted soil layer below the puddled zone, whose strength increase very rapidly as the soil dries, limiting the depth of root exploitation (IRRI 1986).The resulting poor stands is one of the factors in poor yield of rice. Another factor is the low N availability resulting from extensive removal of mineralized N by rice and microbial immobilization of N applied to the following wheat crop (Meelu *et al.*, 1979). Crops grown in low land soil after rice harvest may also suffer from deficiencies of other plant nutrients and from a lack of suitable micro organisms, such as rhizobia, or VA mycorrhiza, which may not survive prolonged water logged condition.

In irrigated rice- wheat system , soils become aerobic after rice harvest and high levels of NO_3 are expected in such soils. These are prone to losses by excessive irrigation and rain (Modgal *et al.*, 1995). The rate of N mineralization is greatest during the wet season. It increased exponentially with increasing soil moisture content from 5 to 23% indicating that N mineralization is moisture limited in dry lands (Singh and Singh, 1994). Cultivation accelerates the oxidation of organic matter in soils and generally results in higher NO_3 -N in the profile . Cultivation may also decrease the rates of denitrification , immobilization and leaching of NO_3 - N (Rice and Smith, 1982).

The month wise distribution of rain fall of Bangladesh indicates the wheat growing season (November – March) as the driest period of the year. Unfortunately 60 – 65% of the

total wheat area still remains with out irrigation and is dependant on residual moisture (Ahmed *et al.*, 1986). Soil moisture stress is reported to adversely affect the wheat yield (Islam 1990).

2.6.2. Soil moisture profile of Bangladesh soil

The amount of soil moisture available for plant growth is considered to be the moisture held in the range from field capacity to permanent wilting point. Soil moisture profile refers to the sum of the available moisture in the different individual horizon of a profile. Soil moisture supply in turn depends on rainfall, soil moisture storage, evaporation and the flooding and drainage regime of the site. The soils of river flood plain area of Bangladesh are unique in retaining extraordinary amounts of available moisture in the profile (Joshua and Rahman, 1983 and SRDI, 1986).

Most of the soils of Barind and Madhupur tract of Bangladesh are generally heavy textured ranging from silty clay to clay. The available moisture in the root zone of 100 cm. depth of these soil is well below the total evapotranspiration of rabi crops. Therefore, rainfed rabi crops in these area in general is not feasible. Higher moisture content at both field capacity and wilting point may causes the low available moisture for Madhupur and Barind tract soils (Joshua and Rahman, 1983 and Rahman *et al.*, 1991).

On the other hand, silt loam is the dominant soil series of Tista flood plain, old Brahmaputra and old Meghna estuarine flood plain soils. The available soil moisture storage of silt loam is very high. Soil moisture storage in a root zone of 100 cm depth is sufficient for almost all rabi crops to be grown in the deeper phase of all soils on the flood plain except the silty clay soils. Furthermore, the surplus soil moisture storage with additional recharge from high water tables enables crops to be grown well before the pre monsoon raining in the flood plain areas (Joshua and Rahman 1983; and SRDI,1986). Expansion of wheat cultivation largely depends on the efficient utilization of soil residual moisture. Karim *et al.*, (1980) reported that a considerable potential moisture is available in the surface layer of Bangladesh soils which remains to be utilized by wheat plant.

2.6.3. Tillage practices, moisture regimes, N fertilization and their interactions on wheat crop performance.

2.6.3.1. Tillage practices

Tillage has been used in crop production to obtain a seed bed physically, chemically, and biologically suitable for plant growth. The requirements for optimum soil tillage varies widely with cropping systems, soil type and climatic conditions. However, to date, the effect of tillage on yields are unclear. In some experiments, tillage caused insignificant or no increase in yield (IRRI, 1989). In other experiments, deep tillage produced significant yield increase (IRRI, 1988 and Karim *et al.*, 1983). Zero tillage or minimum tillage produced crop yields of barley comparable with or superior to those under conventional tillage, and also improved soil water conservation (Malhi *et al.*, 1992). Majid *et al.* (1988) pointed out that zero tillage was equivalent to traditional tillage in regard to wheat yield when the crop was planted at the same time, and was superior economically in terms of power use. Reduced tillage may increase grain yield of sorghum by increasing the infiltration of water into the soil (Hamblin and Tennant, 1979), while at the same time decreasing the mineralization of N (Dowdell and Cannell, 1975).

No tillage sowing method of wheat after rice gave significantly higher grain yield than that of conventional tillage practices (Ahmed and Chatha, 1992). Direct drilling of wheat after paddy harvest produced higher yield than that sown with CT (Shafiq *et al.*, 1995). Early sowing and minimum tillage produced higher grain yield of wheat (Shaha *et al.*, 1991). Dhinam and Sharma, (1986) compared zero tillage with traditional tillage for wheat after rice and concluded that direct drilling with zero tillage economically saves the farmer substantial production cost and makes wheat cultivation after rice more profitable.

Karim *et al.* (1985) tested wheat under minimum and conventional tillage systems after wetland rice in Bangladesh and found higher yield in minimum tillage than conventional tillage in the silty clay loam soil. The tillage method have not shown any significant yield differences in sandy clay loam soil. When minimum tillage was compared with one, three, and five ploughing minimum tillage was found promising in establishing wheat after wet land rice (Mondal 1986). Yield advantages of wheat from minimum tillage practices under both rain fed and irrigated wetland rice in different locations have also been reported (Khan *et al.*, 1985). The yield of directly drilled wheat, rap and mustar, safflower, winter maize and lentil on silty loam

soil of West Bengal, India was found as good as the yield from conventional tillage (Chatterjee, 1985). Muskina *et al.* (1993) pointed out no effect of tillage or interactions among variable of soil properties, crop growth and N uptake by corn. On a fertile and deep soil, tillage was shown to be unnecessary. Roy and Sarker (1993) and Prihar *et al.* (1996) also reported no effect of tillage on the grain yield of wheat. On the other hand Singh *et al.* (1993), Das *et al.* (1993) and Shafiq *et al.* (1995) reported higher yield with increased tillage. Narang *et al.* (1992) also reported higher yield under conventional tillage system than under no-till system at all the levels of N.

The effect of three tillage treatments, minimum, conventional and deep tillage were compared relative to yield of wheat, water use efficiency and cost of production on a Grey Terrace Soil of Bangladesh under rainfed and irrigated conditions. In the irrigated area a maximum yield of 3.33 t/ha was produced from conventional tillage, but in the rainfed area, maximum yield of 2.25 t/ha, a 36% increase in yield over the conventional tillage was obtained from deep tillage. Cost of production of 100 kg grain was much higher, \$7.5, in the rainfed conventional tillage compared to \$4.5 in deep tillage with maximum water use efficiency of 294.6 kg/ha/cm. The higher wheat yield resulting from deep tillage sufficient to break the plowpan in the rainfed experiment was likely due to improved adaptation of the plant to utilize residual soil moisture through a large number of roots distributed in the deep layers of soil profile (Karim *et al.*, 1983).

Gajri *et al.*, (1992) reported increased rooting depth and density of wheat with tillage regimes. Adeoye (1982) reported more vertical penetration of maize roots in deep tilled soils. In general soil strength was the major cause of reduced root growth under the no tillage treatment (Mahata *et al.*, 1992). The root distribution pattern in wheat is adversely affected under a rice-wheat system and wheat roots are more concentrated in the surface layer compared to a maize-wheat system due to the formation of hard pan (Sur *et al.*, 1981). Narang *et al.* (1992) reported less rooting density in zero tillage than conventional tillage and found maximum rooting density to the plough layer with -, or with out -, nitrogen. Under tilled soil condition higher rooting density induced by plough - sole layer in surface layer has also been reported by Ehlers *et al.* (1981).

2.6.3.2. Moisture regimes

Better performances of wheat, maize and barley with irrigation than without irrigation have been reported by several investigators (Singh *et al.*, 1991; Khalil and Rahaman, 1991; Nandal and Agarwal, 1991). Averaged over cultivation treatments, irrigation has a positive effect on grain yield and quality (Matejikova, 1990). Singh *et al.* (1991) reported taller plants height and better yield attributes of wheat, viz., number of effective tillers, grains/ear and grain weight/ear with irrigation than without irrigation. Increased root length and root density of wheat plant with irrigated plots compared to no irrigated plots were also reported by Khalil and Rahman (1991).

(Matejikova, (1990) also reported the highest yield of winter wheat with irrigation and tillage with a depth of 0.22m while without irrigation the highest yield was obtained with shallow tillage to 0.15m. On the other hand Karim *et al.* (1983) found maximum grain yield of wheat in irrigated area from CT but in the rain fed area from deep tillage. Videonovic *et al.*, (1986) also reported increased corn yield with irrigation in conventional tillage than minimum tillage. Rahman and Islam, (1991) reported increased grain yield of wheat with increasing tillage depth and found no interaction of irrigation and tillage.

2.6.3.3. Nitrogen fertilization

In general, grain yield increases with N application up to a certain limit. A considerable body of research has indicated the positive response of rice, wheat and sorghum to N fertilization (Locke and Honse, 1988; Castillo *et al.*, 1992; Narang *et al.*, 1992). Root mass density of wheat at different growth stages increased with the application of N (Verma and Acharya, 1996). Wells (1984) showed that, for corn, less fertilizer N was required under conventional tillage than under no-tillage system to reach maximum production attainable. Dickson *et al.*, (1996) also reported that, additional N and P are required to maximize yield of no-tillage wheat following rice. Grain yield from no-till plots at the high rate of fertilizer N exceeded that from conventionally tilled plots by a greater margin than was observed with either zero N or lower rates of fertilizer N. A likely explanation is that soil moisture became more yield limiting in conventional tillage than in zero tillage, making it possible for grain yield of no-tillage plots to reach higher levels with additional fertilizer N. Locks and Hons (1988)

reported that at low N rates, conventional tillage produced more stover and grain of sorghum but at high N rates tillage differences did not occur. Nitrogen was more likely to be limiting to grain sorghum production under no-tillage than under conventional tillage.

Zero tillage produced significantly less barley yield than conventional tillage when N fertilizer was not applied (Nyborg and Malhi, 1989). On the other hand, yields of the zero tillage plots approached those of the conventionally tilled plots when N was added. Nevertheless, the yields were often similar under both tillage treatments when the plant available N levels were apparently sufficient. Videonovic *et al.* (1986) found the highest yield increase due to fertilizer application in minimum tillage, somewhat lower when the rotovator was used and the lowest in conventional tillage. This indicated decreased fertilizer effect under more intensive soil tillage.

Behera and Sharma (1991) reported a significant influence of the interaction of irrigation and fertility levels on the grain yield of wheat. Lower levels of irrigation with higher levels of fertility resulted in reduced grain yield. This indicated that with increasing fertility levels a higher quantity of irrigation water was needed by the crop to realize full yield potential. The effects of fertilizer and irrigation water were complementary to each other in increasing the yield of wheat. Karim *et al.*, (1985) reported a high order yield response of N fertilizer under optimum water supply. The interaction effect of irrigation and N levels was also found significant on the grain yield of wheat by Lathwal *et al.* (1991). They reported that under all the levels of N adequate irrigation produced higher yield compared with limited irrigation. Both the irrigation regimes produced significantly higher grain yield with 120 kg N/ha than with 40 or 80 kg N/ha. This was attributed to a greater production of photosynthates and their translocation to the sink under adequate irrigation and higher doses of N. Irrigation and N interactions showed that for the same yield level of wheat less N was required in a more frequent irrigation regime compared with less frequent irrigation regimes (Gajri *et al.*, 1992). A positive co-relation between moisture supply and grain yield of wheat was reported by Gauer *et al.* (1992). They stated that the grain yield with 0 and 120 kg N/ha were 1.7 and 2.59 t/ha, respectively at moderate soil moisture and 1.64 and 3.12 t/ha at higher moisture levels.

There are some reports that within certain limits, water and nutrients substitute for each other and tillage increases efficiency of water and fertilizer use (Sharma, 1985). For a given yield level, higher inputs of water and N are required under zero tillage than under conventional

tillage (Gajri *et al.*, 1992). In absence of crop residues, tillage of coarse textured low organic matter soil increased the water and fertilizer N efficiency in wheat following rice through its favorable effects on root and shoot growth.

Development of appropriate tillage systems, and water and fertilizer management practices for rice and wheat can play an important role in energy and time savings as well as in increasing the productivity of rice-wheat cropping systems in Bangladesh. The effect of tillage, water regimes, N fertilization and their interactions on soil properties, nutrient availability, and mineral nutrition of rice and wheat have been studied in details in other countries of the world. But little work under the specific agro-ecological conditions of Bangladesh has been done in this respect. Considering the importance of tillage, water regimes and fertilizer management practices in crop production, research to develop appropriate tillage, water and fertilizer management practices for rice and wheat, the major cereal crops of Bangladesh, deserves special attention.

3. Materials and Methods

This study was conducted at the central experimental station of the Bangladesh Rice Research Institute (BRRI) at Gazipur during the period from July 1992 to May 1994 and from July 1998 to March 1999. The soil is a clayey, mixed, non acid Acric Haplaquept (Zijevell, 1980). Six experiments involving rice and wheat were conducted.

3.1. Description of the Experimental site

3.1.1. Location

The BRRI experimental farm in Gazipur is located about 35 km north of the capital city of Dhaka. The farm lies between $23^{\circ} 59' 01''$ to $23^{\circ} 59' 16''$ North latitude and $90^{\circ} 24' 35''$ to $90^{\circ} 24' 40''$ East longitude. The elevations is 8.4 m above mean sea level. The experimental farm has an area of 70.85 hectares.

3.1.2. General physiography and geology

The BRRI farm is representative of the level upland areas sub-regions 28d and 28f of the Madhupur Tract, Agro-ecological zone 28 (AEZ28). The Madhupur Tract is underlain by the Madhupur clay consisting of Tertiary and Pleistocene tidal and marine alluvium (UNDP/FAO, 1988). The soil conditions are surprisingly heterogeneous. Grey Terrace soils occupy about 15% of the Madhupur Tract.

3.1.3. Present land use/ vegetation

Mainly rainfed transplanted HYV As followed by local transplanted aman varieties. Rainfed As followed by mashkalai or mustard, with jackfruit trees on field boundaries are also important crops in some areas. HYV Boro followed by HYV Aman on irrigated land. Sugarcane, Kharif ground nut (grown to produce seed) mesta, wheat and rabi crops are locally important. In the BRRI farm, rice is the dominant crop with some patches planted to wheat and legumes as rotational and green manure crops.

3.1.4. Climate

The climate of the experimental station belongs to tropical monsoon characterized by three distinct seasons. The monsoon or rainy season (May to October) is warm and humid and receives about 90 percent of the total annual rainfall during the period in the form of occasional thunder showers. The winter or dry season (November to February) is cool and dry and receives about 2 percent of the total annual rainfall mostly as occasional drizzles.

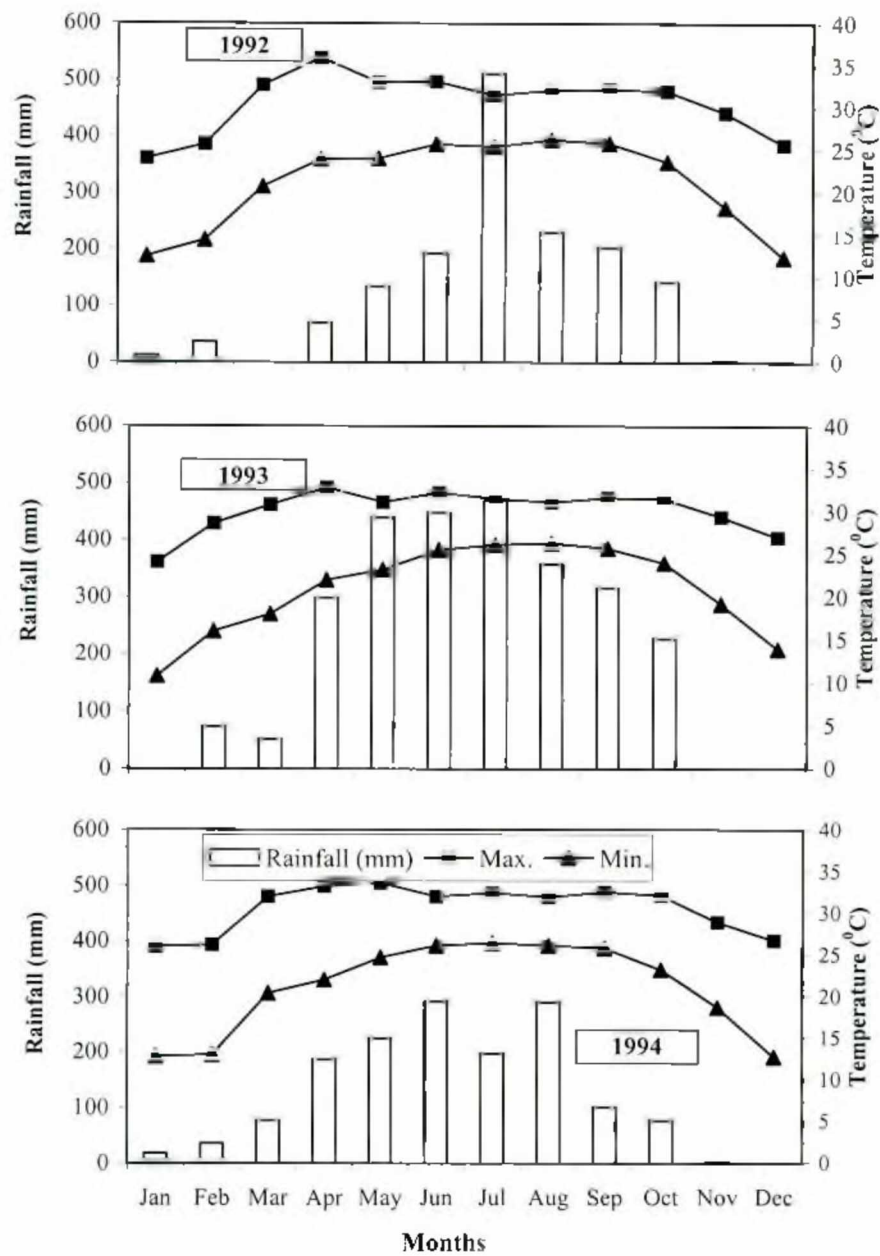


Fig.1. Rainfall and temperature at Gazipur during different cropping season (1992-1994).

The pre-monsoon or hot season prevails from March to April. The rainfall and air temperature (maximum and minimum) data were collected from weather report section of Plant Physiology Division, BRRI, Gazipur and presented in figure 1. The annual rainfall for the year 1992, 1993 and 1994 at Gazipur were 1523, 2679 and 1495 mm respectively. Mean monthly temperatures of the warmest and coldest months were recorded in April (31°C) and January (16°C).

3.2. The soil morphological characteristics of the experimental site

A soil profile was opened by digging a pit up to a depth of 150 cm at the experimental site with coordinates $23^{\circ} 59' 09''$ North latitude and $98^{\circ} 24' 03''$ East longitude. The morphological profile of the soil is presented in Appendix Table1 and Picture 1.

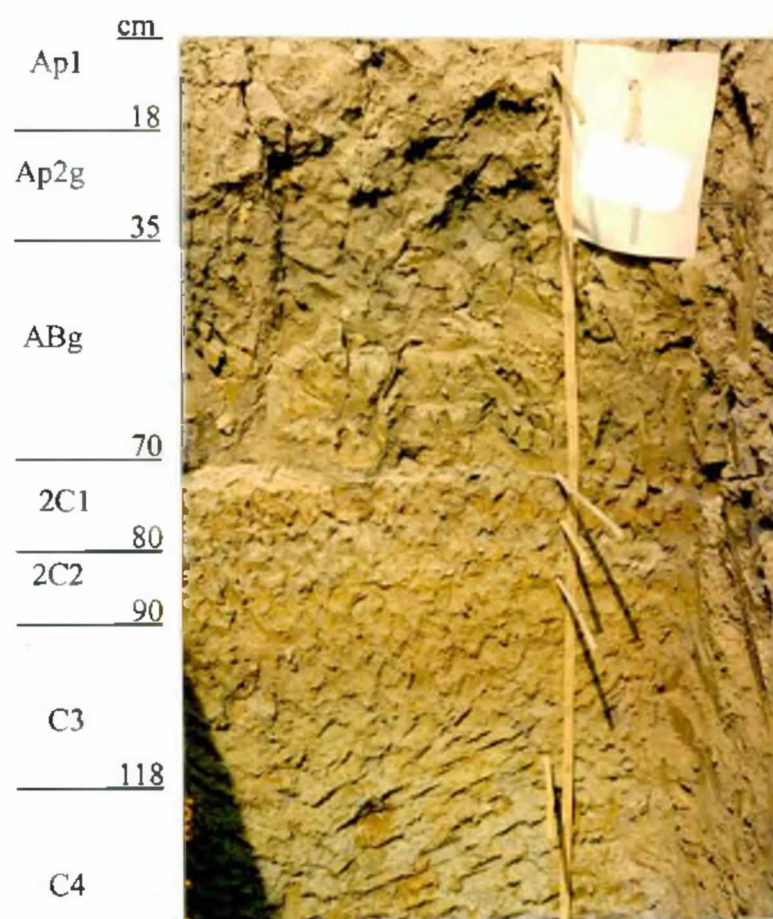


Plate 1. A profile of the soil at the experimental site.

The taxonomic classification of the soil is presented in Appendix Table 2. The soil of experimental site represents the Chhiata series, a major soil series of the Madhupur Tract. The soil developed from Madhupur clay. The parent material is a deeply and strongly weathered, leached and strongly mottled clay. The A horizon is grayish brown to grey, silty clay to clay in texture. The soil structure is weak, fine to medium sub angular blocky. The B horizon is light grey, silty clay in texture. The soil structure is weak, medium and coarser sub angular blocky, probably due to difference in time and mode of deposition, at the depth of 35-70 cm some embedded calcareous gravels were observed. The buried C horizon is grey in color and silty clay in texture; the structure is weak, medium to coarse angular and sub angular blocky. Mottles and Fe/Mn concretions are prominent in this horizon (Appendix Table 1).

Soil samples for laboratory analyses were collected at 15 cm increments from surface up to 105 cm depth. Some important characteristics of the soil of the experimental site are presented in Table 1. Throughout the profile the soil texture is silty clay, with the exception that, at the 15 to 30 cm depth, the texture is clay. While the particle density was homogenous throughout the profile, a higher bulk density at the 15-30 cm depth gives the impression of some compaction or the existence of a hard pan. The surface and sub-soils are slightly acidic to neutral in reaction. The organic matter content is low at the surface (1.08%) which decreased further in the lower horizons. The general fertility status of the soil is poor with very low N, low P and medium K contents. The fertility level of the soil decreases with increasing soil depth (Table 1).

Table 1. Some important characteristics of the soil of the experimental site.

Soil depth (cm)	Soil texture	Field capacity (% w/w)	pH	Bulk density (g/cm ³)	Particle density (g/cm ³)	Porosity (%)	CEC (me/100g soil)	Organic matter (%)	Available nutrients		
									N	P	K
									mg/kg soil		me/100g soil
0 – 15	Silty clay	32	6.9	1.40	2.62	46.6	26.2	1.08	13.21	10.86	0.26
15 – 30	clay	32	6.9	1.58	2.63	38.9	23.5	0.82	10.78	9.23	0.24
30 – 45	Silty clay	32	7.0	1.54	2.64	41.6	19.8	0.67	10.03	8.76	0.24
45 – 60	Silty clay	31	7.0	1.55	2.64	41.3	17.2	0.45	8.94	8.50	0.21
60 – 75	Silty clay	31	6.9	1.56	2.64	39.4	12.0	0.38	8.46	7.54	0.20
75 – 90	Silty clay	32	6.8	1.60	2.65	39.6	11.3	0.36	7.09	7.01	0.19
90-105	Silty clay	31	6.5	1.60	2.65	39.8	12.4	0.29	6.02	6.90	0.17

3.3. Experiment 1. Effect of tillage and N levels on available NH₄- and NO₃-N in soil and on the growth, yield and N nutrition of wetland rice.

Hypothesis: *Tillage intensity and applied N levels influence N availability in soil and performance of transplanted rice.*

The experiment was conducted in the transplanted aman (T. Aman) season of 1992. The objective of the study was to determine the effect of tillage and N levels and their interactions on the availability of N in wet soil and on the growth, yield and N nutrition of irrigated rice.

3.3.1. Experimental design and treatments

The experiment was laid out in a split-plot design with four replications. Tillage treatments were assigned to the main plots and N levels to the sub-plots. The sub-plot size was 5m x 4.5m.

Treatments

Tillage levels

- T_1 = Zero tillage (ZT) i.e. no land preparation: The plots were submerged for 3 days before transplanting to make the soil soft enough for facilitating transplantation of rice seedlings under zero tillage situation. The existing weeds were cleaned manually.
- T_2 = Reduced tillage (RT), two ploughing and two laddering: The plots were submerged and ploughed twice with a country plough 3 d before transplanting followed by two laddering 1 d before transplanting. The plots were then kept submerged.
- T_3 = Conventional tillage or puddling (CT), five ploughing and four laddering : The plots were submerged and ploughed thrice with a country plough followed by two laddering 3 d before transplanting and again ploughed twice followed by two laddering 1 d before planting. The plots were then kept submerged.

Nitrogen levels

Four N levels 0, 60, 80 and 100 kg per hectare were used as the N treatment.

3.3.2. Experimental procedure

After establishing the tillage treatments, levees were constructed to create 48 plots each 5m x 4.5m.in size. Nitrogen fertilizer (urea) was applied in 3 equal splits, once basally (broadcast just before transplanting and incorporated), once 25 days after transplanting (DAT) and finally 45 DAT. All plots received basal doses of P, K, S and Zn at the rate of 26, 33, 20 and 5 kg/ha as triple super phosphate, muriate of potash, gypsum and zinc sulfate respectively. All basal fertilizer doses were applied in the morning of the day of transplanting. The fertilizers were thoroughly mixed with the soils and the plots were leveled manually before transplanting.

A modern rice (*Oryza sativa* L.) variety, BR11, with a growth duration of 140-145 days was used as the test crop. Seedlings were raised in wet seedbed with appropriate measures against pest infestation. Forty-day-old seedlings were transplanted at the rate of 2-3 seedlings per hill at a spacing of 20 cm x 20 cm. All plots were kept submerged under 3-5 cm water during growing period. However the standing water was drained out from the plots 10 days before harvest. The crop was kept weed free by two hand weeding 20 and 35 DAT. The rice crop was kept pest free with the application of the insecticide Diazinon 10 G at the rate of 17 kg/ha 40 DAT.

3.3.3. Soil and plant sample collection, processing and analysis.

Soil samples (0-15 cm) from each block were collected once before treatment application and once after harvest, air dried and sieved for physico-chemical analysis. For $\text{NH}_4\text{-N}$ and $\text{NO}_3\text{-N}$ determination, soil from each individual plot was sampled at 15-day intervals during the crop growth period (15, 30, 45, 60, 75, 90 and 105 DAT), using the core sampling technique. At each time sampling, 4 random soil samples per plot at a depth of 0-15 cm were collected for one composite sample. Just after collection, the samples were mixed thoroughly and sub-sampled for KCl extraction and moisture determination. About 20 g wet soil was extracted with 2N KCl solution, the volume was made up to 100 ml and the concentrations of $\text{NH}_4\text{-N}$ and $\text{NO}_3\text{-N}$ were determined by micro-Kjeldhal distillation method as described by Bremner (1965). Straw and grain samples were collected from each plot. Straw samples were washed with distilled water and dried at 70°C in an oven for 48 hours and were ground using a Wiley micro-mill. Prior to analysis, samples were oven dried at 60°-70°C for 24 hours. The plant samples were analysed for N.

3.3.4. Data collected

- A. Soil parameters: Texture, bulk density, particle density, total porosity, organic carbon, organic matter, CEC, pH, available P, exchangeable K, total N, ammonium-N and $\text{NO}_3\text{-N}$ in soil.
- B. Rice plant growth parameters: Plant height was measured from the ground level to the tip of the tallest leaf or panicle from four randomly selected sample units consisting of four consecutive hills in two consecutive rows per plot at the active tillering stage (35 DAT) and at maturity. The sample units were selected from outside the harvest area.

Tillers and panicles were counted on each of these sample hills. Tiller numbers were counted at 35DAT and at maturity, and the panicle numbers at maturity. Panicles from these 16 hills samples from each plot were used for yield component analysis

- C. Grain and straw yield: The crop was harvested from a 5m² area at the center of each plot when about 80-90% of the grains turned golden yellow. The harvested hills from each plot were threshed, and the grains were cleaned, dried for 2-3 days, and weighed. Immediately after taking the grain weight from each plot the grain moisture content was determined, and the grain weight was adjusted to 14% moisture level. The straw was sun-dried for almost a week before weighing.
- D. Yield components: Panicles from 16-hill samples stated earlier were separated for yield component analysis, and threshed by hand. The grains were sun-dried for 2-3 days. The following yield contributing characters were determined :
 - i. Total number of panicles/m²
 - ii. Number of spikelets/panicle
 - iii. Percentage of unfilled spikelets
 - iv. Weight of 1000 filled spikelets.
- E. Nitrogen nutrition: Shoot at 35 DAT and straw and grain samples at maturity were analyzed for nitrogen concentration.
- F. Nitrogen uptake and use efficiency:
 - i. Nitrogen uptake kg/ha was determined using estimates of percent nitrogen content in each of straw and grain tissue and their dry matter yield
 - ii. Efficiency of fertilizer nitrogen was calculated based on kg grain per kg applied nitrogen
 - iii. Percentage of N recovery based on kg absorbed nitrogen over 100 kg applied N.
 - iv. Efficiency of utilization based on kg grain over kg absorbed nitrogen.

3.4. Experiment 2. Effect of irrigation and N levels on soil physical properties and the growth, yield and mineral nutrition of rice.

Hypothesis: *Water regimes influence soil properties which modifies the effect of applied N doses on the performance of transplanted rice.*

The experiment was conducted in the Boro season of 1993. The objective of this experiment was to determine the effect of irrigation and N levels and their interactions on soil physical properties, N availability in the soil and on the growth, yield and nutrient status of rice.

3.4.1. Experimental design and treatments

The experiment was laid out in a split plot design with four replications. Irrigation levels were used as the main plot and N levels as the subplot. The subplot was 5m x 3m in size.

Treatments

Moisture regimes

- I₁ = Continuous submergence under 3-5 cm water (CS).
- I₂ = Apply irrigation 4 days after disappearance of standing water (4 DW).
- I₃ = Apply irrigation 7 days after disappearance of standing water (7 DW).
- I₄ = Apply irrigation 10 days after disappearance of standing water (10 DW).

Nitrogen levels

Four nitrogen levels (0, 40, 80 and 120 kg /ha) were used as the N treatments. Since 120 kg N/ha is the maximum recommended dose by BRRI for Boro rice in the BRRI farm site, no higher dose than 120 kg/ha has taken into consideration.

3.4.2. Experimental procedure

After thorough puddling and leveling, levees were constructed to create 64 plots each 5m X 3m. Dikes were constructed between main plots by placing polyethylene sheets up to 15 cm soil depth to control seepage among irrigation treated plots. Nitrogen fertilizer (urea) was applied in 3 equal splits, once 15, once 40 days after transplanting (DAT) and finally 60 DAT. All plots received basal doses of P, K, S and Zn at the rate of 26, 34, 20 and 5 kg/ha as triple super phosphate, muriate of potash, gypsum and zinc sulfate respectively. All basal fertilizer doses were applied one day before transplanting. The fertilizer were thoroughly mixed with the soils and the plots were leveled manually before transplanting.

A modern rice (*Oryza sativa* L.) variety, BR3, with a growth duration of 170-175 days used as the test crop. Seedlings were raised in wet seedbed and protected from pest infestation. Fifty five-day-old seedlings were transplanted at the rate of 3-4 seedlings per hill at 20 cm x 20 cm spacing. The crop was kept weed free by two hand weeding 20 and 40 DAT. The plants

were also protected from pest infestation by applying insecticide Furadon 3 G at the rate of 17 kg/ha 21 DAT and Malathion (57 EC) at the rate of 1 L/ha 50 DAT.

All plots received water as per irrigation treatment. The CS plots were kept submerged under 3-5 cm standing water throughout the growing season. The other irrigated plots were irrigated at the respective days after disappearance of standing water. The first disappearance of ponded water occurred 32 DAT and the first irrigation was applied 36, 39 and 42 DAT as per treatment requirements. The 4DW and 7DW irrigated plots were kept submerged until the disappearance of standing water of 10 DW plots to maintain the irrigation cycle. A total of 4 irrigation cycles 32-42, 48-58, 72-82 and 92-102 DAT were maintained throughout the growing period. The last irrigation was applied 102 DAT and the crop was harvested 120 DAT. At each irrigation time the amount of water applied to each individual plot was measured. The rainfall data was also recorded. The cumulative water used for each treatment including rainfall is presented in Fig.4. Evapotranspiration (ET) was calculated by multiplying the potential or reference crop evapotranspiration (ET_o) and crop co-efficient (K_c), $ET = K_c \cdot ET_o$ as suggested by Doorenbos and Pruitt, (1977). The ET_o and K_c values were taken from Karim and Akhand (1982) and presented in Appendix Table 3 and 4.

3.4.3. Soil and plant sample collection, processing and analysis.

Soil samples (0-10 and 10-20 cm) from each individual plot were collected at different intervals during the crop growth period using the core sampling technique for soil moisture content, bulk density, and porosity determination. For NH₄-N and NO₃-N estimation, soil from each individual plot was sampled at 45 and 65 DAT. Samples were collected 3 days after urea top dressing. Four randomly collected soil samples from each plot were used as one composite sample. Immediately after collection, the soil samples were mixed thoroughly and sub sampled for KCl extraction and moisture determination. About 20 gram wet soil was extracted with 2N KCl solution, the volume was made up to 100 ml and the concentration of NH₄⁺ and NO₃⁻-N were determined by micro-Kjeldahl distillation method (Brenner, 1965). Plant samples were collected from 4 randomly selected sample unit consisting of 4 consecutive hills in 2 consecutive rows out side the harvest area of each plot at 45 DAT (Active tillering stage), 65 DAT (Panicle initiation stage) and at harvest. The plant samples were washed with tap water to remove soil particles, followed by distilled water, wiped with paper towel dried at 70°C in an

oven for 48 hours and were ground using a Wiley micronmill. Prior to analysis, samples were oven dried at 60^o-70^oC for 24 hours.

Root samples for 0 to 30 cm soil depth were collected from the center of each plot using 40 cm long and 10 cm - dia metal core. Each soil core was halved cross wise. The core sampler was placed over a plant after harvest in such a way that the plant was in the center. Each soil core was cut in to three 10 cm lengths and root length was measured by using technique described by Newman (1966). Roots were then dried at 70^oC for 3 d and weighed.

3.4.4. Data Collected

- A. Weather data: Rainfall and pan evaporation data were collected from weather report section of physiology division, BRRI, Gazipur (The data were recorded from meteorological observatory of BRRI HQ situated within 500 M of experimental site).
- B. Soil parameters: The soil samples collected at different growth stages were analyzed for soil moisture content, bulk density, total porosity and, NH₄ and NO₃-N concentration.
- C. Rice plant growth parameter: Plant height was measured from the ground level to the tip of the tallest leaf or panicle from randomly selected four sample unit consisting of 4 consecutive hills in 2 consecutive lines per plot at active tillering (45 DAT), panicle initiation stage (65 DAT) and maturity. The sample units were selected from out side of harvest area. Tillers and panicles from each of the 4 hills of 4 sample unit were also counted at 45 and 65 DAT and at maturity from the same sample unit used for plant height measurement. Root length density and root mass from 0-30 cm soil depth at maturity.
- D. Grain and straw yield: When about 80-90% of the grain in the panicle become straw-colored, the crop was harvested from 5m² area at the center of each plot. The grains were threshed, cleaned, dried and weighed separately. The grain yield was adjusted to 14% moisture content while the straw was sundried for almost a week before taking weight and were reported as t/ha basis.
- E. Yield component: Panicles from 16 hills were separated for yield component analysis and then threshed by hand and determine the following parameters.

- i. Total number of panicles/m².
- ii. Number of spikelet/panicle.
- iii. Percentage of unfilled spikelets.
- iv. Weight of 1000 filled spikelets.
- F. Mineral nutrition: The shoot at 45 and 65 DAT were analyzed for nitrogen and the straw and grain at harvest were analyzed for N, P, K, Ca, Mg, Mn, Zn and Cu.
- G. Nitrogen uptake and use efficiency: The method of data collection were the same as in experiment I.

3.5. Experiment 3. Effect of tillage on soil physical properties and on the yield and mineral nutrition of rice under irrigated and rainfed conditions.

Hypothesis: *Tillage intensity influence soil physical properties, and thus, the mineral nutrition and yield of transplanted rice under varying water regimes.*

The experiment was conducted in the season of T.Aman 1993. The objective of this study was to determine the effect of tillage and water levels on soil physical properties and the growth, yield and mineral nutrition of rice.

3.5.1. Experimental design and treatments

The experiment was laid out in a split-plot design with 4 replications. Irrigation levels were used as the main plot and tillage treatment as the sub plot. The sub plot size was 9m x 5m.

Treatment

Moisture regimes

- I₁ = Irrigated (IRG). Irrigation was applied as and when required.
- I₂ = Rainfed (RF). No irrigation was applied during the crop growing period except at land preparation.

Tillage level

- T₁ = Zero tillage (ZT) i.e. no land preparation. The plots were submerged 3 d before transplanting to make the soil soft enough for transplanting seedlings of rice. The existing weeds were cleaned manually.

- T_2 = Reduced tillage (RT), two ploughing and two laddering: The plots were submerged and ploughed twice with country plough 3 d before planting followed by two laddering 1 d before planting. The plots were then kept submerged.
- T_3 = Conventional tillage (CT), five ploughing and four laddering: The plots were submerged and ploughed thrice with country plough followed by two laddering 3 d before transplanting and again ploughed twice followed by two laddering 1 d before transplanting. The plots were then kept submerged.

3.5.2. Experimental procedure

After establishing the tillage treatments, levees were constructed to create 24 plots each 9m x 5m. Dikes were constructed between main plots by placing polyethylene sheets up to 15 cm soil depth to control seepage among irrigated and rainfed plots. Nitrogen fertilizer (urea) at the rate of 80 kg/ha was applied in 3 equal splits once basally, once 25 DAT and finally 45 DAT. All plots received basal doses of P, K, S and Zn at the rate of 25, 34, 20 and 5 kg/ha as triple super phosphate, muriate of potash, gypsum and zinc sulfate respectively. The applied fertilizers were thoroughly incorporated and plots were leveled manually before transplanting.

A modern rice (*Oryza sativa* L.) variety, BR11, with 140-145 days growth duration was used as the test crop. Seedlings were raised in wetbed and protected from pest infestation. Thirty three-day-old seedlings were transplanted at the rate of 2-3 seedlings per hill at a spacing of 20 cm x 20 cm. The crop was kept weed free by hand weeding and protected from pest infestation by applying insecticide as and when required. Irrigated plots were kept submerged with 3-5 cm water depth through out the growing period and the water was drained out 10 days before maturity. At each irrigation time, the amount of water applied to each individual plot was recorded. Rainfed plots remained submerged up to 75 DAT with rain water. The crop was harvested at 104 DAT. The rainfall data was also recorded. The cumulative water used in each treatment including rainfall is presented in Fig. 14.

The evapotranspiration was calculated in the same way as in the experiment 2. The percolation rates of soil were measured in tillage treated plots using a double ring infiltrometer and measuring the fall of water level with time by a point gauge. The depth of water in both inner and outer ring was maintained roughly equivalent and was about 5-7 cm

through out the period of observation. The initial reading was taken one hour after adjustment of water level in the inner ring and the procedure was continued. On the first day, the percolation measurements were taken at intervals of 1, 2, 4, 6 and 8 hours and then at noon at each day. The percolation measurement were taken for a period of 26 days during the rice growing season. In estimating the percolation rate, the rainfall and the panevaporation were taken into consideration. Total discharge of water for a day were recorded as percolation for that period.

Soil penetration resistance (SPR) was measured by pocket penetrometer. In each treatment, a soil pit about 30 cm deep was excavated to measure the penetrometer resistance at an interval of 5 cm. Several measurements were made at each depth to obtain an average value. The piston needle of the penetrometer was pushed into the soil at right angles to the vertical soil surface until penetration reached the calibration groove and recorded the value in MPa scale (Davidson, 1965). Soil temperature (0-10 and 10-20 cm) from each individual plot were recorded at 15 day intervals during the crop growing period (15, 30, 45, 60, 75 and 90 DAT) using the bimetallic soil thermometer (Taylor and Jackson, 1965). The readings were recorded at noon each day.

3.5.3. Soil and plant sample collection, processing and analysis

Soil samples (0-10 and 10-20 cm) from each individual plot were collected at 25 -day intervals during the crop growing period (0, 25, 50, 75 and 100 DAT) using the core sampling technique to determine the physical characteristics of soil. After drain out standing water at harvest, soil sample from 0-10 cm layer was collected at 5-day intervals from each tillage treatment to determine the drying rate by estimating gravimetric moisture content. Straw and grain samples from each individual plot were collected at harvest and dried and ground for chemical analysis.

3.5.4. Data collected

- A. Weather data: Rainfall and Panevaporation data were Collected from the same source as in experiment 2.
- B. Soil parameters: Percolation rate, soil moisture content, bulk density, moisture retention capacity, soil penetration resistance, soil temperature and soil drying after drainage.

- C. Grain and straw yield of rice.
- D. Mineral nutrition of rice : Nitrogen, P, K, Ca, Mg, Fe, Mn, Zn & Cu of straw and grain at harvest.

3.5.5. Statistical analysis

Analysis of variance (ANOVA) as of split plot design was applied to all sets of collected data of experiment 1, 2 and 3 to test treatment variation. Mean comparison was done by Duncans' Multiple Range Test (DMRT) with 0.05 level of probability (Gomez and Gomez, 1984).

3.6. Experiment 4. Effect of water regimes, tillage systems and N levels on soil physical properties and on the growth, yield and mineral nutrition of post-rice wheat.

Hypothesis: *Water regimes, tillage intensity, applied N doses and their interactions influence soil physical properties, and hence, the performance of post-rice wheat.*

The experiment was conducted in the rabi season, 1994 in the same layout of the last T. Aman experiment keeping the tillage treated plots constant. The objective of this experiment was to determine the effect of tillage and N fertilization under two water levels and their interactions on soil physical properties and the growth, yield and mineral nutrition of post rice wheat.

3.6.1. Experimental design and treatments

The experiment was conducted in a split-split plot design with 4 replications. Irrigation levels were used as the main plot, tillage practices as the sub-plot and N levels as the sub-subplots. The sub-subplot size was 5m x 3m.

Treatments

Moisture regimes

- I_1 = Irrigated (IRG). Irrigation was applied once at sowing, once 25 days after sowing (DS) and finally 60 DS.
- I_2 = Rainfed (RT). No irrigation was applied during growing period except at sowing.

Tillage levels

- T_1 = Zero tillage (ZT). No land preparation. The seeds were sown below 2-3 cm depth in furrows (3 – 5 cm wide) prepared by hand tools.
- T_2 = Reduced tillage (RT), three ploughing and two laddering: Two ploughing with a country plough followed by one laddering and again one plough followed by another laddering.
- T_3 = Conventional tillage (CT), five ploughing and four laddering: Three ploughing with a country plough followed by two laddering and again ploughed twice followed by two laddering.

Nitrogen doses

Three N levels 0, 100 and 140 kg/ha were used as N treatments.

3.6.2. Experimental procedure

Land preparation was done 15 days after T.Aman rice harvest. Tillage treatments were established first and then the levees were constructed to make 72 individual plots. Nitrogen fertilizer (urea) was applied in 2 splits to irrigated plots, 2/3rd at land preparation and 1/3rd at 1st irrigation time while to rainfed plots the complete dose of N fertilizer was applied basally. All plots received basal doses of P, K, and S at the rate of 30, 33 and 20kg/ha as triple super phosphate, muriate of potash and gypsum.

A modern wheat (*Triticum aestivum*) variety, Kanchan, with a growth duration of 100-105 days was used as the test crop. Seeds were treated with Vitavax-200 at the rate of 3g/kg wheat before sowing to protect seedlings from different seed and soil born diseases. For all tillage systems, seeds were broadcast on the same day into furrows made by hand tools at 20 cm apart from line to line at the rate of 130 kg seed/ha. One day after sowing, an irrigation with 35 mm water was applied to all plots to germinate the seeds uniformly and then two irrigation

one with 50 mm at 25 DS and another with 60 mm at 55 DS were applied to the irrigated plots. The rainfed plots received no irrigation water. The crop was kept weed free by hand weeding and protected from pest infestation by applying insecticide as and when required. Plants were thinned at 20 and 35 DS. The amount of rainfall occurred during growing period was also recorded. The cumulative water used in each treatment including rainfall is given in Fig. 21. The infiltration rate of soil was measured in all the tillage treated plots using a double ring infiltrometer and measuring the fall in water with time by a point gauze (Karim *et al.* 1988). Two metallic rings, each of 30 and 50 cm in diameter, were driven into the soil to a depth of about 15cm by keeping a steel plate over both the ring and hammering uniformly and slowly. Water was added to the circular compartment between the two rings, which acted as a buffer. To avoid disturbance in the soil, a polyethylene sheet was placed on the soil surface inside the inner ring and then water was added up to about 20.0 cm height and the polyethylene sheet was removed carefully. The initial reading was taken one minute after the addition of water in the inner ring and the procedure was continued. The infiltration measurements were taken at intervals of 1, 2, 5, 10, 20 and 30 minutes and continued up to 400 minutes. The Cumulative infiltration and intake rates were computed and plotted in graphs. The crop was harvested at 103 DS.

3.6.3. Soil and plant sample collection, processing and analysis

Soil samples (0-10 and 10-20 cm.) from each individual plot were collected at 20-day intervals during the growth period (0, 20, 40, 60, 80, and 100 DS) using the core sampling technique to determine bulk density and moisture content. Straw and grain samples from each individual plot were collected at harvest. Plant samples were dried and then ground for chemical analysis.

3.6.4. Data collected

- A. Weather data: The rainfall and pan evaporation data collected from the same source as in experiment 2.
- B. Soil parameters: Infiltration rate, cumulative infiltration, moisture content and bulk density from different soil depth.
- C. Growth parameters: Plant height and number of tillers per m² at maximum tillering (35 DS) and booting stage (55 DS) and at maturity.

- D. Straw and grain yield of wheat.
- E. Yield components:
 - i. Number of panicles per m²
 - ii. Number of spike lets per panicle
 - iii. Percentage of unfilled spike lets
 - iv. Weight of 1000 filled spike lets.
- F. Mineral nutrition: Straw and grain samples were analyzed for N, P, K, Fe, Mn, Zn and Cu concentration.
- G. Total N uptake and use efficiency. The method of data collection were the same as in experiment 1.

3.6.5. Statistical analysis Analysis of variance (ANOVA) as of split-split plot design was applied to all sets of collected data to test treatment variation. Mean comparison was done by DMRT and LSD (Gomez and Gomez, 1984) with 0.05 level of probability. ANOVA of all important data are presented in Appendix Tables 8.1- 8.30.

3.7. Experiment 5. Tillage and Nitrogen effects on wetland rice performance.

Hypothesis: Tillage depth influences some soil physical properties, and thus the effect of applied nutrients and yield of wetland rice may be modified..

The experiment was conducted in the wet season of 1998. The objective of this study was to determine the effect of tillage depth and N levels on some soil physical properties and the yield of rice.

3.7.1. Experimental design and treatments:

The experiment was laid out in a split-plot design with 3 replication. Tillage treatments were used as the main plot and N levels as the sub plot. The sub plot size was 3.4 m x 6 m.

Treatments:

T₁ = Zero tillage (ZT), no land preparation: In ZT treatment, water was retained in the plots for several days to make the soil soft enough for transplanting rice seedlings. The existing weeds were cleaned manually.

T₂ = Conventional tillage (CT), five ploughing and four laddering: The plots were ploughed thrice with a country plough followed by two laddering 3 days before transplanting and again ploughed twice followed by two laddering 1 day before transplanting. The soils were thoroughly puddled so that transplanting of rice could be done easily. The ploughing depth were 10-12 cm.

T₃ = Deep tillage (DT), one spading, three ploughing and four laddering: The land was opened first by spading and then submerged followed by two laddering and again ploughed thrice with a power tiller followed by two laddering. The ploughing depth was 20-22 cm.

Nitrogen levels

Four N levels 0, 60, 80 and 100 kg per hectare were used as the N treatment.

3.7.2. Experimental procedure:

After establishing the tillage treatments, levees were constructed to create 36 plots each 3.4 m x 6 m. All plots received basal doses of P, K, S and Zn at the rates of 26, 35, 20 and 5 kg/ha as triple super phosphate, muriate of potash, gypsum and zinc sulfate, respectively. Nitrogen fertilizer (urea) was applied in 3 equal splits once basally, once 25 DAT and finally 50 DAT.

A modern rice (*Oryza sativa* L.) variety, BR11, with a growth duration of 140-145 days was used as the test crop. Seedlings were raised in a wet seedbed and protected from pest infestation. Thirty four-day-old seedlings were transplanted at the rate of 2-3 seedlings per hill at a spacing of 20 cm x 20 cm. The crop was kept weed free by hand weeding and protected from insect infestation by applying insecticides as and when required. The plots were kept submerged to a depth of 3-5 cm water throughout the growing period. The water was drained out a week before harvest.

The percolation rates of soil were measured in the main plots using a double ring infiltrometer and measuring the fall of water level with time by a point gauge in the same way as in Experiment 3. Bulk density was determined by obtaining undisturbed soil sample of known volume and dividing the oven-dry soil mass by the field volume of the samples. To

determine bulk density of different soil layers, undisturbed soil cores were collected at 5 cm interval up to 30 cm depth with the help of manually operated core sampler. The soil was trimmed to the exact volume of the cylinder and oven dried at 105°C (Blake 1965).

3.7.3. Data collected:

1. Soil parameters: Percolation rate and soil bulk density
2. Grain and straw yields: The crop was harvested from a 5m² area at the center of each plot when about 80-90% of the grains turned golden yellow. The straw and grain yields were determined in the same way as in Experiment I.
3. Yield components: Panicles from 16 hills were separated for yield component analysis and then threshed by hand and the following parameters were determined.
 - i. Total number of panicles/m²
 - ii. Number of filled grains/panicle
 - iii. Percentage of unfilled grains
 - iv. Weight of 1000 filled grains

3.7.4. Statistical analysis:

Analysis of variance (ANOVA) applicable for the split plot design was performed for all sets of collected data to test treatment variation. Mean comparison was done by DMRT and LSD (Gomez and Gomez, 1984) at the 0.05 level of probability.

3.8. Experiment 6. Tillage and irrigation effects on some soil physical properties and the performance of post-rice wheat.

Hypothesis. Depth of tillage and water regimes and their interactions influence some soil physical properties, and hence the performance of post-rice wheat.

The experiment was conducted in the rabi season, 1998-99 on a terrace soil at the experimental farm of the Bangladesh Rice Research Institute, Gazipur. This soil has a well developed 5-7 inches thickness compact layer formed at about 15 cm below the soil surface due to conventional puddling for transplanted rice cultivation. The morphological profile

character of the soil are given in Appendix Table I. After harvest of transplanted aman rice wheat was planted. The objective of this experiment was to determine the effect of tillage depth under two water regimes on some soil physical properties and the growth and yield of post -rice wheat.

3.8.1. Experimental design and treatments

The experiment was conducted in a randomized complete block design with 4 replications. There were three tillage treatments and two water regimes as follows:

Treatments

Tillage levels

- T_1 = Minimum tillage (MT): Only one shallow ploughing with a country plough which scrapped the surface soil. The ploughing depth was 2.5-3.5 cm. The seeds were sown below 2-3 cm depth in the furrow (3-5 cm wide) prepared by hand tools.
- T_2 = Conventional tillage (CT), five ploughing and four laddering: The land was opened first by ploughing twice with a country plough followed by two laddering; then tilled with a power tiller thrice followed by two laddering. The ploughing depth was 12-14 cm.
- T_3 = Deep tillage (DT), five ploughing and four laddering: The compact layer below 15 cm depth of the profile was broken with a disc tractor followed by two harrowing and then two laddering. Thereafter, tilled with a power tiller twice followed by two laddering. The ploughing depth was 20-22 cm.

Moisture Regimes

- I_1 = Irrigated: Two irrigation, one with 7.0 cm water 16 days after sowing (DAS) and another with 7.5 cm water 46 DAS were applied to the concerned plots on the basis of calculated ET using the modified Penman equation. During each irrigation total volume of water was measured by a long throat flume.

$I_2 =$ Rainfed: The rainfed plots received no irrigation. The rainfall data during the growing season was recorded. No rainfall occurred during the wheat growing period.

3.8.2. Experimental procedure

Following the tillage treatments mentioned above, levees were constructed to make individual plots. Nitrogen fertilizer (urea) was applied in 2 splits to irrigated plots, $2/3^{rd}$ at land preparation and $1/3^{rd}$ at 1^{st} irrigation time while to rainfed plots the complete dose of N fertilizer was applied basally. All plots received basal doses of P, K, and S at the rate of 30, 33 and 20 kg/ha as triple super phosphate, muriate of potash and gypsum, respectively.

A modern wheat (*Triticum aestivum*) variety, Kaucham, with a growth duration of 100-105 days was used as the test crop. Seeds were treated with the fungicide Vitavax-200 at the rate of 3g/kg wheat before sowing to protect seedlings from different seed and soil born diseases. For all tillage levels seeds were broadcast on the same day into furrows made by hand tools 20 cm apart (line to line) at the rate of 130 kg seed/ha. The crop was kept weed free by hand weeding and protected from insect infestation by applying insecticide as and when required. Plants were thinned 25 and 40 DAS. The infiltration rate of soil was measured in all the tillage treated plots using a double ring infiltrometer and measuring in the fall in water depth with time by a point gauge exactly in the same way as in Experiment 4. The cumulative infiltration and intake rates were computed and plotted in graphs.

To estimate the depletion of soil profile moisture, field soil moisture content and bulk density were determined for each of the experimental plots during the wheat growing season. Soil samples were collected from every 15 cm depth segments upto 60 cm by using the core sampling technique at 15-day intervals. Moisture contents of the soil samples were determined by using the standard thermo-gravimetric method and soil moisture was calculated on weight basis (w/w). Moisture content on volume basis (Q_v) was estimated by multiplying the moisture content on weight basis with the corresponding bulk density (D_b) values and depth of water (cm) per 15 cm segment of soil was calculated. The changes in soil water content with time at a particular depth (0-60 cm) was recorded. The soil water depletion (difference in initial and final moisture content $\times S$) of each depth interval was thus calculated for the wheat growing period. Total water use by the wheat crop was calculated by

water balance equation as described by Turk and Hall (1980). Total water use = $IW + P + S - R - DP$ where, IW is the irrigation water, P is the precipitation, S is the difference in initial and final moisture (Qv) of the root zone (soil water depletion), R is the runoff and DP is the deep percolation. Runoff and deep percolation were assumed to be negligible in the present investigation during wheat growing period.

Water use efficiency was calculated on grain yield basis and expressed as the ratio of grain yield to water used. Root length density was determined up to 60 cm soil depth with segments of 10 cm at harvest. Root samples were collected from the center of each plot using 40 cm long and 10 cm diameter metal core. To obtain root samples, core sampler was driven in to the soil at desired site of a treatment where plants were standing and were then taken out. The shoots were cut from the ground surface. Each soil core was cut into 10 cm length and kept in a plastic bowl containing a solution of 5 percent sodium hexametaphosphate for 4-6 hours. After that, the roots were washed and root length was measured by using technique described by Newman (1966). The root length density was determined as the ratio of root length to volume of soil and expressed in cm cm^{-3} .

3.8.3. Data collected:

- A. Weather data: Rainfall data were collected from the weather report section of Plant Physiology Division, BRRI, Gazipur.
- B. Soil parameters: Infiltration rate, cumulative infiltration and, moisture content and bulk density for soil moisture depletion.
- C. Growth parameters and yield components: Root length density, plant height, number of tillers per m^2 and number of panicles per m^2 at harvest, number of filled grain per panicle, percent unfilled grains and weight of 1000 filled grains.
- D. Straw and grain yields.
- E. Water use efficiency

3.8.4. Statistical analysis:

Analysis of variance (ANOVA) as of RCB design was applied to all sets of collected data to test treatment variation. Mean comparison was done by DMRT and LSD (Gomez and

Gomez, 1984) at the 0.05 level of probability. ANOVA of all important data are presented in Appendix Table 10.1-10.8.

3.7. Soil and Plant Analytical Methods.

Standard analytical procedures followed by Soil Science Laboratory of Bangladesh Rice Research Institute were used to analyses the soil and plant samples. The analytical methods were selected considering the condition of experimental site. For example the soil pH was 6.9. For such an almost neutral soil the Olsen method of determining available P was considered most appropriate. The analytical methods are presented in table 2, 3 and 4.

Table 2. Analytical methods used for chemical analysis of soil

Determination	Methods	Reference
pH	Glass electrode (1:1 soil:H ₂ O ratio) pH meter	Peech (1965)
CEC	Ammonium acetate saturation followed by KCl extraction	Chapman (1965)
Organic carbon	Walkley – Black wet digestion	Allison (1965)
Organic matter	Walkley – Black wet digestion	Broadbent (1965)
Total Nitrogen	Micro-Kjeldahl distillation (Steam distillation Methods)	Bremner (1965)
Inorganic N (NH ₄ and NO ₃)	Micro-Kjeldahl distillation (Steam distillation Methods)	Bremner (1965)
Available Phosphorus	Olsen NaHCO ₃ method	Olsen and Dean (1965)
Exchangeable K	Extracted by 1 N neutral ammonium acetate and determined by atomic absorption spectrophotometer	Pratt (1965)

4. Results and Discussion

4.1. Experiment 1. **Effect of tillage and N levels on available NH_4 - and NO_3 -N in soil and on the growth, yield and N nutrition of wetland rice.**

4.1.1. Physico-chemical characteristics of soil

Changes in some physico-chemical characteristics of post harvest wetland rice soil due to tillage treatments are shown in Table 5. The pH, cation exchange capacity (CEC) and NH_4 and NO_3 -N of soil were higher under conventional tillage (CT) than those under reduced (RT) or zero tillage (ZT). Possible development of more continuous pores between the surface and sub surface under ZT may lead to more rapid passes of soluble nutrients deeper in to the soil profile than when soil is tilled, i. e. CT (Kay, 1990). Greater nitrate leaching and deep penetration of water and NO_3 – N through large pores in the no-tilled soil than that of tilled soil (Wells, 1984) may explain the findings of higher NO_3 – N content in CT compared to no tillage (NT) plot soil. On the other hand the organic C, available P and exchangeable K contents of soil were higher under zero till than those in tilled plots. Similar results were reported by other investigators (Lal *et al.*, 1990; Gordon and Rickerl, 1992; and Hargrove *et al.*, 1982). These changes in soil characters were attributed to a slower release of nutrients, ion-leaching, accumulation of organic residues and less disturbance of the plough layer under ZT or RT. The bulk density of post harvest soil at 40% moisture content was higher and the total porosity was lower in zero tilled plots than those in tilled plots. Similar results were reported by Hamblin (1987), Hallowang and Dexture (1991) and Yoshida *et al.* (1991). The other soil parameters were not markedly affected by tillage treatments.

Table 5. Changes in some physico-chemical characteristics of previously tillage treated wetland post rice soil.

Properties	Initial soil sample ¹	Post harvest sample ²		
		ZT	RT	CT
pH	6.89	6.80	6.85	6.92
CEC (cmol H/100 g soil)	27.90	27.43	27.85	28.10
Organic carbon (%)	1.05	1.17	1.06	1.04
Organic matter (%)	1.81	2.01	1.83	1.80
Total nitrogen (%)	0.08	0.08	0.08	0.08
NH ₄ -N (mg/kg soil)	8.26	7.42	7.68	7.75
NO ₃ -N (mg/kg soil)	1.95	1.88	1.92	2.12
Available P (mg/kg soil)	10.00	10.22	10.02	9.98
Exchangeable K (cmol H/100 gram soil)	0.26	0.28	0.26	0.24
Particle density (g/cm ³)	2.66	2.66	2.66	2.65
Bulk density (g/cm ³)	1.13	1.26	1.23	1.22
Total porosity (%)	57.5	52.6	53.50	54.00
Particle size analysis (%)				
Sand	11.80	11.81	11.79	11.76
Silt	44.40	44.42	44.42	44.44
Clay	43.80	43.77	43.79	43.80
Texture	Silty clay	Silty clay	Silty clay	Silty clay

¹Moisture content 51.5 %; ²Moisture content $\pm$ 40 %

4.1.2. Kinetics of $\text{NH}_4\text{-N}$

The kinetics of $\text{NH}_4\text{-N}$ in soil is presented in Fig.2 and Analysis of variance in Appendix Table 5.1 – 5.7. The $\text{NH}_4\text{-N}$ concentration at all N levels increased sharply at 15 DAT and the value remained almost unchanged up to 30 DAT and decreased thereafter up to maturity. The reduction was sharp from 30 to 60 DAT and then declined at a slower rate up to maturity. Application of N fertilizer significantly influenced the $\text{NH}_4\text{-N}$ concentration in soil. It increased with the increased rate of N fertilization. High $\text{NH}_4\text{-N}$ content was also maintained at higher N levels throughout the growing period. However, the difference narrowed down with time. Irrespective of N levels, tillage systems influenced the $\text{NH}_4\text{-N}$ content in soil at early growth stage (15 to 30 DAT) when increasing tillage intensity increased the $\text{NH}_4\text{-N}$ content, but with time the tillage effect became insignificant.

The higher concentration of $\text{NH}_4\text{-N}$ in soil at early growth stage of rice was due to a lower uptake of N by the young seedlings. The sharp reduction in $\text{NH}_4\text{-N}$ content from 30 to 60 DAT may be attributed to an increased uptake of $\text{NH}_4\text{-N}$ by the vigorously growing plants, gaseous losses of NH_3 and mineralization of NH_4 by soil microorganisms. Other investigators also reported similar findings (Sarker *et al.*, 1991; Bhardwaj and Sing, 1992; and George *et al.*, 1993). Slower N mineralization and more denitrification in zero or reduced tillage may have been responsible for the lower $\text{NH}_4\text{-N}$ concentration in ZT or RT plots at early growth stage. Rice and Smith (1992) and Gordon and Rickerl (1992) also observed lower $\text{NH}_4\text{-N}$ concentration in soil under ZT or RT.

4.1.3. Kinetics of $\text{NO}_3\text{-N}$

The changes in $\text{NO}_3\text{-N}$ content in soil at different growth stages of rice are shown in Fig. 2 and ANOVA in Appendix Table 5.8 – 5.14. The $\text{NO}_3\text{-N}$ content in soil was quite low varying from 0.52 to 2.10 ppm during the growing period. Tillage treatment had little effect on soil $\text{NO}_3\text{-N}$ content. However, the increasing level of N application enhanced $\text{NO}_3\text{-N}$ content in soil and the trend was maintained throughout the growing period. It was observed that, irrespective of N level and tillage system the $\text{NO}_3\text{-N}$ content in soil decreased sharply between 0 to 15 DAT and remained almost unchanged upto 30 DAT and then increased between 30 to 60 DAT. With further advancement of growth period, $\text{NO}_3\text{-N}$ declined gradually upto 90 DAT and then again

increased with time. The initial decrease in $\text{NO}_3\text{-N}$ content was due to the anaerobic condition resulting

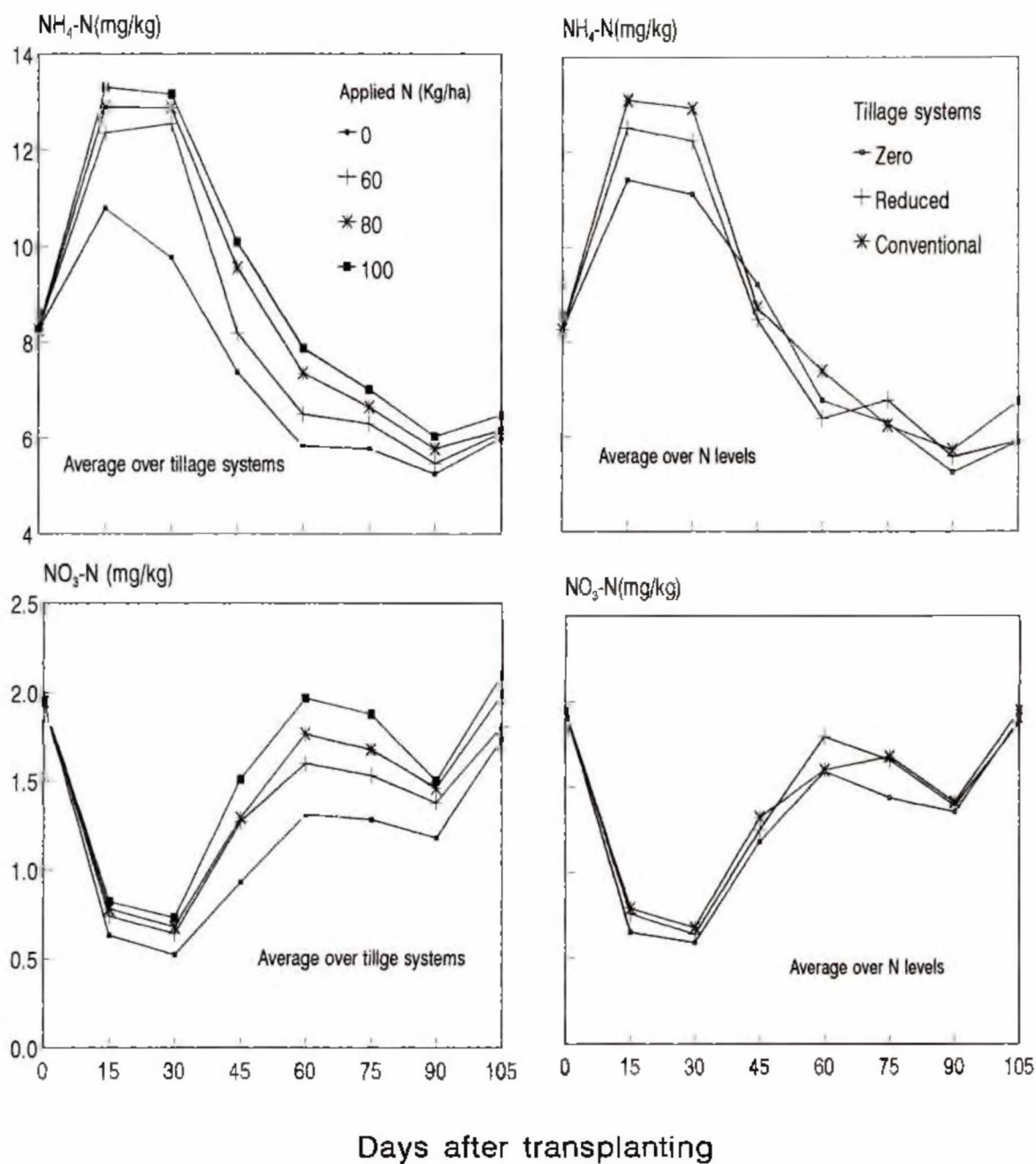


Fig.2. Effect of Tillage system and applied N levels on the kinetics of $\text{NH}_4\text{-N}$ and $\text{NO}_3\text{-N}$ in wet land rice soil(0-15cm)during T. Aman.

from the submergence of soil. Under a reducing condition, $\text{NO}_3\text{-N}$ existing in the soil was rapidly lost by denitrification. Some loss may also have occurred due to leaching. Moreover, the $\text{NH}_4\text{-N}$ formed due to mineralization could not be oxidized to $\text{NO}_3\text{-N}$ in the reducing environment. These results are in agreement with those reported by Sarker *et al.* (1993). The increase in $\text{NO}_3\text{-N}$ content from 30 to 60 DAT may be explained by the fact that the vigorously growing rice roots created an oxidizing atmosphere in the soil which permitted the oxidation of $\text{NH}_4\text{-N}$ to $\text{NO}_3\text{-N}$. The decrease in $\text{NO}_3\text{-N}$ from 60 DAT to 90 DAT was apparently due to the release of reducing substances accompanying oxygen depletion before Mn (IV) and Fe (III) oxides could mobilizes their buffer capacity (Ponnamperuma 1972). Besides, the uptake of $\text{NO}_3\text{-N}$ by the rice plants may also have contributed to the decrease in $\text{NO}_3\text{-N}$ content between 60 and 90 DAT.

4.1.4. Rice growth parameters

4.1.4.1. Plant height

Tillage and N interactions significantly influenced the rice plant height both at 5 weeks after transplanting (WT) and at maturity (Table 6a and Appendix Table 5.15 – 5.16). At 5 WT, plant height under zero (ZT) and conventional tillage (CT) increased with an increase in applied N up to 60 kg/ha level while under reduced tillage (RT) the increasing trend continued up to 80 kg/ha applied N. At maturity applied N at the rate of 60 kg/ha significantly increased plant height over no N treatment under any tillage system but no further increase was observed beyond this N level. Plant height increased with an increase in tillage intensity when N fertilizer was applied, but in the absence of N fertilization no effect of tillage was observed. Thus, puddling, i.e., high intensity tillage, appeared to increase the efficiency of N fertilizer in terms of plant growth.

Table 6a. Effect of tillage and N levels on plant height of rice (BR11) at different growth stages in T.Aman.

Applied N (kg/ha)	Plant height (cm)		
	Tillage system		
	Zero	Reduced	Conventional
<i>5 WT</i>			
0	52 b A	52 c A	50 b A
60	59 a AB	57 b B	60 a A
80	58 a A	60 a A	60 a A
100	57 a B	60 a A	60 a A
CV for main plot = 3.1% and CV for sub plot = 3.3%			
<i>Maturity</i>			
0	95 b A	97 b A	98 b A
60	105 a B	108 a AB	110 a A
80	104 a B	110 a A	110 a A
100	105 a B	110 a A	109 a AB
CV for main plot = 1.7% and CV for sub plot = 3.3%			

For each growth stage, in a column means followed by common small letter(s) and in a row means followed by common capital letter(s) do not differ significantly at 5% level by DMRT.

4.1.4.2. Tiller number

Tillage and N fertilization significantly influenced tiller production of rice (Table 6b and Appendix Table 5.17 – 5.18). Under similar tillage systems N fertilization significantly increased tiller production over the no N treatment. Under ZT and CT no difference in tiller production was observed among N levels while under RT 80 and 100 kg/ha applied N produced statistically similar numbers of tillers which were significantly higher than with 60 kg N/ha. Differences in tillage system did not

influence tiller production at 0 and 60 kg/ha applied N level while at the higher levels of N (80 and 100 kg/ha) the tiller number was higher in the puddled soil than that in the unpuddled soil. This was true at both 5 WT and maturity. These results indicated that the rice plants utilized fertilizer N more efficiently when the soil was puddled. Similar findings were reported by Ogunremi *et al.* (1986).

Table 6b. Effect of tillage system and N level on tiller production of BR11 rice at different growth stages in T.Aman.

Applied N (kg/ha)	Tiller no./m ²		
	Tillage system		
	Zero	Reduced	Conventional
<i>5 WT</i>			
0	198 b A	226 c A	211 b A
60	270 a A	296 b A	298 a A
80	272 a B	332 a A	305 a A
100	273 a B	338 a A	309 a A
CV for main plot = 15.1% and CV for sub plot = 3.2%			
<i>Maturity</i>			
0	170 b A	180 c A	177 b A
60	205 a A	212 b A	218 a A
80	204 a B	232 a A	228 a A
100	207 a B	232 a A	229 a A
CV for main plot = 6.4% and CV for sub plot = 4.8%			

For each growth stage, in a column means followed by common small letter(s) and in a row means followed by common capital letter(s) do not differ significantly at 5% level by DMRT.

4.1.4.3. Yield components

Application of N fertilizer significantly increased the panicle number irrespective of tillage treatment (Table 7 and Appendix Table 5.19). Panicle number increased with 60 kgN/ha without further increase beyond this N level with ZT and CT, but under RT, panicle number increased upto 80 kg N/ha. At zero and low N level (60 kg/ha), tillage treatment did not affect panicle number while at higher levels of N (80 and 100 kg/ha), RT produced higher number of panicles than with ZT or CT. Tillage system did not influence the number of spikelets per panicle but there was a significant positive effect of N fertilization (Table 7 and Appendix Table 5.20). Regardless of tillage system, application of 60 kg N/ha significantly increased the number of spikelets per panicle over N control, but further increase was not observed beyond this N level.

Tillage system and N fertilization significantly influenced the level of grain sterility in BR11 rice (Table 7 and Appendix Table 5.21). Nitrogen fertilization did not influence the sterility percentage under ZT, but under RT and CT, the increasing the N dose up to 80 kg/ha increased grain sterility percentage (Table. 6) .At zero and low N level (60kg/ha), tillage intensity had no significant effect on grain sterility percentage, but at the higher N levels (80 and 100 kg/ha),increasing level of tillage intensity increased grain sterility. According to Tanaka *et al.* (1964) two factors may determine the yield of rice plants; the total spikelet volume in which starch may accumulate and the amount of starch which actually accumulates in spikelets. The former generally is increased by N application, but the later does not necessarily increase with an increase in N level. This may be the reason of higher grain sterility percentage at higher N levels. Tillage system and N level either singly or in combination had no significant effect on the weight of 1000 filled grains of BR11 rice (Table 7 and Appendix Table 5.22).

4.1.5. Grain and straw yields of rice

Tillage methods and applied N levels significantly affected the grain and straw yield of rice (Fig. 3 and Appendix Table 5.23 – 5.24). The grain and straw yield showed increased trend with increasing N dose with in tillage method. The grain yield response to N rate was quadratic at ZT and CT but linear at RT (Fig. 3.), while for straw yield quadratic response model gave the best fit under all tillage methods. The figure 3 and the Appendix Table 5.23

Table 7. Effect of tillage system and N level on yield components of rice (BR11) in T.Aman.

Applied N (kg/ha)	Tillage system			
	Zero	Reduced	Conventional	N-mean
<i>No. of panicle/m²</i>				
0	158 b A	162 c A	162 b A	161
60	183 a A	186 b A	193 a A	187
80	182 a B	206 a A	193 a AB	194
100	183 a B	214 a A	194 a B	197
CV for main plot = 4.6% and CV for sub plot = 5.8%				
<i>No. of grains/panicle</i>				
0	99	115	101	105 b
60	126	130	123	126 a
80	127	129	124	127 a
100	128	130	125	128 a
CV for main plot = 6.1% and CV for sub plot = 10%				
<i>Grains sterility percentage</i>				
0	28 a A	27 c A	26 b A	27
60	28 a A	28 bc A	27 b A	28
80	28 a B	29 ab AB	31 a A	29
100	29 a B	31 a AB	32 a A	31
CV for main plot = 5.7% and CV for sub plot = 4.6%				
<i>1000 filled grain weight (g)</i>				
0	23	22	22	22
60	23	22	23	23
80	23	22	23	23
100	23	23	23	23
CV for main plot = 4.1% and CV for sub plot = 2.5%				

For each parameter, in a column means followed by common small letter(s) and in a row means followed by common capital letter(s) do not differ significantly at 5% level by DMRT.

clearly indicates the interaction between tillage and N levels in case of grain yield and this interaction was due to linear response of N under RT. However, no interaction was observed between tillage and N rate in case of straw yield (Fig. 3).

Nitrogen fertilization increased grain and straw yield under all tillage systems. Under ZT and CT, N application of 60 kg/ha significantly increased grain yield over N control, but no appreciable yield increase was observed at higher N levels. However, with RT yield increase continued up to 100 kg N/ha. With moderate level of N, (60 and 80 kg/ha) grain yield was not influenced by tillage system, but with 0 N and high N (100 kg/ha), RT plots produced significantly higher grain yield than ZT plots and equaled CT plots. At all N levels, straw yield was similar under RT and CT, but this yield was remarkably higher than that obtained under ZT (Fig. 3).

The application of N fertilizer led to better nutrition of the rice crop throughout its growth period, enhancing vegetative growth, increasing the number of panicles per unit area and spikelets per panicle, finally resulting in increased grain and straw yields. A higher yield on tilled soil than on untilled soil when no N fertilizer was applied probably resulted from the release of more available N when the soil was tilled. A higher yield on tilled soil than on no-tilled soil at a high rate (100 kg/ha) of N fertilizer suggests that a higher fertilizer N dose would be required on a no-till than on a tilled soil to obtain comparable yield. A higher yield increase (Table 8) due to N fertilization under ZT (43-44%) in comparison with RT (24-42%) and CT (33-39%) indicates a decreased fertilizer effect in tilled soil. Applied N levels beyond 60 kg/ha did not remarkably increase the grain yield of rice with in ZT and CT, but at RT applied N appreciably increased the grain yield from 124% at 60 kg/ha N level to 142% at 100 kg/ha N level. It is assumed that when lower dose of N (60kg/ha) fertilizer was applied in RT, fertilizer granules are distributed deeper in to the soil and introduced to a larger volume of soil in comparison with ZT resulting the dilution effect of N fertilization. On the other hand, intensive tillage (CT) may have enhanced mineralization increasing soil N availability and decreasing the effect of applied N fertilizer than that of RT. These may explain the higher increasing rate in grain yield production under RT than those of ZT and CT with increasing level of N fertilizer beyond 60 kg/ha. Videonovic *et al.* (1986), and Nyborg and Malhi (1989) also reported reduced fertilizer N effect under more intense tillage.

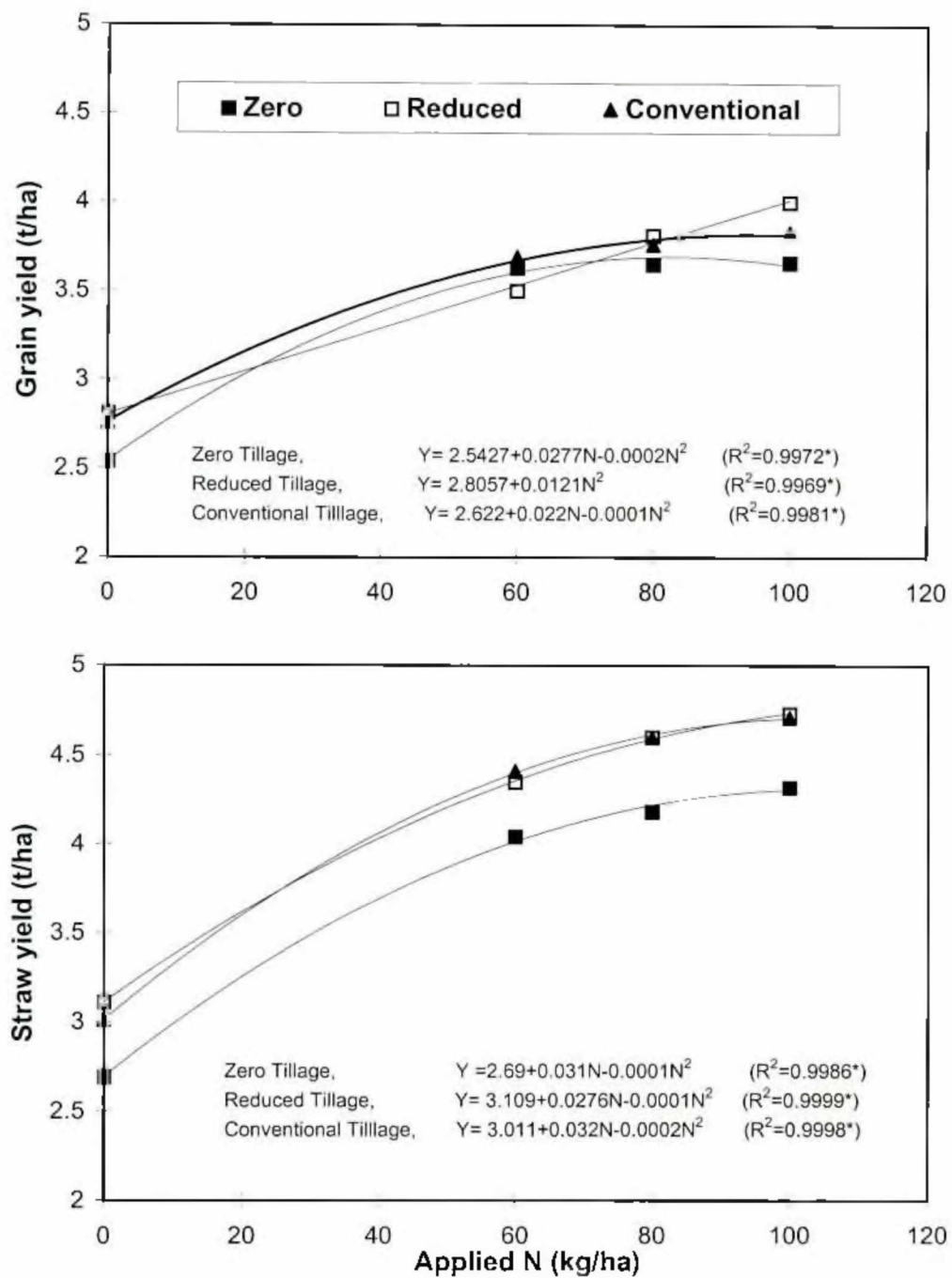


Fig 3. Fitted regression depicting the interaction between N rate and tillage systems on the grain and straw yield of T. Aman rice.

The increased number of panicles/m² and 1000 filled grain weight (Table 7) as well as the increased concentration of total N in shoot and grain (Table 9) and total N uptake (Fig. 4) of rice under RT than those of ZT and CT with increasing level of N may support the result. Contradictory results as to tillage effect on rice yield have been reported by different investigators.

Table 8. Grain yield increase (%) due to N fertilization under different tillage systems¹

Applied N (Kg/ha)	Grain yield increase due to N fertilization		
	ZT	RT	CT
60	143	124	133
80	143	135	136
100	144	142	139

1/ Grain yield at zero N = 100%

Some investigators reported similar rice grain yield under no-till, minimum till and conventional till systems (Mabbayad, 1968; De Data *et al.*, 1979; Rodriguez and Lal, 1979; Griffith *et al.*, 1986 and Lal, 1986), while others reported a higher grain yield of rice on puddled soil (Dayanand and Sing, 1980; De Data, 1981; Sharma and De Data, 1986). On the other hand Hamblin and Tennant (1979) reported increased grain yield under the reduced tillage system. Significant interactions between tillage and N in crop production were reported by Davis and Cannel (1975), Buchholz and Hanson (1982) and Lal (1986). According to them, zero tillage may require more N fertilizer for crop yields similar to those under tilled soil as observed in the present experiment.

4.1.6. Nitrogen nutrition of rice.

4.1.6.1. Nitrogen concentrations in shoot, straw and grain.

The N content of shoot varied from 1.60 - 2.32% and that of straw from 0.37 to 0.50%. Grain N content ranged from 0.91 to 1.13% (Table 9 and Appendix Table 5.25 – 5.27). The N content of shoot and grain was significantly influenced by tillage and N fertilizer

Table 9. Effect of tillage system and applied N level on the N content (%) of shoot, straw and grain of BR11 in T. Aman.

Applied N (kg/ha)	Tillage systems			
	Zero	Reduced	Conventional	N-mean
<i>Shoot (SWT).</i>				
0	1.60 b B	2.01 a A	2.00 a A	1.87
60	1.81 a B	2.05 a A	2.01 a A	1.96
80	2.12 a A	2.20 a A	2.14 a A	2.16
100	2.28 a A	2.32 a A	2.28 a A	2.29
CV for main plot = 12.2% and CV for sub plot = 9.1%				
<i>Straw</i>				
0	0.40	0.38	0.37	0.38 b
60	0.49	0.50	0.47	0.49 a
80	0.48	0.50	0.48	0.49 a
100	0.48	0.50	0.49	0.49 a
CV for main plot = 5.9% and CV for sub plot = 6.1%				
<i>Grain</i>				
0	0.94 b A	0.95 b A	0.91 c A	0.93
60	0.99 ab A	1.02 b A	1.04 b A	1.02
80	1.01 ab B	1.09 ab A	1.10 ab A	1.07
100	1.02 a B	1.11 a A	1.13 a A	1.09
CV for main plot = 3.4% and CV for sub plot = 5.0%				

For each parameter, in a column means followed by common small letter(s) and in a row means followed by common capital letter(s) do not differ significantly at 5% level by DMRT.

interactions while the straw N content was influenced by N fertilizer level only. Fertilizer N level had no effect on shoot N concentration under RT or CT, but under ZT the application of 60 kg N/ha significantly increased the N concentration. Increasing the N fertilizer dose beyond 60 kg/ha did not increase the shoot N content further. The N content of shoot in tilled plots was higher than that of shoot in no-tilled plots when N fertilizer was not applied or applied at a low rate (60 kg/ha). With a higher dose of N (80 or 100 kg/ha) tillage system did not affect the N concentration of shoot.

The straw N content was not influenced by tillage methods. Application of 60 kg N/ha significantly increased the straw N content over the zero N treatment irrespective of tillage system, but no further increase was observed at the higher N rates. Nitrogen fertilization increased the N content in grain under all tillage systems. At zero or low N level (60 kg/ha), tillage systems did not affect the grain N content, while at the higher levels of applied N (80 or 100 kg/ha), increasing the intensity of tillage increased the grain N concentration.

Increased N concentration in shoot, straw and grain of crops with application of N fertilizer up to a certain level were also reported by other investigators (Locke and Hons, 1982 and Bhardwaj and Singh, 1992). A higher N concentration in the rice plant grown on puddled soil was also reported by Syarifuddin and Zandstra (1978). The observed low N accumulation in the rice plant under a no-tillage system supported the contention that N is less available in no-tillage soils (Locke and Hons, 1988).

4.1.6.2. Nitrogen uptake and N use efficiency

At zero or low level of N fertilization (60 kg/ha) tillage method had no effect on the total N uptake of rice while at a higher level of applied N (80 or 100 kg/ha) the rice plants from tilled plots absorbed significantly higher amount of N than no-till plots (Fig.4 and Appendix Table 5.28). Nitrogen fertilization significantly increased the N uptake of rice over N control plots irrespective of tillage system. However, N uptake increases with increasing N dose varied with tillage system. Under ZT, the application of 60 kg N/ha significantly increased the total N uptake over N control, but no additional increase was observed with higher N doses, while under RT and CT, N uptake increased with increasing level of N up to 100 and 80 kg /ha, respectively.

Better vegetative growth coupled with increased dry matter yield and higher N content in rice tissue on N fertilized soil compared with the plots receiving no fertilizer N may explain

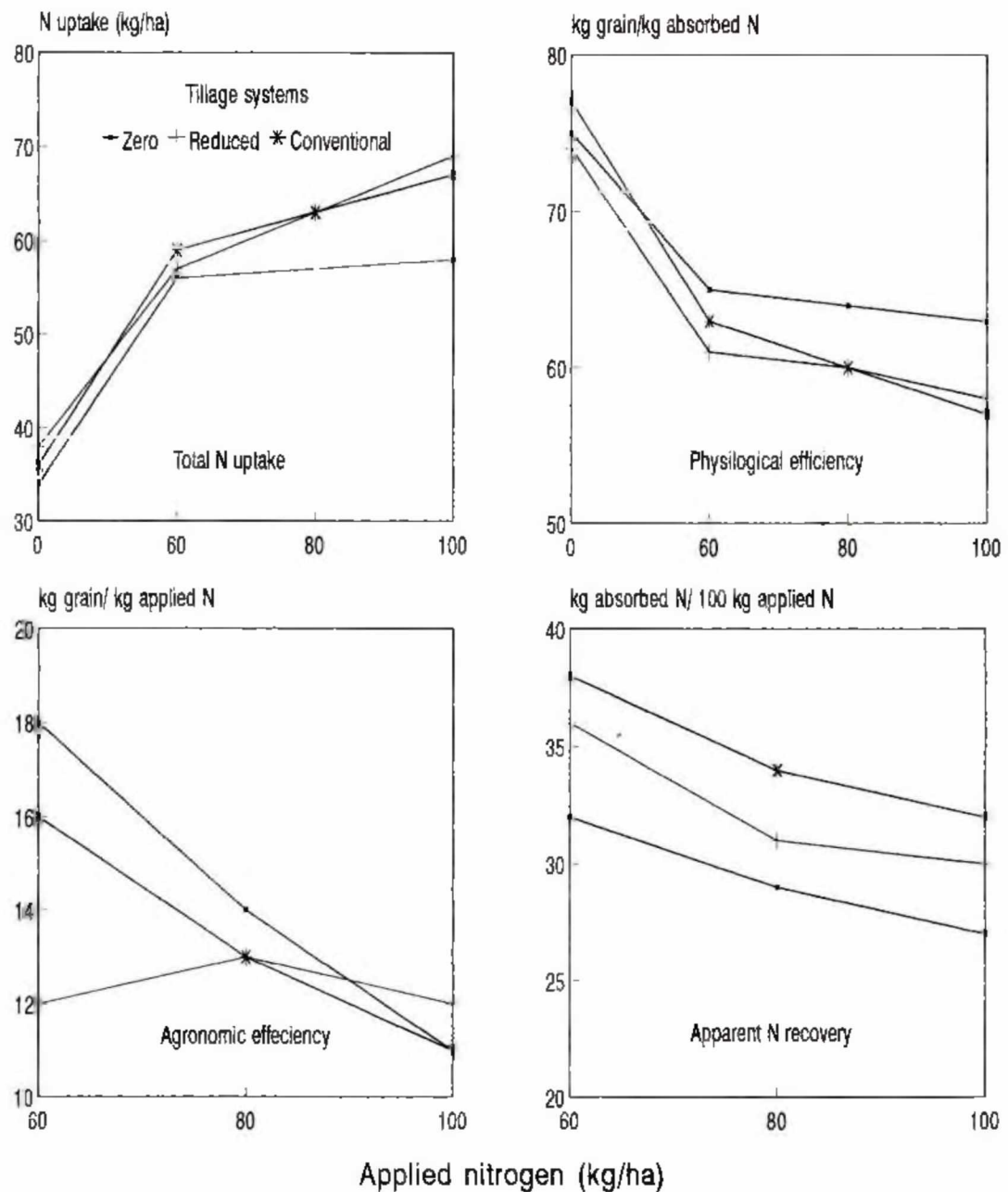


Fig. 4. Effect of tillage systems and nitrogen levels and their interactions on total nitrogen uptake, percent recovery and use efficiency in T. Aman.

the higher N uptake of rice on N fertilized soil under all tillage systems. Similar results were reported by Gordon and Rickerl 1992. A higher N accumulation in rice in tilled soil than in no-till soil at higher N levels, indicated a possible limitation in N availability in no-till soils as suggested by Syarifuddin and Zandstra 1979 and Ogunremi *et al.* 1986.

The effect of tillage and N fertilizer interaction were found significant on the agronomic efficiency of fertilizer N i.e. kg grain produced per kg N applied. Increasing dose of N decreased the agronomic efficiency of N fertilizer under ZT or CT, but this was not true in case of RT (Fig.4 and Appendix Table 5.29). Irrespective of tillage system, increasing N dose decreased the efficiency of N utilization i.e., physiological efficiency (kg grain produced per kg absorbed N). This efficiency was higher under ZT than that under RT or CT (Fig. 4 and Appendix Table 5.30). Tillage and N fertilizer dose individually influenced N recovery in rice. Irrespective of tillage system, increasing level of N fertilizer decreased the N recovery percentage which, however, reached a plateau beyond 80 kg/ha (Fig.4 and Appendix Table 5.31). On the other hand tillage intensity increased the N recovery percentage at any applied N level.

The decrease in N use efficiency with increasing level of N fertilizer has also been reported by Clarke *et al.* (1990). An increased efficiency of N utilization in terms of kg grain produced per kg absorbed N under ZT was also observed by Wells (1984), and may be attributed to a decreased total N uptake with no-till than with tilled soil

4.2. Experiment 2. Effect of irrigation and N levels on soil physical properties and the growth, yield and mineral nutrition of rice.

4.2.1. Moisture regime

Figure 5 show the cumulative water from land preparation to maturity and water loss through evapotranspiration from transplanting to maturity. The cumulative water added was the sum total of estimated from water supplied by irrigation and that added from rainfall. Evapotranspiration (ET) was estimated by multiplying the potential evapotranspiration (ET_p) and crop coefficient (K_c) value as suggested by Karim and Akhand (1982). The continuous submergence (CS) treatment received a total of 891 mm water while 4 DW, 7 DW and 10 DW (i. e. 4, 7 and 10 days after disappearance of standing water) received 742, 696 and 628 mm of water respectively. Evaporation was the same for all treatment levels. The amounts of water supplied by irrigation were different for the different treatment levels, but the amount of rain water added from rain fall (160 mm) was the same for each treatment.

4.2.2. Development of moisture stress

For all irrigation treatments except CS, the point of disappearance of standing water was considered as the initiation of moisture stress situation. Such situation, referred as DW, was imposed 4 times during the crop growing period with different span of stress period Fig.6). While there was no moisture stress in CS, in the 4DW, 7DW and 10 DW there were 16, 28 and 40 stress days respectively at different growth stages of rice. In general, moisture stress during the growing period was relatively low at 10-20 cm soil depth compared with 0-10 cm soil depth (Fig.7) partly due to capillary rise of ground water and less soil water extraction by roots. Wind (1954) reported that under favorable circumstances in a heavy clay soil, a capillary rise of 3 to 4 mm per day is possible. Visual symptoms of moisture stress were not very evident in terms of leaf tip drying or leaf rolling. Nevertheless, the degree of soil cracking increased with increased moisture stress.

4.2.3. Soil moisture content, bulk density and porosity

Soil moisture content was determined gravimetrically (w/w), at two soil depths 4 times in each moisture stress cycle. The difference in soil moisture content among the water treatments were not appreciable in 1st cycle (32-42DAT) but the difference became distinct with time and

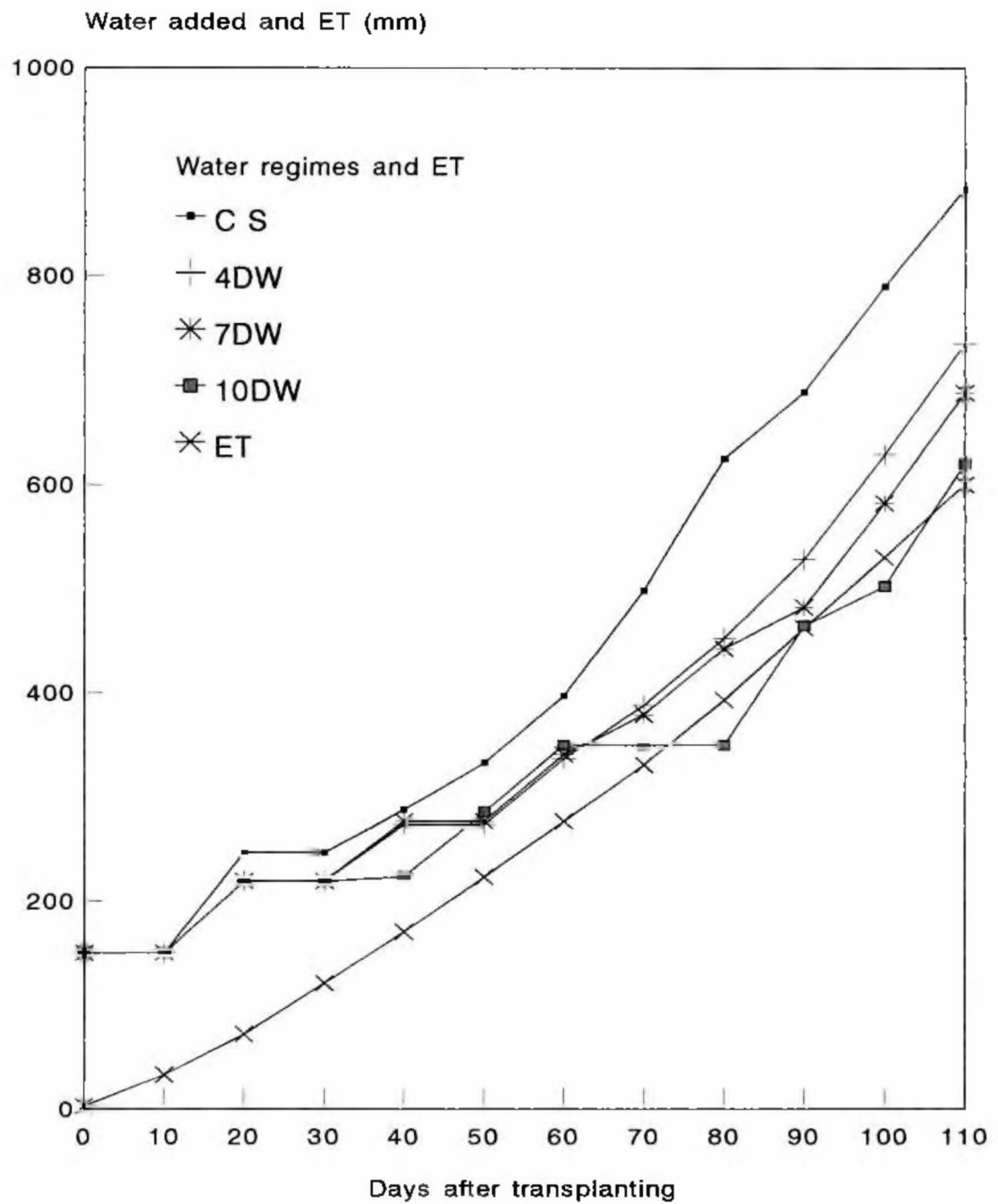
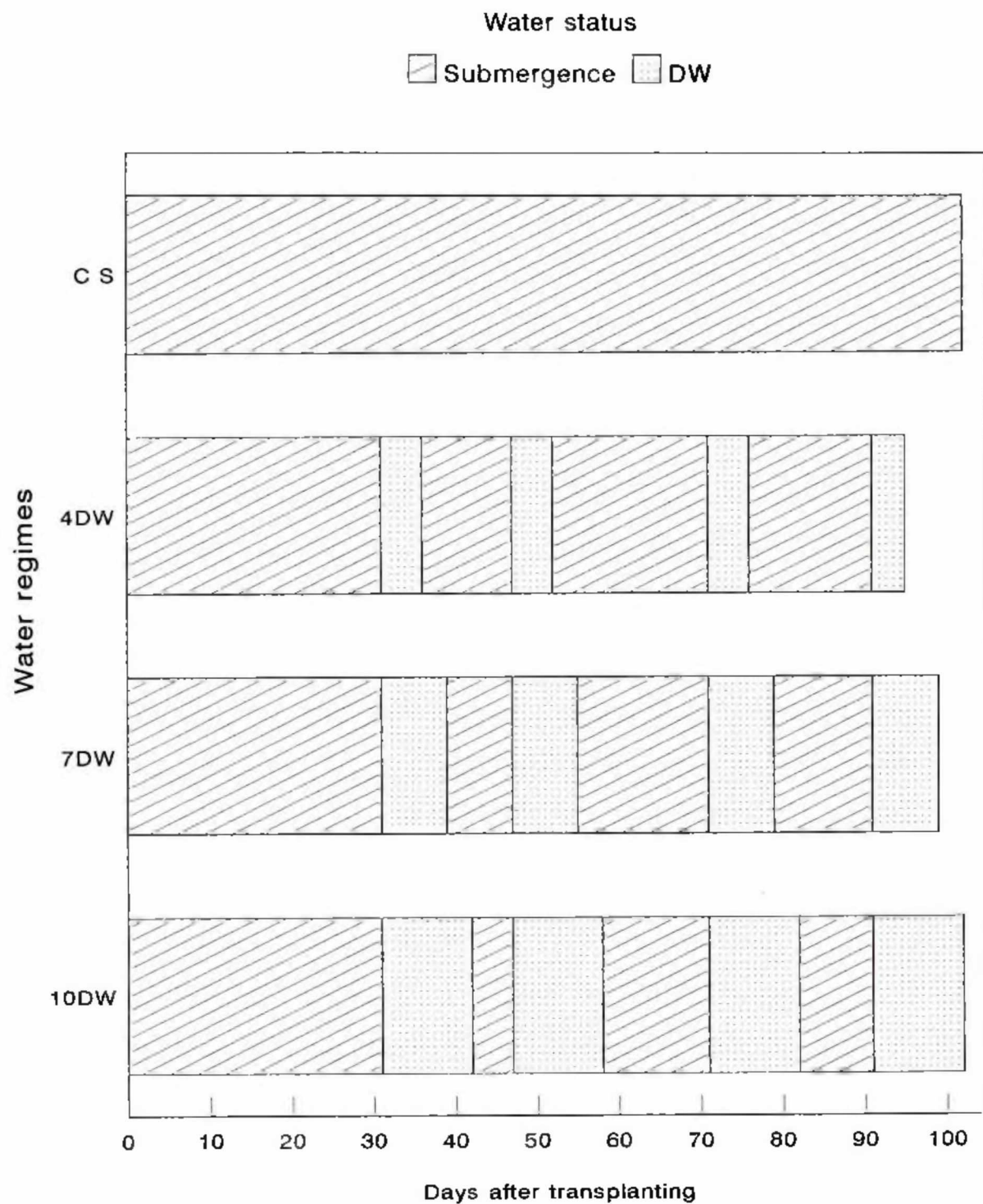


Fig. 5. Cumulative water added and evapotranspiration from land preparation to maturity of BR3 in Boro.



with an increase in the number of stress cycle (Fig.7) .The highest moisture content was recorded under CS throughout the growing season both at 0-10 and 10-20 cm soil depth (Fig. 7). An increase in the stress period decreased the moisture content in each drying and wetting cycle. Within the same treatment, increasing number of stress cycle decreased the soil moisture content, and the decrease was more marked at 0-10 cm soil depth.

The changes in soil moisture content under different moisture regimes were much lower at 10-20 cm soil depth than those at 0-10 cm soil. Compared with 10-20 cm soil depth, the top 0-10 cm soil had a higher moisture content throughout the growing period under saturated condition. On the other hand, under moisture stress condition, the top 0-10 cm soil had a lower moisture content than that at 10-20 cm depth during the 3rd (72-82 DAT) and 4th (92-102 DAT) stress cycles partly due to capillary rise from water Table and less soil water extraction by roots. Reflooding after each moisture stress cycle increased the moisture content but not to the level of previous flooding indicating the hysteresis effect of the soil. According to Brady (1974), this phenomenon may be attributed to the entrapment of air as a soil is rewetted. This clogs some pores and prevents effective contact between others. Also soil colloids shrink as the soil dries and upon rewetting do not always give the same kind of pore configuration.

The bulk density of soil under CS remained almost unchanged throughout the growing period (0.96-1.10 g/cc) while under moisture stress the bulk density varied to a great extent (0.96-1.63 g/cc) under different moisture regimes. Compared with CS, the soil under moisture stress treatment had a higher bulk density (Fig. 8). In general, re-flooding at the end of each moisture stress cycle under different Moisture regimes reduced the bulk density but not to the level of previous flooding. Similar findings were also reported by Aragon *et al.* (1990).The total porosity under CS was mostly unaffected during the growing season and the values were 64% at planting and 59% at maturity. Moisture stress, however, had a marked effect on porosity. From Fig. 8, it is clear that increasing stress period decreased porosity under different moisture regimes. Reflooding at the end of each moisture stress cycle increased the total porosity but not to the level of previous flooding.

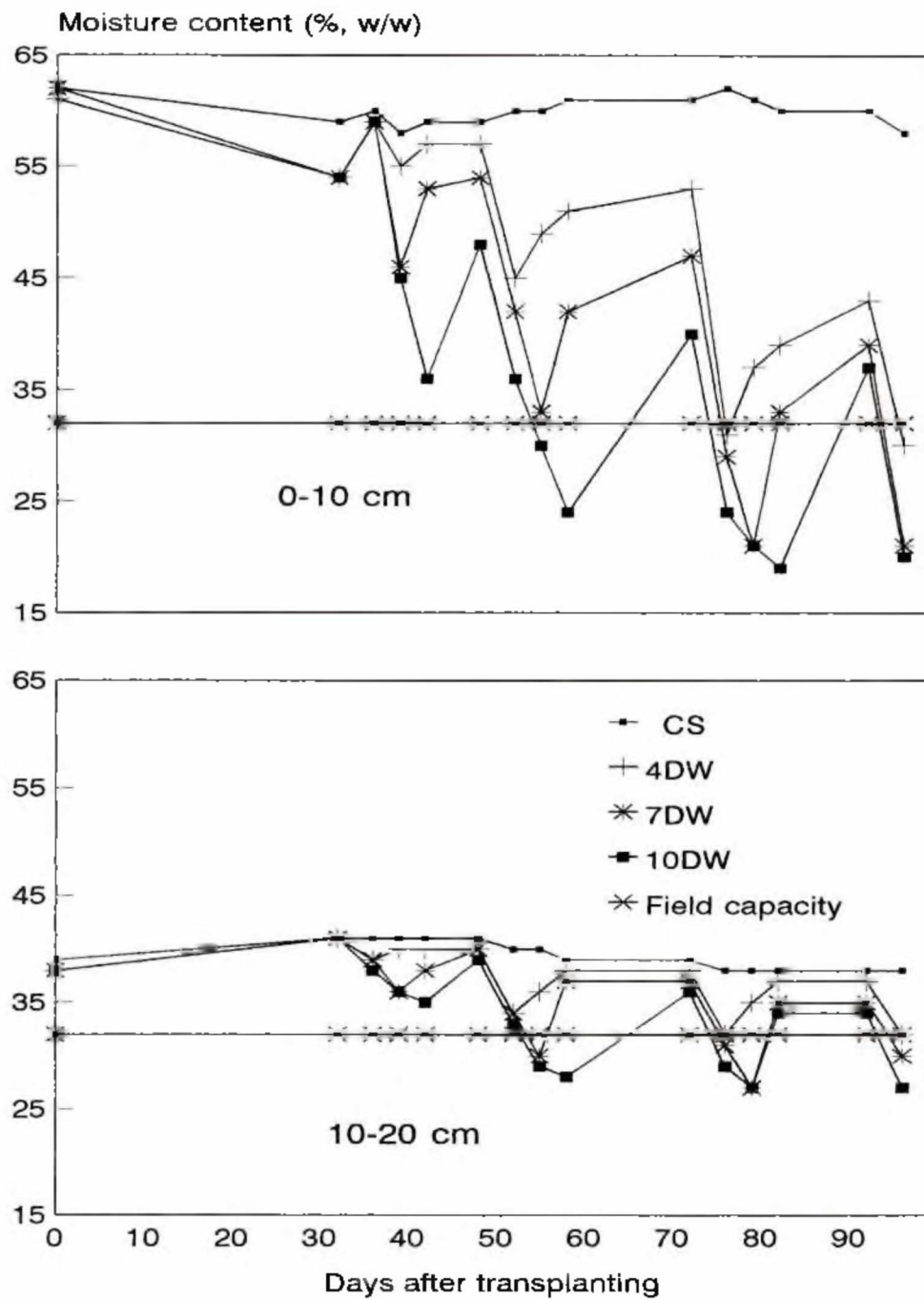


Fig. 7. Changes in soil moisture content at two soil depths with time as influenced by moisture regime during the growing period of BR3 in wetseason.

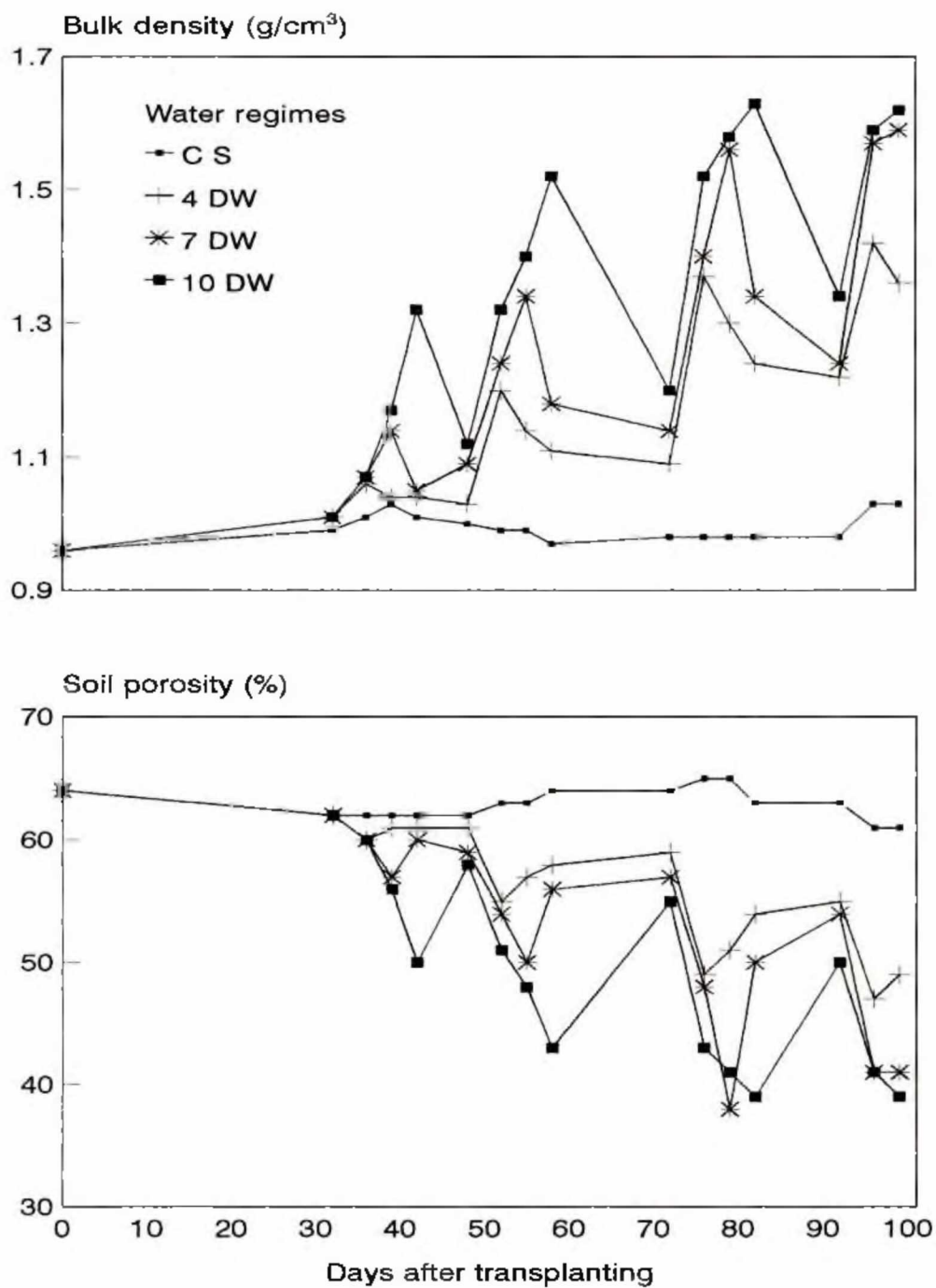


Fig. 8. Changes in soil bulk density and total porosity in 0-10 cm soil layer with time as influenced by moisture regimes during the growing period of BR3 in Boro.

4.2.4. Ammonium N in soil

The effects of moisture regimes and applied N levels on exchangeable $\text{NH}_4\text{-N}$ at 2 depths of the soil at the active tillering (45 DAT) and panicle initiation (65 DAT) stages of rice are shown in Fig. 9 and ANOVA in Appendix Table 6.1 – 6.4. Moisture regime and N level interaction effect on $\text{NH}_4\text{-N}$ content in soil was significant at 45 DAT while at 65 DAT the interaction effect was not significant at any soil depth. At 45 DAT the $\text{NH}_4\text{-N}$ in top 0-10 cm soil layer increased with increasing N dose and reached a plateau beyond 80 kg/ha applied N under 10 DW while under other moisture regimes the increasing trend continued up to 120 kg N/ha. On the other hand, in the 10-20 cm soil layer N fertilization did not affect the $\text{NH}_4\text{-N}$ content in soil under 10 DW while under other moisture stress treatments the $\text{NH}_4\text{-N}$ increased with increasing N dose. Bhardwaj and Sing (1992) also reported increased $\text{NH}_4\text{-N}$ with an increase in N level in rice soil.

Water deficit significantly reduced $\text{NH}_4\text{-N}$ in both soil layers at 45 DAT. In the top 0-10cm soil layer, water deficit period slightly affected the $\text{NH}_4\text{-N}$ content in soil under zero applied N but under 40, 80 or 120 kg N/ha the concentration of $\text{NH}_4\text{-N}$ were found to be in order $\text{CS} > 4 \text{ DW} > 7 \text{ DW} > 10 \text{ DW}$ (Fig. 9). In the 10-20 cm soil layer the $\text{NH}_4\text{-N}$ content was generally much lower than in the upper soil layer, but the treatment effects were found to be similar as those in the upper layer (Fig. 9). The effect of moisture stress in decreasing $\text{NH}_4\text{-N}$ content in soil in both layers was more pronounced under the highest level of applied N (120 kg/ha) followed by that under moderate (80 kg/ha) and low level (40 kg/ha). The effect was minimum under zero added N.

At 65 DAT, the $\text{NH}_4\text{-N}$ concentration in soil were much lower in the 0-10 cm layer than those at 45 DAT. The $\text{NH}_4\text{-N}$ content of soil at the 10-20 cm depth, however, appeared to have changed little during the period from 45 to 65 DAT (Fig. 9). The treatment effects in both soil layers were by and large similar at 45 DAT and 65 DAT. A negligible effect of moisture stress on the $\text{NH}_4\text{-N}$ content of soil at zero or low level (40 kg/ha) of applied N was also reported by Sahrwat (1983). Perhaps soil drying compensated for small N losses that occurred because of nitrification-denitrification by enhanced mineralization. A decrease in $\text{NH}_4\text{-N}$ due to wet-dry cycles compared with continuous submergence was observed by other investigators (Sarker *et al.*, 1991; George *et al.*, 1993; and Buresh *et al.*, 1993). The decrease in soil $\text{NH}_4\text{-N}$ due to soil drying probably resulted from increased nitrification. According Buresh *et al.*

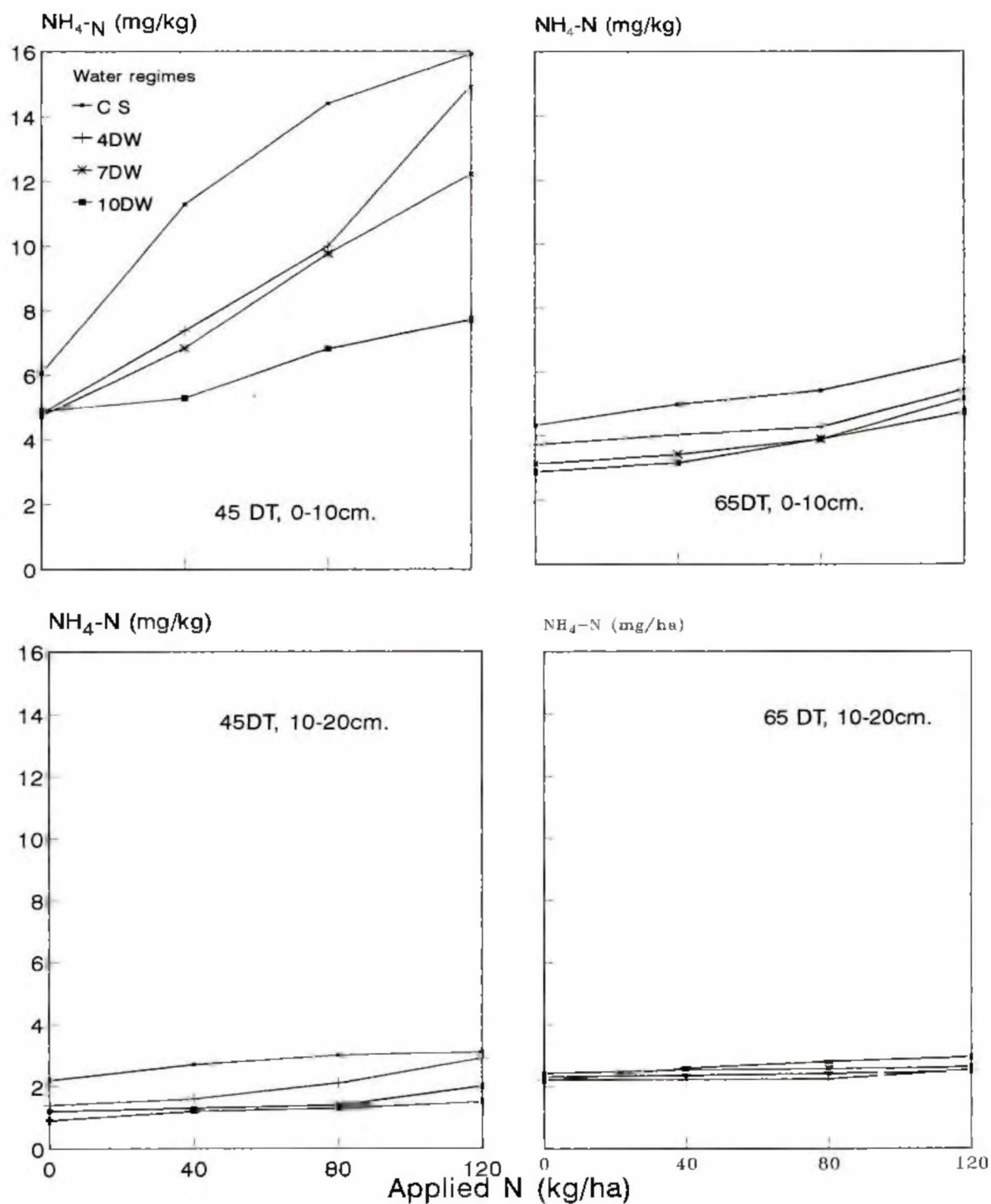


Fig. 9. Effect of water regime and applied N level on $\text{NH}_4\text{-N}$ concentration at two soil depths at the active tillering and panicle initiation stages of BR3 in Boro.

(1993), under aerobic conditions the $\text{NH}_4\text{-N}$ is oxidized to $\text{NO}_3\text{-N}$ and under anaerobic condition the resulting NO_3 is lost through denitrification. Soil NO_3 which accumulated during water deficit, rapidly disappeared after flooding. To the contrary, other scientists (Fillery and Vlek, 1982; IRRI, 1982; and Khind and Ponnampereuma, 1981) reported no effect of alternate drying and flooding on $\text{NH}_4\text{-N}$ content in soil.

The sharp reduction in $\text{NH}_4\text{-N}$ content at 65 DAT, may be attributed to : (i) increased uptake of $\text{NH}_4\text{-N}$ by the plants because of more active growth; (ii) increased transpiration correlated with nutrient uptake (O'Toole and Baldia, 1982); (iii) Gaseous losses of NH_3 or incorporation of $\text{NH}_4\text{-N}$ into microbial tissues (immobilization). Rapid increase in plant height (Table 10), Tiller number (Table 11) and water consumption in terms of evapotranspiration (Fig. 5) from 45 DAT to 65 DAT may support the results. Moreover, soil drying and subsequent flooding which occurred in the moisture stress treatments might also have increased N loss through the nitrification-denitrification process (Reddy and Patrick, 1975). Other investigators also reported the similar results (Sarker *et. al.*, 1991; Bhardwaj and Sing, 1992; and George *et. al.*, 1993).

4.2.5. Nitrate N

Compared with $\text{NH}_4\text{-N}$ concentration, the $\text{NO}_3\text{-N}$ concentration in both soil layers at all plant growth stages were negligible (Fig. 10 and Appendix Table 6.5 – 6.8). At 45DAT, moisture regimes or N treatment did not affect the $\text{NO}_3\text{-N}$ concentration in the top 0-10 cm soil layer, while in 10-20 cm soil layer, the $\text{NO}_3\text{-N}$ concentration decreased with soil moisture stress regardless of N treatment. At 65 DAT, $\text{NO}_3\text{-N}$ concentration in the top 0-10 cm soil layer increased with an increase in the N dose irrespective of moisture regime while in the lower soil layer moisture stress beyond 4 DW decreased $\text{NO}_3\text{-N}$ concentration in soil. In general, 10-20 cm soil layer had a higher soil $\text{NO}_3\text{-N}$ concentration than the top 0-10 cm soil layer at 65DAT. Soil drying followed by flooding might have moved some nitrate downward through the soil.

4.2.6. Rice plant growth and agronomic characteristics

4.2.6.1. Plant height

During the active tillering stage of rice, plant height was not affected by N treatment in 10 DW, while under the other moisture regimes plant height increased with an increase in the N

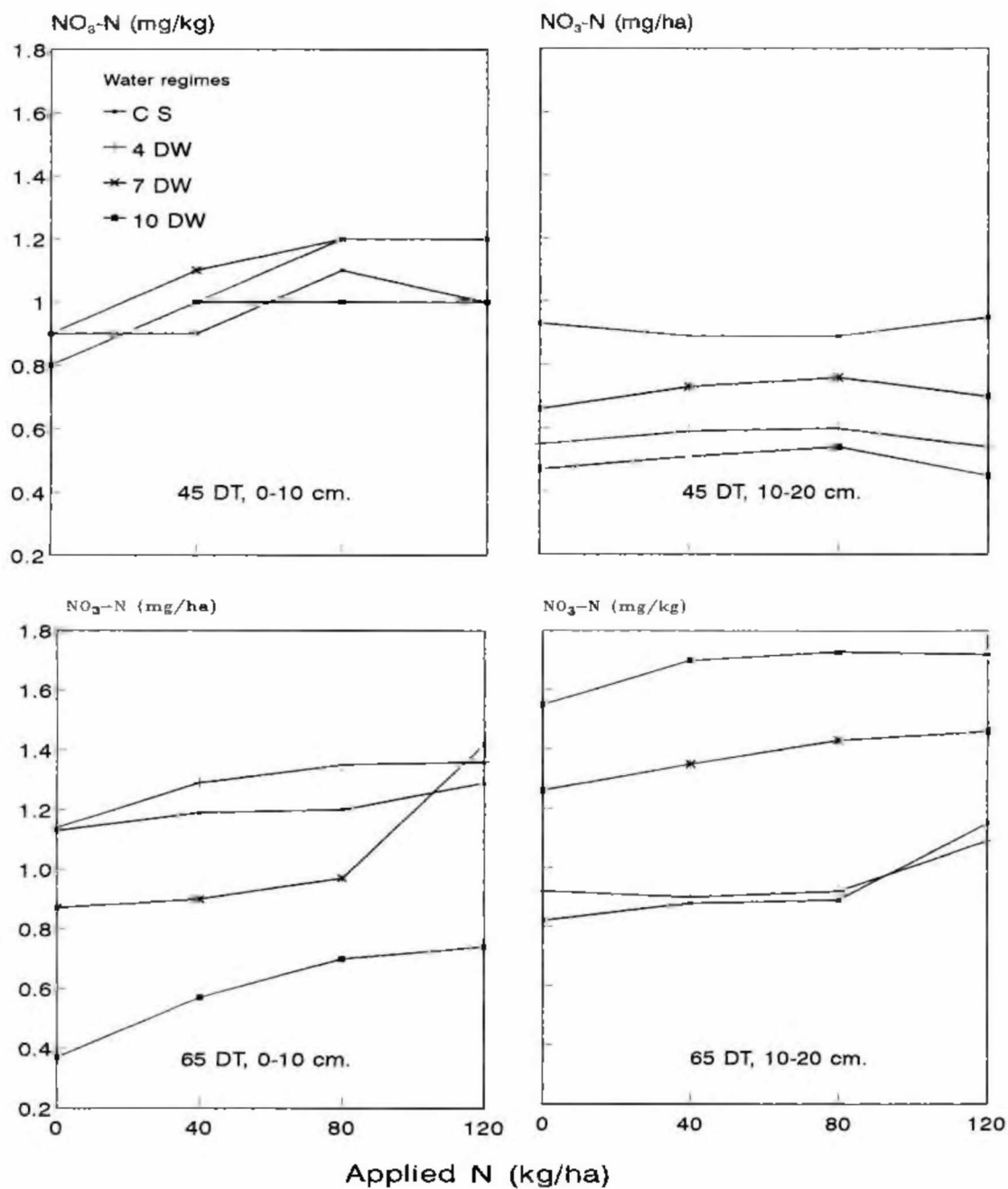


Fig.10. Effect of water regimes and N level on $\text{NO}_3\text{-N}$ concentration at two soil depth at vegetative and panicle initiation stages of BR3 in Boro season.

fertilizer dose (Table 10 and Appendix Table 6.9 – 6.11). Under CS, rice plants in plots receiving 80 or 120 kg N/ha were significantly taller than those in plots receiving 0 or 40 kg N/ha level, while under 4 or 7 DW, increasing doses of N fertilizer increased the plant height which reached a plateau beyond the 80 kg N/ha level. In general, the plants were taller under CS than under any other moisture regimes regardless of the applied N dose. The plant heights were statistically similar with the lower N doses (40 and 80 kg N/ha) but with 120 kg N/ha, increasing the length of the stress period decreased plant height significantly.

At the panicle initiation stage, the applied N increased plant height under all moisture regimes (Table 10). Increasing N upto 120 kg/ha increased plant height under moderate moisture stress (4 DW) while under other Moisture regimes applied N upto 80 kg/ha increased plant height which leveled off with a further increase in the N dose.

At maturity too, taller plants were observed in N treated plots irrespective of moisture regime (Table 10). Applied N upto 120 kg/ha increased plant height under CS, while under the other moisture regimes plant height increased with increasing N upto 80 kg/ha.. At the highest level of applied N (120 kg/ha), different moisture stress treatments produced plants of similar height which was significantly lower than that under CS, while at other N levels the tallest plants were observed with the 4DW and the shortest with 10 DW treatment.

4.2.6.2. Tiller production

Tiller production increased consistently from the active tillering to the panicle initiation stage, and then decreased at maturity (Table 11 and Appendix Table 6.12 – 6.14). The application of N increased tiller production. At the active tillering stage, tiller production under CS increased with applied N upto 80 kg/ha, while under other moisture regimes the trend continued upto the 120 kg N/ha level. At the panicle initiation stage, tiller production increased with increasing level of N upto 120 kg/ha under CS and mild moisture stress (4 DW) while under moderate and intense moisture stress (7 DW and 10 DW), the increasing trend continued upto 80kg N/ha. At maturity, the number of tillers per unit area was greater the higher the N dose was across the moisture regimes.

The effect of moisture stress on tiller production at a given N dose was generally not statistically significant (Table 11). However, a slightly increase in the number of tillers per unit area was mostly noticed with an increase in the intensity of stress.

Table 10. Effect of moisture regimes and N levels on the plant height (cm) of BR3 at different growth stages in Boro.

Applied N (kg/ha)	Moisture regimes			
	CS	4 DW	7 DW	10DW
<i>Active tillering stage (45 DAT)</i>				
0	29.5 b A	25.5 c C	26.3 c BC	27.3 aB
40	31.8 b A	28.3 b B	28.5 bc B	28.3 aB
80	35.3 a A	31.3 a B	31.3 a B	29.5 aB
120	34.8 a A	33.5 a B	30.5 ab C	27.5 aD
CV for main plot = 6.4% and CV for sub plot = 6.0%				
<i>Panicle initiation stage (65 DAT)</i>				
0	43.3 c A	38.8 d B	41.3 c AB	44.3 bA
40	48.3 b A	43.3 c B	46.5 b AB	44.8bAB
80	54.5 a A	52.0 b A	52.3 a A	50.5 aB
120	57.0 a AB	58.5 a A	54.3 a B	48.5 aC
CV for main plot = 6.4% and CV for sub plot = 5.0%				
<i>Maturity</i>				
0	75.0 c B	79.5 b A	72.0 b BC	70.8 bC
40	77.5 c AB	79.8 b A	74.8 b BC	73.8 bC
80	84.8 b AB	85.8 a A	82.8 a AB	87.8 aB
120	91.5 a A	84.8 a B	84.8 aB	84.8 aB
CV for main plot = 2.5% and CV for sub plot = 2.7%				

For each growth stage, means in a column followed by common small letter(s) and in a row followed by common capital letter(s) do not differ significantly at 5% level by DMRT.

Table 11. Effect of moisture regimes and N levels on tiller production of BR3 at different growth stages in Boro.

Applied N (kg/ha)	Moisture regimes			
	CS	4 DW	7 DW	10 DW
<i>Active tillering stage (45 DAT)</i>				
0	195 c B	201 d AB	198 d AB	223 d A
40	274 b A	260 c A	273 c A	251 c A
80	334 a A	317 b AB	337 b A	307 b B
120	344 a A	347 a A	365 a A	367 a A
CV for main plot = 1.2% and CV for sub plot = 3.5%				
<i>Panicle initiation stage (65 DAT)</i>				
0	222 d B	228 d B	235 c B	338 c A
40	330 c B	375 c AB	356 b AB	403 b A
80	401 b A	442 b A	441 a A	447 a A
120	488 a A	501 a A	475 a A	340 a B
CV for main plot = 16.4% and CV for sub plot = 8.0%				
<i>Maturity</i>				
0	195 d A	196 d A	193 d A	188 d A
40	223 c B	228 c B	228 c B	253 c A
80	273 b B	272 b B	275 b B	308 b A
120	319 a A	333 a A	317 a A	333 a A
CV for main plot = 5.8% and CV for sub plot = 3.8%				

For each growth stage, means in a column followed by common small letter(s) and in a row followed by common capital letter(s) do not differ significantly at 5% level by DMRT.

4.2.6.3. Root length density

The vertical distribution of roots of the mature rice plants in terms of root length is shown in Fig. 11 and ANOVA in Appendix Table 6.15 – 6.17. Regardless of moisture regime or N dose about 90% of the total root length was distributed in the 0 to 10cm soil layer. The roots did not grow very deep, but were still present at the 20-30 cm soil depth although very

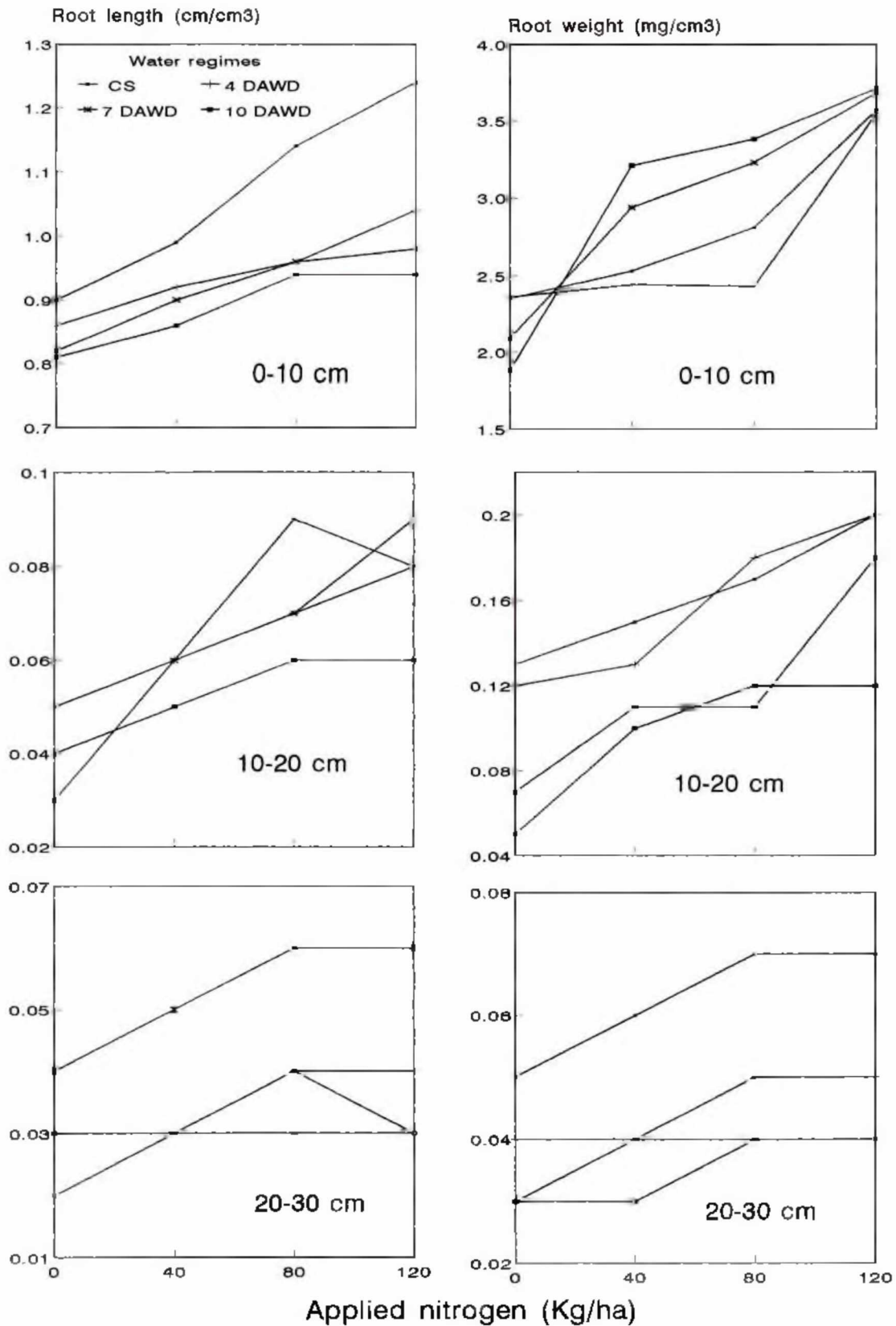


Fig. 11. Effect of water regimes and nitrogen levels on root length and root mass densities of BR3 in Boro at different soil depths.

minimally. The application of N increased the root length irrespective of moisture regime in the 0-10 and 10-20 cm soil layers, while in the 20-30 cm soil layer, no effect of either moisture regime or N level on the root length density was observed. Regardless of the N dose, the moisture stressed plots gave lower root length values than the CS plots. This was due to increased soil strength resulting from increased bulk density and decreased moisture content in the moisture stress plots (Fig. 8). In addition, root growth in stressed plots might have been adversely affected by decreased N efficiency due to alternate wetting and drying. Aragon *et al.* (1990) also reported similar results. Although the measurement of bulk density at the 0-10 cm depth would not tell about the existence of a hard pan in the soil, it is not impossible that such situation existed here. Nevertheless, the impact of higher bulk density at the surface soil of the moisture stressed plot is evident. However, clearer understanding on the existence of hard pan may be obtained from Experiment 5.

4.2.6.4. Root mass density

The distribution of root mass in the different soil layers is shown in Fig.11 and ANOVA in Appendix Table 6.18 – 6.20. Like root length density about 90-95% of the total root mass was found within the shallow depth of 0-10 cm with the remaining 5-10% root mass distributed in the deeper soil layers. In the 0-10 cm soil layer, under all moisture regimes, the application of N increased the root mass. The greatest root mass was observed with 120 kg N/ha and the smallest with zero N. The effect of moisture regime on root mass was not consistent for the different N levels. Without applied N, moisture stress decreased the root mass, but with 40 or 80 kg N/ha moisture stress imposed by the 10 DW treatment increased the root mass. On the otherhand, with the higher dose of applied N (120 kg/ha), moisture regimes had no influence on root mass density. In the 10-20 cm soil layer, the root mass increased with increasing level of N fertilization and decreased with moisture stress. Neither moisture regimes nor N dose affected the root mass density in the deeper (20-30 cm) soil layer. These results confirm the findings of Chamuah and Dey (1988).

4.2.6.5. Yield components

Increasing level of N fertilization 120 kg/ha increased the panicle number per unit area under all moisture regimes (Table 12 and Appendix Table 6.21). Moisture stress in general appeared to have a negligible effect on panicle production. The number of grains per panicle was unaffected by N fertilization upto 40 kg N/ha, but beyond this level, an increase in the number of grains per panicle was observed (Table 12 and Appendix Table 6.22). Irrespective of the N dose, moisture stress significantly decreased the number of grains per panicle. Under all moisture regimes, applied N increased the 1000 grain weight (Table 12 and Appendix Table 6.23). Under CS, increasing the N dose upto 120 kg/ha increased 1000 grain weight while under the other moisture regimes, 1000 grain weight reached a plateau beyond the 80kg N/ha level. In the absence of applied N, moisture regime did not affect the 1000 grain weight. Water deficit for 10 days (10 DW) decreased 1000 grain weight at 40 and 80 kg/ha applied N while at 120 kg N/ha, 1000 grain weight was decreased with an increase in length of the stress period beyond 4 days.

Nitrogen fertilizer did not influence the percentage of unfilled grains under the most intense moisture stress (10 DW). However, at other water treatments N application upto 40 kg/ha significantly decreased the sterility percentage, but no further decrease was observed with increasing N dose upto 120 kg/ha (Table 12 and Appendix Table 6.24). The higher 1000 grain weight and lower grain sterility under adequate to moderate soil moisture than under limited water supply may be attributed to greater photosynthesis and source-to-sink translocation of photosynthates under the former condition than under the later. Increased number of panicles per unit area, and grain per panicle, 1000 grain weight, decreased grain sterility with applied N, and decrease of number of grains per panicle and 1000 grain weight under moisture stress have also been reported by other investigators (Yoshida and Hayakawa, 1970; Aragon *et al.*, 1984). On the other hand, Aragon *et al.* (1990) found no significant interactions between N and water management in terms of plant height and tiller and panicle production of rice.

Table 12. Effect of moisture regimes and N level on the yield components of BR3 rice grown in Boro.

Applied N (kg/ha)	Moisture regimes				
	CS	4 DW	7 DW	10 DW	N-Mean
<i>No. of panicles/m²</i>					
0	186 d A	195 d A	183 d A	183 d A	186
40	224 c A	225 c A	224 c A	235 c A	227
80	263 b B	262 b B	265 b B	287 b A	269
120	305 a A	316 a A	303 a A	303 a A	307
CV for main plot = 8.7% and CV for sub plot = 3.6%					
<i>No of grains/panicle</i>					
0	76	74	69	68	72 c
40	79	77	74	74	76 c
80	88	80	83	79	82 b
120	93	89	84	85	88 a
W-mean	84 A	80 AB	77 B	76 B	79
CV for main plot = 8.7% and CV for sub plot = 8.5%					
<i>100 filed grain weight (g)</i>					
0	26.1 c A	26.1 b A	26.1 b A	25.5 c A	25.9
40	26.9 c A	27.3 b B	26.7 b AB	26.2 bc	26.7
80	28.4 b A	28.3 a A	27.5 a AB	26.8 ab B	28.0
120	29.3 a A	29.2 a A	27.9 a B	27.2 a B	28.4
CV for main plot = 2.8% and CV for sub plot = 2.2%					
<i>Unfilled grains (%)</i>					
0	26 a A	28 a A	25 a A	25 a A	26
40	21 b A	25 b A	21 b A	23 a A	22
80	20 b A	22 b A	21 b A	23 a A	22
120	20 b B	22 b AB	20 b B	25 a A	22
CV for main plot = 18.1% and CV for sub plot = 10.5%					

For each component, means in a column followed by common small letter(s) and in a row means followed by common capital letter(s) do not differ significantly at 5% level by DMRT.

4.2.7. Grain and straw yields of rice

Moisture regimes and applied N levels significantly affected the grain and straw yield of rice (Fig.12 and Appendix Table 6.25 – 6.26). The grain and straw yield showed increased trend with increasing N doses under all Moisture regimes. The grain yield response to N rate was quadratic (Fig.12), while for straw yield linear response model gave the best fit under all moisture regimes (Fig.12). The figure 12 and the Appendix Table 6.25 clearly indicates the interaction between moisture regimes and N doses incase of grain yield, and this interaction was due to increased yield gap with the increase of N rates among the moisture regimes. Incase of straw yield, the response of N were observed in two distinct groups of moisture regimes CS – 4DW and 7DW – 10DW where the yield gap was narrow within the group but wider between the group.

The application of N increased the grain yield of rice over the no N treatment under all moisture regimes (Fig. 12). Grain yield consistently increased with successive additional doses of applied N up to 120 kg/ha under all moisture regimes. With a given N treatment, there was generally a gradual decrease in grain yield with an increase in the length of the period of imposed water stress. With zero applied N, grain yield was statistically similar under CS and mild to moderate stress (4-7 DW), but this yield was significantly higher than that obtained under the most prolonged stress (10 DW). With 40 kg N/ha, increasing level of moisture stress from CS to 10 DW consistently decreased the grain yield, while with the higher doses of N (80 and 120 kg/ha) increasing level of moisture stress up to 7 DW decreased the grain yield, but prolonging the stress period to 10 DW did not result remarkable yield decrease. Like grain yield, N application also increased the straw yield under all Moisture regimes. In general, there was a gradually decreasing yield with increasing soil moisture stress under any given N dose.

The increased grain yield due to N application may be attributed to increased panicle number per unit area, number of grains per panicle and 1000 grain weight (Table 12). The adverse effect of moisture stress on total spikelets/panicle and 1000 grain weight may partially explain the reduction of grain yield due to moisture stress. A higher straw yield with increased N fertilization may be attributed to greater tillering. Similar findings were also reported by Saikia and Datta (1989); and Wahab and Daniel (1992).

Moisture regimes and N levels interaction shows that for the same yield level, less N was required in a more frequent moisture regimes compared with less frequent moisture regime.

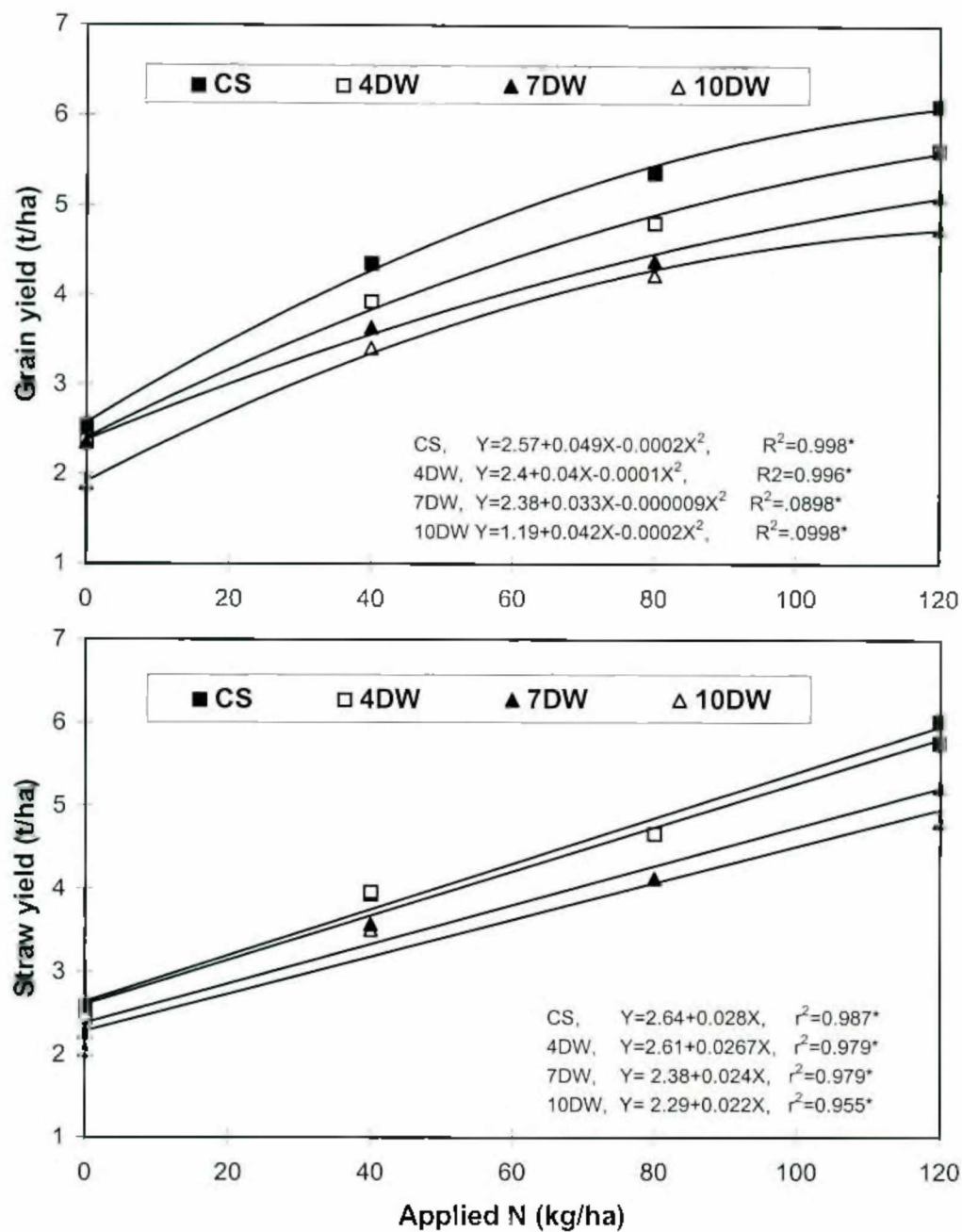


Fig 12. Fitted regression depicting the interaction between N rate and water regimes on grain and straw yield of T. Aman rice.

It is generally agreed that the relative response obtained from a given increment of N is related to the supply of moisture. A medium to high level of N fertilization aggravated the effects of moisture stress (Aragon *et al.* 1984). Severe water deficit may mask the benefits derived from additional N fertilizer which is beneficial under well watered condition. This may explain the observed consistent yield increase with successive additional doses of applied N under zero and lower soil moisture stress and the yield stagnation with higher dose of N under more intense soil moisture stress. Consistently increased grain yield with successive additional doses of N was reported by Dalai and Dixit (1987). A higher grain yield with higher level of N under continuous flooding or under a high soil moisture level was reported by Nageswara and Raju (1987) and Sheik Dawood *et al.* (1990), while Castillo *et al.* (1992) reported no significant interactions between N and moisture regimes on the grain yield of rice.

4.2.8. Mineral nutrition of rice

4.2.8.1. Nutrient concentrations

The maximum N concentration was found in shoot at 45 DAT and the minimum in straw (Table 13 and Appendix Table 6.27 – 6.30). The highest N concentration in shoot at 45DAT can be attributed to (i) high plant demand as a result of active root and shoot growth and concentration effect due to low dry matter. It is likely that N absorption by plants continued vigorously at this active vegetative stage. It may be recalled here that a relatively high $\text{NH}_4\text{-N}$ concentration in soil was observed at this growth stage (Fig.9).

An increase in the N dose increased the concentration of N in shoot at 45 DAT and in grain regardless of moisture regime (Table 13). According to Patrick and Reddy (1976), the application of fertilizer N establishes good crop growth and root system, which aids the extraction of larger proportions of soil N. The higher N concentration in shoot and grain with increasing level of applied N may also be related to a higher amount of available N in soil. The present results are in agreement with those of Locke and Hons (1988); and Bhardwaj and Sing (1992). Nitrogen concentration in shoot at 65DAT was significantly influenced by moisture regime and N interactions. Increasing level of N increased the N concentration and reached a plateau beyond 80 kg N/ha under the longest period treatment (10 DW), while under the other moisture regimes the increasing trend of N concentration continued upto 120 kg applied N/ha. With 80 kg N/ha, the shoot N content under 7 DW was significantly lower than that under 10 DW, while with other N levels the effect of moisture regime was not marked.

Table 13. Effect of moisture regimes and N levels on the N content (%) in the shoot, straw and grain of BR3 rice in Boro

Applied N (kg/ha)	Moisture regimes				
	CS	4 DW	7 DW	10 DW	N-Mean
<i>Shoot at 45 DAT</i>					
0	2.41	2.45	2.37	2.21	2.36 d
40	2.64	2.74	2.68	2.76	2.70 c
80	2.84	2.98	3.24	3.22	3.07 b
120	3.21	3.20	3.29	3.68	3.24 a
CV for main plot = 12.9% and CV for sub plot = 7.2%					
<i>Shoot at 65 DAT</i>					
0	1.38 d A	1.32 d A	1.33 d A	1.31 c A	1.33
40	1.69 c A	1.69 c A	1.63 c A	1.82 b A	1.71
80	1.96 b AB	2.02 b AB	1.88 b B	2.24 a A	2.03
120	2.25 a A	2.21 a A	2.29 a A	2.30 a A	2.26
CV for main plot = 14.4% and CV for sub plot = 5%					
<i>Straw</i>					
0	0.43	0.42	0.40	0.35	0.40
40	0.44	0.40	0.39	0.36	0.40
80	0.45	0.39	0.39	0.35	0.40
120	0.45	0.40	0.43	0.35	0.40
CV for main plot = 23.9% and CV for sub plot = 8.1%					
<i>Grains</i>					
0	0.79	0.76	0.81	0.79	0.79 b
40	0.79	0.77	0.82	0.82	0.80 b
80	0.78	0.79	0.84	0.84	0.81 ab
120	0.82	0.84	0.86	0.84	0.84 a
CV for main plot = 5.3% and CV for sub plot = 5%					

For a given plant part, column means followed by common small letter(s) and row means followed by common capital letter(s) do not differ significantly at 5% level by DMRT.

The P, K, Ca and Mg in straw and grain as affected by moisture regime and N levels are presented in Table 14 and ANOVA in Appendix Table 6.31 – 6.38. Regardless of N level, moderate to intense moisture stress (7-10 DW) decreased the P content both in straw and grain compared with CS and 4 DW. Tommer *et al.* (1992) reported similar results for mustard. The K content of straw was influenced by water and N interaction while Moisture regime alone influenced the grain K content. In general, the straw K content increased with increasing N dose under CS and mild to moderate moisture stress (4 to 7 DW), but decreased under the most severe stress (10 DW) treatment. On the otherhand, the straw K content increased with increasing severity of moisture stress with 0 and 40 kg N/ha, but with the higher N levels, reduction in the straw K content occurred as the moisture stress period increased from 7 to 10 days. In case of grain K content, consistent decrease was observed as the moisture stress period was increased from 0 (CS) to 10 days (10 DW), irrespective of the applied N level. Almost no effect of N application under any Moisture regime was observed in this regard. The Ca content of straw was not affected by N application under any Moisture regime, but with a given N dose, the straw Ca content tended to decrease with increasing severity of moisture stress (Table 14). To the contrary, the grain Ca content was clearly affected by both N dose and moisture regime. Under CS, the grain Ca content remained unaffected by N application, but when moisture stress of different intensities was imposed, an increase in the grain Ca content occurred with N application upto 80kg/ha and then a sharp decrease at 120 kg/ha was observed. With all applied N dose, the grain Ca content increased consistently as the moisture stress increased in severity.

The Mg content in straw tended to decrease with an increase in the N dose especially under moisture stress while that of grain remained unaffected by N fertilization (Table 14). Moisture stress increased the straw Mg content at lower N levels (0 or 40 kgN/ha), but with higher N doses moisture stress appeared to have no effect. The grain Mg content showed a decreasing tendency with increased moisture stress irrespective of the applied N level.

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Table 14. Effect of moisture regimes and N levels on P, K, Ca and Mg contents in straw and grain of BR3 in Boro.

Applied N (kg/ha)	Moisture regimes				Moisture regimes			
	CS	4 DW	7 DW	10 DW	CS	4 DW	7 DW	10 DW
<i>Phosphorus(%)</i>								
	Straw				Grain			
0	0.08	0.08	0.06	0.05	0.24	0.24	0.21	0.21
40	0.09	0.08	0.05	0.05	0.24	0.24	0.22	0.21
80	0.09	0.07	0.04	0.04	0.24	0.23	0.21	0.19
120	0.08	0.06	0.05	0.05	0.24	0.22	0.20	0.21
W mean	0.08 A	0.07 A	0.05 B	0.05 B	0.24 A	0.23 A	0.21 B	0.20 B
<i>Potassium(%)</i>								
0	1.88cC	2.04cBC	2.27bAB	2.62aA	0.25	0.20	0.21	0.20
40	2.03bcB	2.23bAB	2.44aA	2.51abA	0.25	0.21	0.20	0.18
80	2.15abB	2.37bAB	2.56 aA	2.43bAB	0.25	0.22	0.19	0.18
120	2.27 aA	2.56 aA	2.52 aA	2.45 abA	0.24	0.22	0.20	0.19
W mean	2.08	2.30	2.44	2.51	0.25 A	0.21 B	0.20 BC	0.19 C
<i>Calcium(%)</i>								
0	0.14	0.18	0.13	0.11	.013	.016	.019	.022
40	0.14	0.16	0.12	0.10	.013	.017	.020	.022
80	0.14	0.13	0.11	0.11	.013	.018	.021	.021
120	0.15	0.13	0.13	0.12	.013	.015	.015	.019
W mean	0.14 A	0.15 A	0.12 B	0.11 B	.013	.016	.018	.021
<i>Magnesium (%)</i>								
0	0.26	0.29	0.30	0.29	0.15	0.14	0.15	0.12
40	0.24	0.26	0.28	0.29	0.14	0.15	0.14	0.13
80	0.26	0.26	0.26	0.26	0.14	0.16	0.13	0.12
120	0.27	0.28	0.28	0.24	0.16	0.14	0.14	0.13
W mean	0.25	0.27	0.28	0.28	0.15 A	0.15 A	0.14 A	0.12 B

For each element, means in a column followed by common small letter(s) and row means followed by a common capital letter(s) do not differ significantly at 5% level by DMRT.

Table 15. Effect of moisture regimes and N levels on micronutrient contents in straw and grain of BR3 in Boro.

Applied N (kg/ha)	Moisture regimes				Moisture regimes			
	CS	4 DW	7 DW	10 DW	CS	4 DW	7 DW	10 DW
<i>Iron (ppm)</i>								
	Straw				Grain			
0	75	64	63	68	148	178	116	151
40	77	67	66	63	167	173	115	136
80	78	70	56	64	184	173	111	119
120	65	69	71	69	219	162	129	149
W mean	74	68	64	66	180A	171 AB	118 C	139BC
<i>Manganese(ppm)</i>								
0	313 aB	547 aA	546 aA	504 bA	39	55	57	50
40	343 aB	536 aA	546 aA	523 bA	40	55	59	49
80	367 aB	514 aA	536 bA	535 bA	42	54	59	48
120	326 aB	559 aA	556 aA	628 aA	40	60	55	58
W mean	337	539	546	547	40 B	56 A	58 A	51 A
<i>Zinc (ppm)</i>								
0	32	41	37	53 41b	15	15	14	14
40	38	42	39	51 42b	15	14	14	14
80	44	42	40	58 44ab	14	13	15	15
120	42	53	47	59 50a	16	14	15	15
<i>Copper (ppm)</i>								
0	2.6	6.2	3.8	6.5	3.5	7.5	5.7	9.7
40	3.0	5.9	4.3	6.4	3.9	7.9	6.4	9.5
80	3.4	5.5	4.8	6.2	4.4	8.2	7.2	9.3
120	3.8	6.9	5.1	6.8	3.6	8.1	7.2	10.3
W mean	3.2 C	6.1 AB	4.5 BC	6.5 A	3.8C	7.9 B	6.7 B	9.7 A

For each element, means in a column followed by common small letter(s) and in a row means followed by common capital letter(s) do not differ significantly at 5% level by DMRT.

The Fe, Mn, Zn and Cu concentrations in straw and grain as affected by moisture regimes and N levels and their interactions are shown in Table 15 and ANOVA in Appendix Table 6.39- 6.46. Moisture regimes and N levels either in singly or in combination had no effect on Fe content in straw while that in grain decreased with an increase in the moisture stress period regardless of the N level. The Mn contents in straw was influenced by moisture regime and N interactions. Under the most severe moisture stress (10 DW) applied N increased Mn concentration in straw while under the other moisture regimes the effect of N fertilization was found to be inconsistent. The straw Mn content was the lowest under CS with all given N dose. The straw Mn content increased with increasing moisture stress regardless of the N dose. The same was true for the grain Mn content. Applied N increased the Zn content in straw irrespective of moisture regimes. The grain Zn content was unaffected by N dose or moisture regime. The Cu content of both straw and grain increased substantially over CS with increasing moisture stress period. Copper is released into the soil solution on submergence (IRRI, 1973) but may decrease in concentration due to precipitation, not of CuS or Cu_2S as earlier believed but of cuprous ferrite $\text{Cu}_2\text{Fe}_2\text{O}_4$ (Lindsay, 1979) which may be the cause of increased Cu content in grain and straw with increasing water stress.

4.2.8.2. Nitrogen uptake and use efficiency

Figure 13 and Appendix Table 6.47 – 6.50 illustrate the effects of moisture regimes and N levels on the total N uptake and N use efficiency of rice. Increasing level of N application increased the N uptake under all moisture regimes. The highest N uptake was observed under CS regardless of the N dose. The total N uptake decreased consistently as the period of imposed moisture stress was prolonged. The influence of moisture stress on N uptake was found to be more prominent at a relatively high level of applied N (80 or 120 kg/ha) than at zero or low level N application. A higher N uptake under CS than that under some degree of moisture stress was due to the exploitation of a larger volume of soil by rice plants by virtue of stronger root growth in length and volume as well as due to higher grain and straw yields. A greater mobility of inorganic N in soil under CS facilitated easier absorption of N by the plant roots, whereas under moisture stress the plant roots probably had to spend more energy to extract a unit amount of N. Similar trends in rice were observed by Saikia and Datta (1989); and Sharma *et al.* (1992).

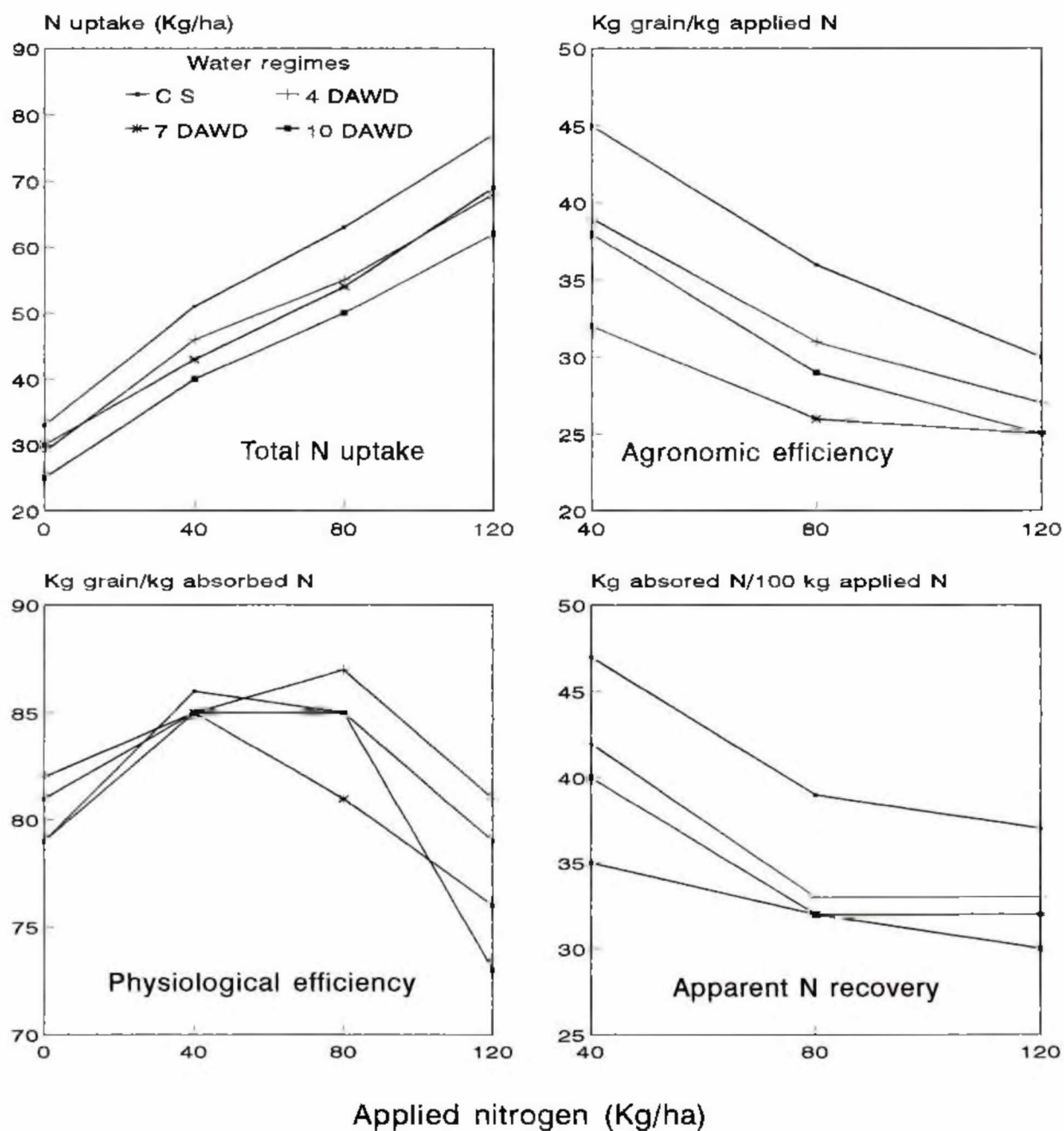


Fig. 13. Effect of water regimes and nitrogen levels on total N uptake, physiological and agronomic efficiency and apparent N recovery of BR3 in Boro.

The agronomic efficiency (kg grain produced per kg applied N), physiological efficiency (kg grain produced per kg N absorbed), and apparent plant recovery of applied N were significantly influenced by moisture regime and N fertilizer interactions (Fig. 13). Application of 40kg N/ha, increased the N use efficiency (physiological) over zero N under all moisture regimes. However, the efficiency value decreased with a further increase in the N dose except under 4DW where N use efficiency increased up to 80 kg/ha applied N and then decreased with a further increase in the N dose. The lowest physiological efficiency was recorded under severe moisture stress (10 DW) with 120 kg N/ha, and the highest under 4 DW with 80 kg N/ha.

Irrespective of moisture regime, the agronomic efficiency of N decreased with increasing level of applied N. For a given N dose, the agronomic efficiency of the applied N was the highest under CS (Fig. 13). Similar results have been reported by Clarke *et al.* (1990) and Gauer *et al.* (1992). The plant recovery of applied N, referred to as apparent N recovery and determined by the difference in plant accumulation of N at maturity between N fertilized and N control plots, significantly decreased as the N dose increased from 40 to 80kg/ha. However, no marked decrease occurred in going from 80 to 120 kg N/ha. This was true for all moisture regimes. For any given N dose, the apparent N recovery was the highest under CS, which decreased significantly under the mildest imposed moisture stress (4DW). Although prolonging the stress period from 4 to 7 days further reduced the plant recovery of applied N, the magnitudes of reduction were not as high.

4.3. Experiment 3. Effect of tillage on soil physical properties and on the yield and mineral nutrition of rice under irrigated and rainfed conditions.

4.3.1. Cumulative water added

Figure 14 show the cumulative water added from land preparation to maturity and water loss through evapotranspiration from transplanting to maturity. The cumulative water added was the sum total of estimated from water supplied by irrigation and that added from rainfall. Evapotranspiration (ET) was estimated by multiplying the potential evapotranspiration (ET_p) by crop co-efficient value as estimated by Karim and Akhand (1982). During land preparation all treatments received the same amount of water (100 mm) supplied by irrigation. During crop growing period no irrigation water was added to rainfed plots but at irrigated plots, 100 mm water was added by irrigation (Fig. 14). Rainfall was uniformly distributed over the growing season and the crop received a total of 535 mm rain water from transplanting to maturity out of which 533 mm was received within 80 DAT. Even during the critical reproductive stage of the crop, sufficient rainfall occurred, and the crop was doing very well. A total of 635 mm water was received by the rainfed and 735 mm by the irrigated plots. A total of 474 mm water was consumed in the process of evapotranspiration during the growing season.

4.3.2. Physical properties of soil

4.3.2.1. Percolation

Tillage practices influenced the percolation rate of the soil (Table 16). Puddling decreased the percolation rate and it decreased as of tillage intensity increased. The percolation rate of the soil was minimum in CT while the maximum percolation rate was recorded in ZT plots. Puddling eliminates large soil pores and, therefore, decreases the hydraulic conductivity of the soil (Sharma and De Datta, 1985). Compaction and shearing by farm implements may create a compact sub-surface zone often called "plough-pan" (Moormann and van Breeman, 1978). In addition, settling and consolidation of dispersed clay particles may occur (Sharma and De Datta, 1985 and Adachi, 1992). Both compaction and clay translocation may reduce the percolation

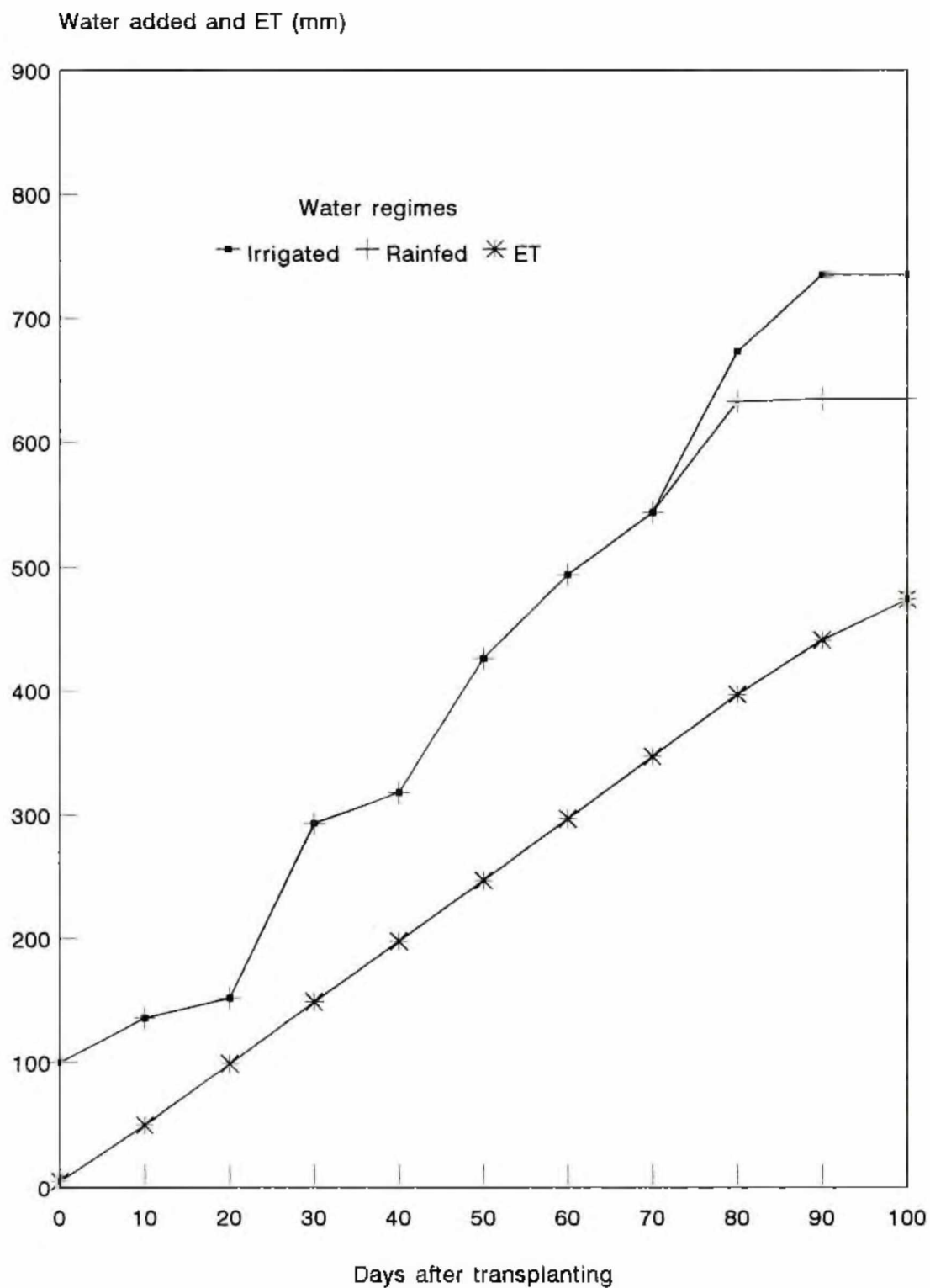


Fig. 14. Cumulative water added and evapotranpiration occurred (mm) under irrigated and rainfed conditions in T. Aman.



Plate 2. The author is measuring the height of water level in a double ring infiltrometer for percolation/infiltration during rice (top) and wheat (below) growing period.

rate in puddled soil. According to Toung *et al.* (1994) the sealing of macro pores with fine particles translocated during puddling predominantly caused formation of a semi-permeable layer just beneath the puddled top soil. This semi-permeable layer was mostly responsible for the low percolation rate of the well puddled soil. A reduction of percolation rate through puddling was also reported by Ossari (1988), Wopperics *et al.* (1992b) and Singh *et al.* (1993).

Table 16. Effect of tillage system on percolation rate of a silty clay soil during wet season.

Tillage systems	Depth of ponding water (cm)	No. of observations	Percolation rate (mm day ⁻¹)
Zero	5-7	26.00	1.89
Reduced	5-7	26.00	1.50
Conventional	5-7	26.00	1.27
LSD (.05)			0.16

4.3.2.2. Soil moisture content

The effects of tillage and moisture regime on soil moisture content (% w/w) of two soil layers during the growing period of T.Aman rice are shown in Fig 15. In the 0-10 cm soil layer the highest moisture content was recorded under conventional tillage (CT) followed by that under reduced tillage (RT) and that under zero tillage (ZT). This was true for both rainfed and irrigated conditions throughout growing season. A higher soil moisture content under CT than in RT or ZT was also reported by Sharma *et al.* (1988). Under any given tillage system, the soil moisture remained almost constant from transplanting to 75 DAT and thereafter declined sharply to less than the field capacity (FC) level by 100 DAT. This trend was also observed in the lower soil layer (10-20 cm) under both irrigated and rainfed conditions. In the deeper (10-20 cm) soil layer, the soil moisture content differed little among the tillage systems.

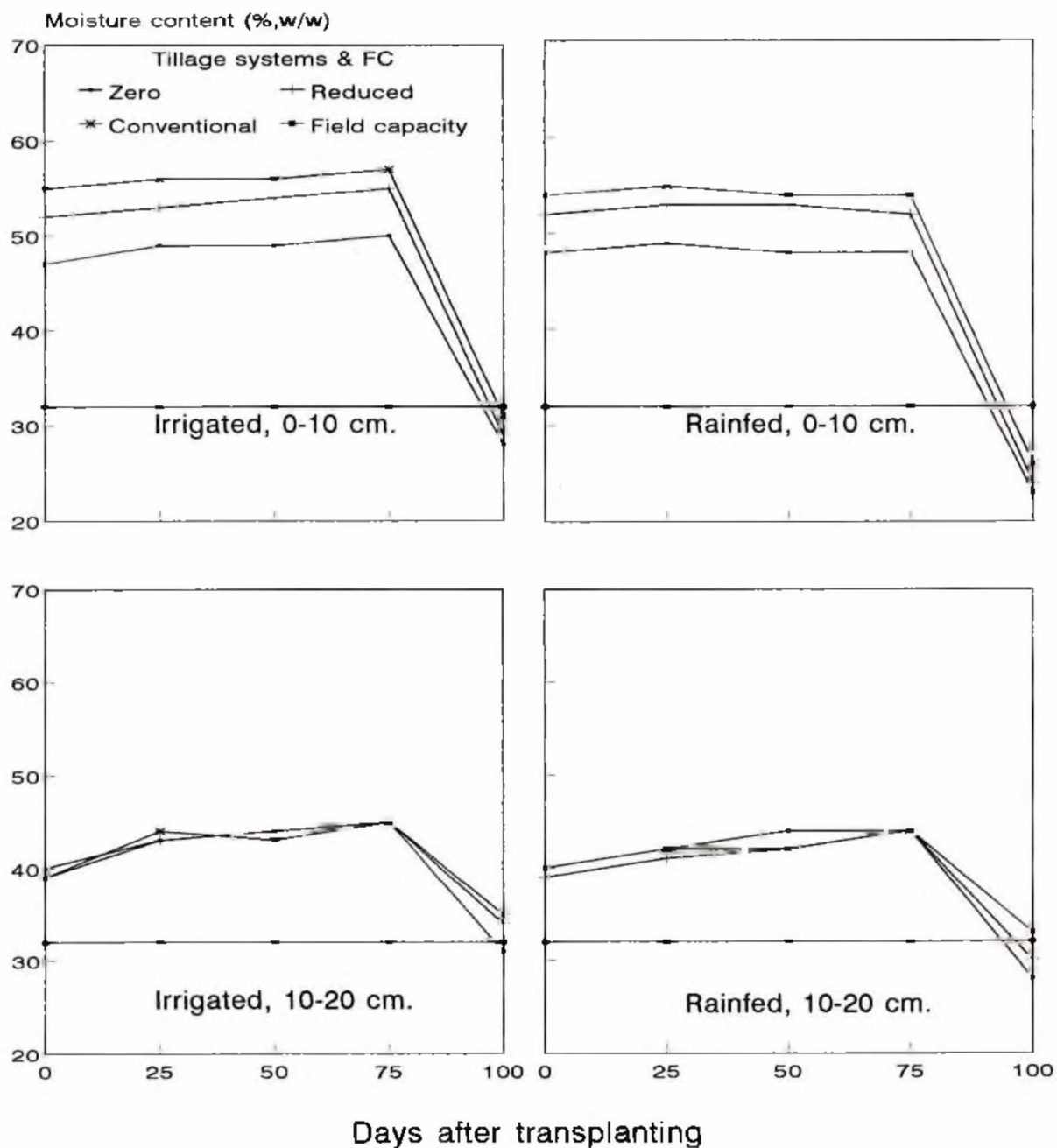


Fig. 15. Changes in soil moisture content with time at two soil depths under irrigated and rainfed conditions as influenced by tillage systems in T. Aman.

4.3.2.3. Bulk density

The effects of tillage and moisture regime on the bulk density (BD) of soil over time are shown in Fig 16. In the top 0-10cm soil layer, BD under RT was almost similar as that under CT but was lower than that under ZT in both irrigated and rainfed conditions. This was true for the period from transplanting to 75DAT. The soil BD in the top 0-10cm layer in both irrigated and rainfed conditions remained almost unchanged from transplanting to 75DAT, and then increased sharply at 100 DAT under dry condition. At this stages, the differences among tillage systems narrowed down to almost nil. This sharp increase in BD occurred due to a sharp decrease in soil moisture content (Fig. 15). In the 10-20 cm soil layer, tillage system affected BD very little in both irrigated and rainfed conditions. This may due to less disturbance of lower soil with tillage practices and similar soil moisture content among the tillage treated plots. Unlike in the top soil layer, BD in the 10-20 cm layer decreased initially sharply and then gradually during the period 0-75 DAT. Thereafter, like in the 0-10 cm layer, BD increased sharply until 100 DAT.

4.3.2.4. Moisture retention capacity

The effect of tillage (averaged over moisture regimes) on moisture retention capacity of soil in the top 0-10cm layer is shown in Fig 17. At any time the soil in puddled plots (CT) retained more water than did the soil under RT or ZT under all tension except 0 bar (saturation). Under 0 bar suction, the water retention was the highest with ZT. Moisture retention at all tensions decreased gradually with time. Mishra *et al.* (1991), showed that puddling decreased the hydraulic conductivity of soil. This might have been the cause of the relatively high moisture retention by the soil under CT (puddling) in the present experiment. As crop growth proceeded, the soil micropores were increasingly being sealed by the fine roots as well as by sediments deposited by the percolating. On the other hand, organic matter decomposition progressed leading to granular structure formation which enhanced macroporosity of soil (Naphade and Ghildayal, 1971). This increase in macroporosity increased soil hydraulic conductivity and infiltration rates which may

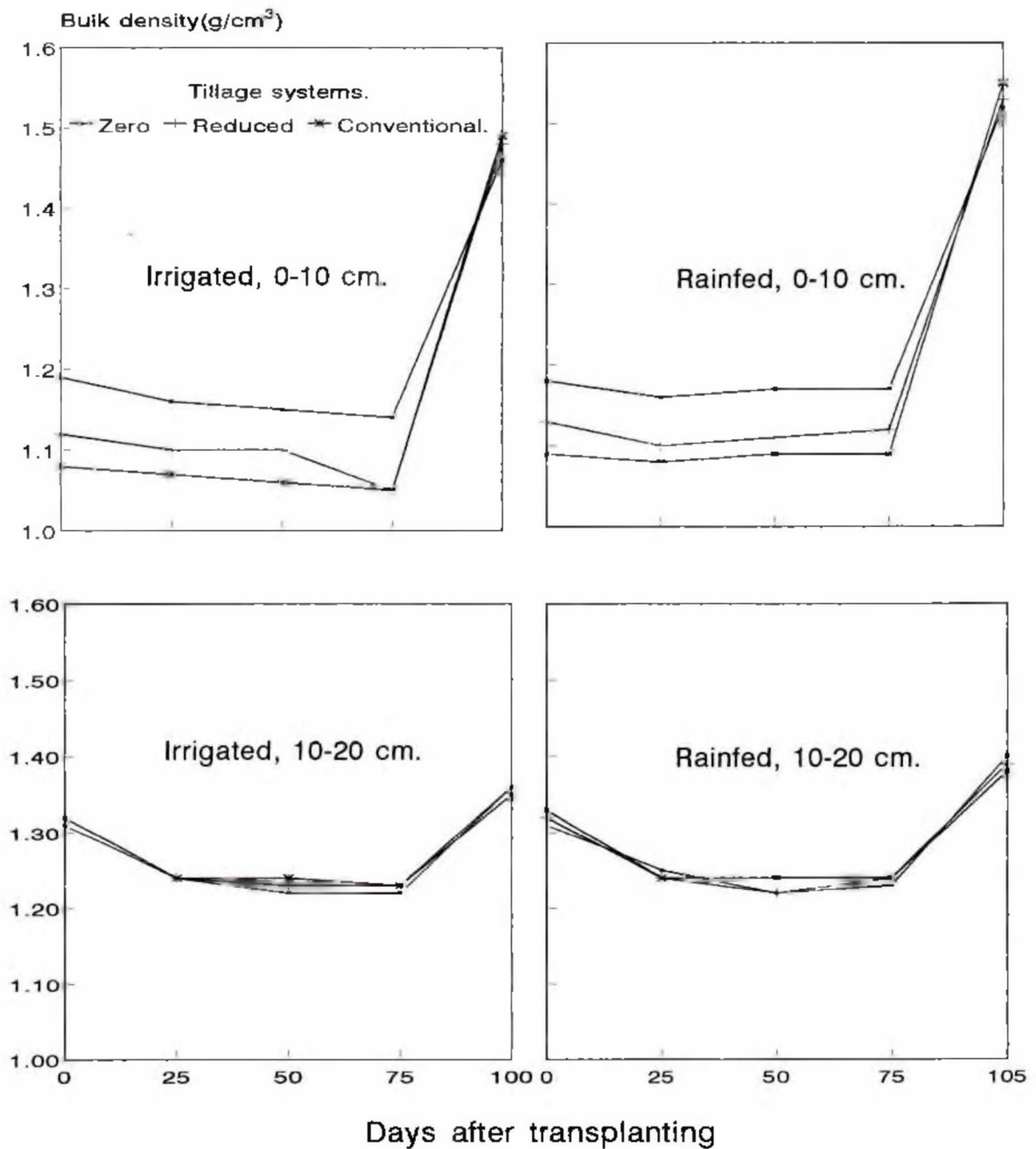


Fig. 16. Changes in soil bulk density with time at two soil depths under irrigated and rainfed conditions as influenced by tillage systems in T. Aman.

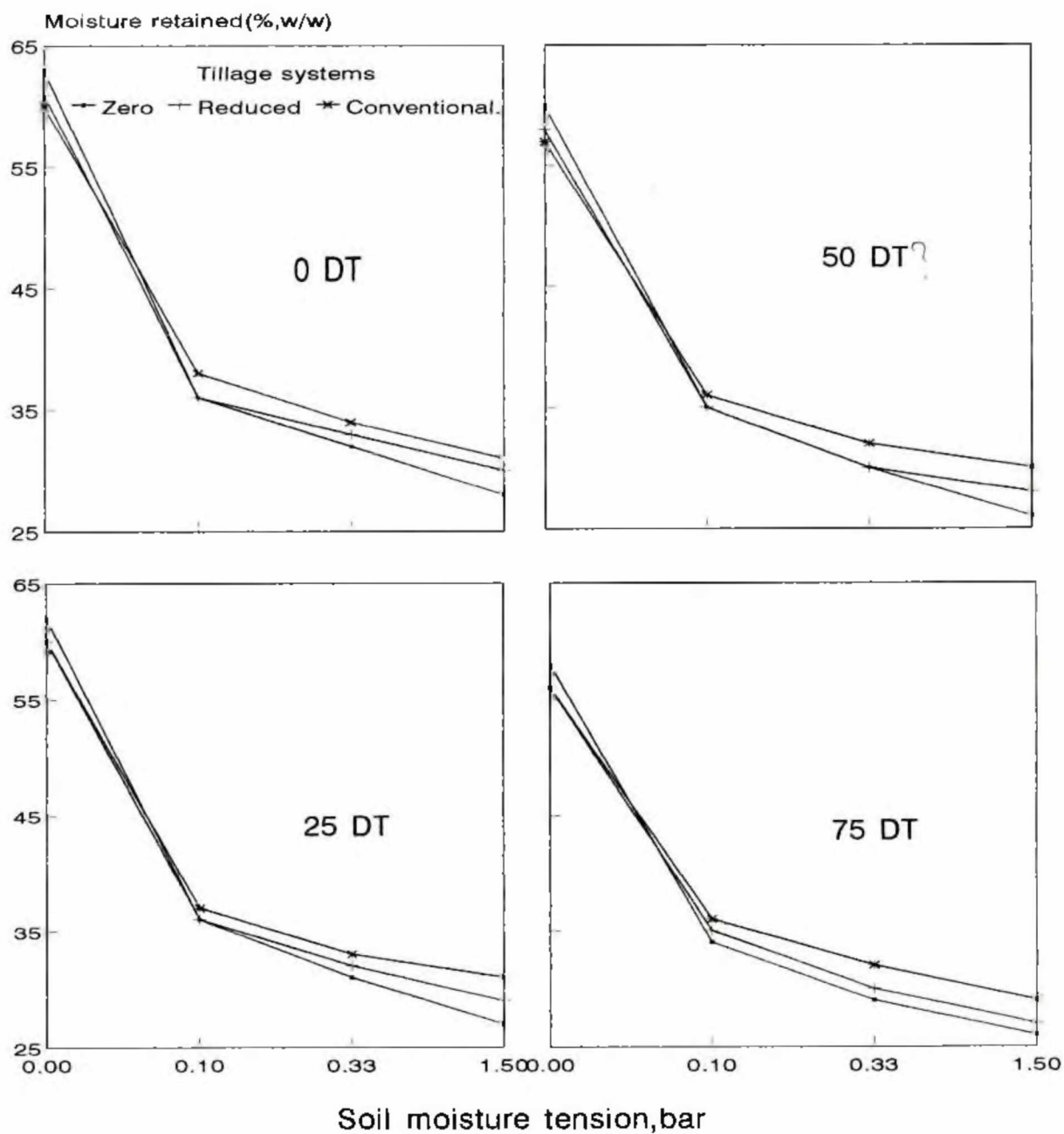


Fig.17. Tillage effects on water retention capacity of silty clay soil at different growth stages under various soil moisture tension.

explain the decreasing soil moisture retention with the progress of time. These soil moisture retention data indicate that the water deficits encountered under rainfed condition were not critical for optimum rice yield. The moisture tensions for most of the time remained below 0.1 bar and only at harvest reached values between 0.33 and 1.5 bar.

4.3.2.5. Soil penetration resistance (SPR)

The effect of tillage on SPR of wet (at transplanting) and dry (post harvest) soil are presented in Fig. 18. Under wet condition the increase of tillage intensity decreased the SPR. Under all tillage systems, SPR increased with soil depth. However, the trend in change in SPR due to soil depth were different with different tillage systems. Under ZT, the SPR differences among soil layers were not marked, but under RT and CT, SPR increased quite sharply with depth in the soil. More disturbance of top soil with tillage practices may explain the results. Similar finding were also reported by Sharma *et al.* (1988) for a clay loam soil. Under dry condition, the previously puddled soil had higher SPR than unpuddled soil at all soil depth and the SPR decreased with increase soil depth at all tillage systems. The changes in SPR was more prominent at surface soil. Relatively higher moisture content at lower soil depth may explain the results.

4.3.2.6. Soil temperature

Soil temperature values as affected by tillage during the growing period of T./Aman rice are presented in Fig.19. Puddling decreased the soil temperature in 0-10cm soil layer, but in the 10-20 cm layer, the tillage effects were not consistent. In general, soil temperature was higher in the top 0-10 cm layer than in the 10-20 cm layer throughout the rice growing period. Ojeniyi (1986) reported no significant differences in soil temperature due to tillage while Blevins (1986) observed a lower soil temperature in reduced tillage systems. The differences in soil temperature among the tillage methods were probably due to differences in soil organic matter content. The soil in the surface layer of the ZT plots had a higher organic matter content than the soil under CT, which may explain the higher soil temperature under ZT than CT.

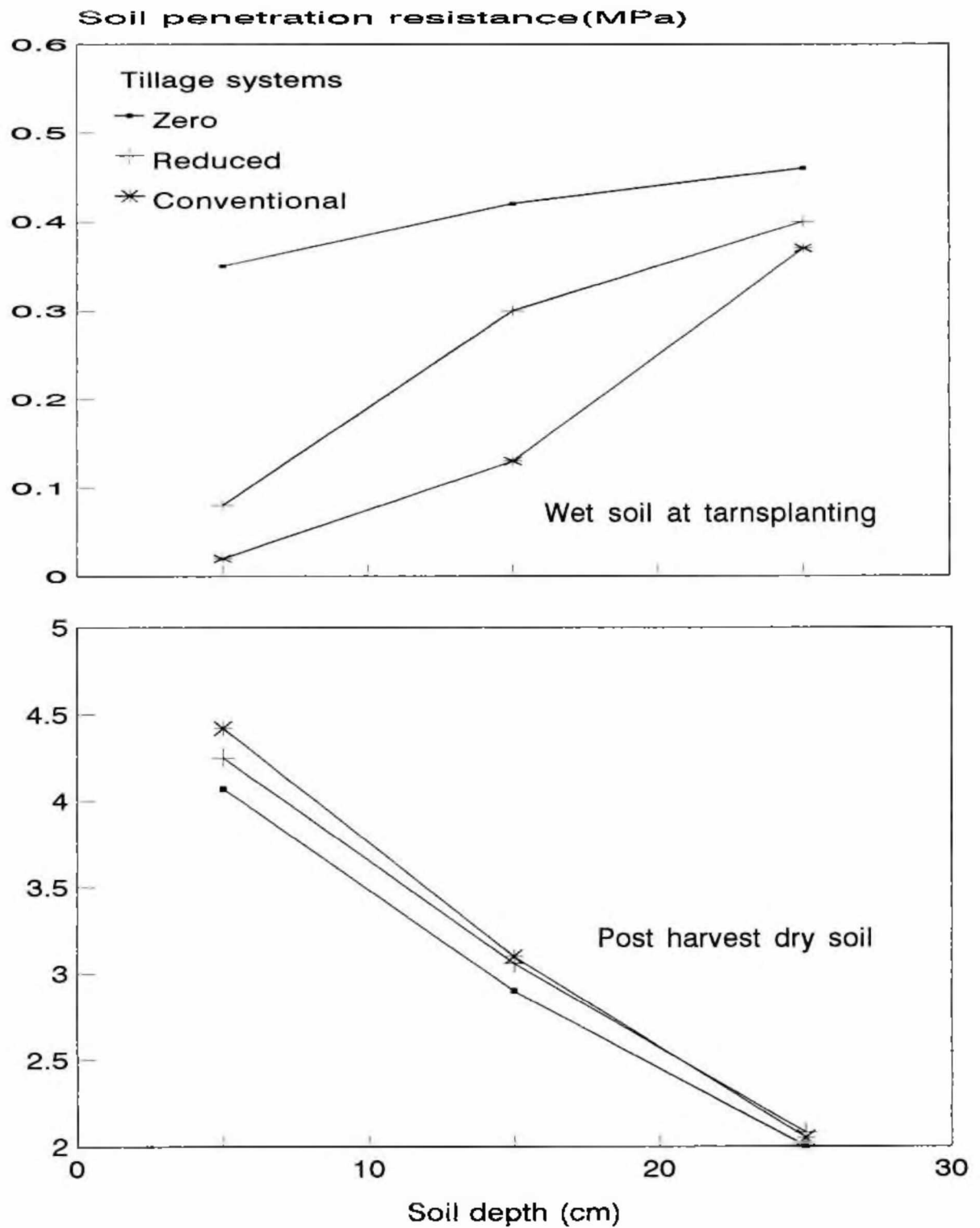


Fig. 18. Tillage effects on penetration resistance of wet and dry soil at differnt depth in wet season

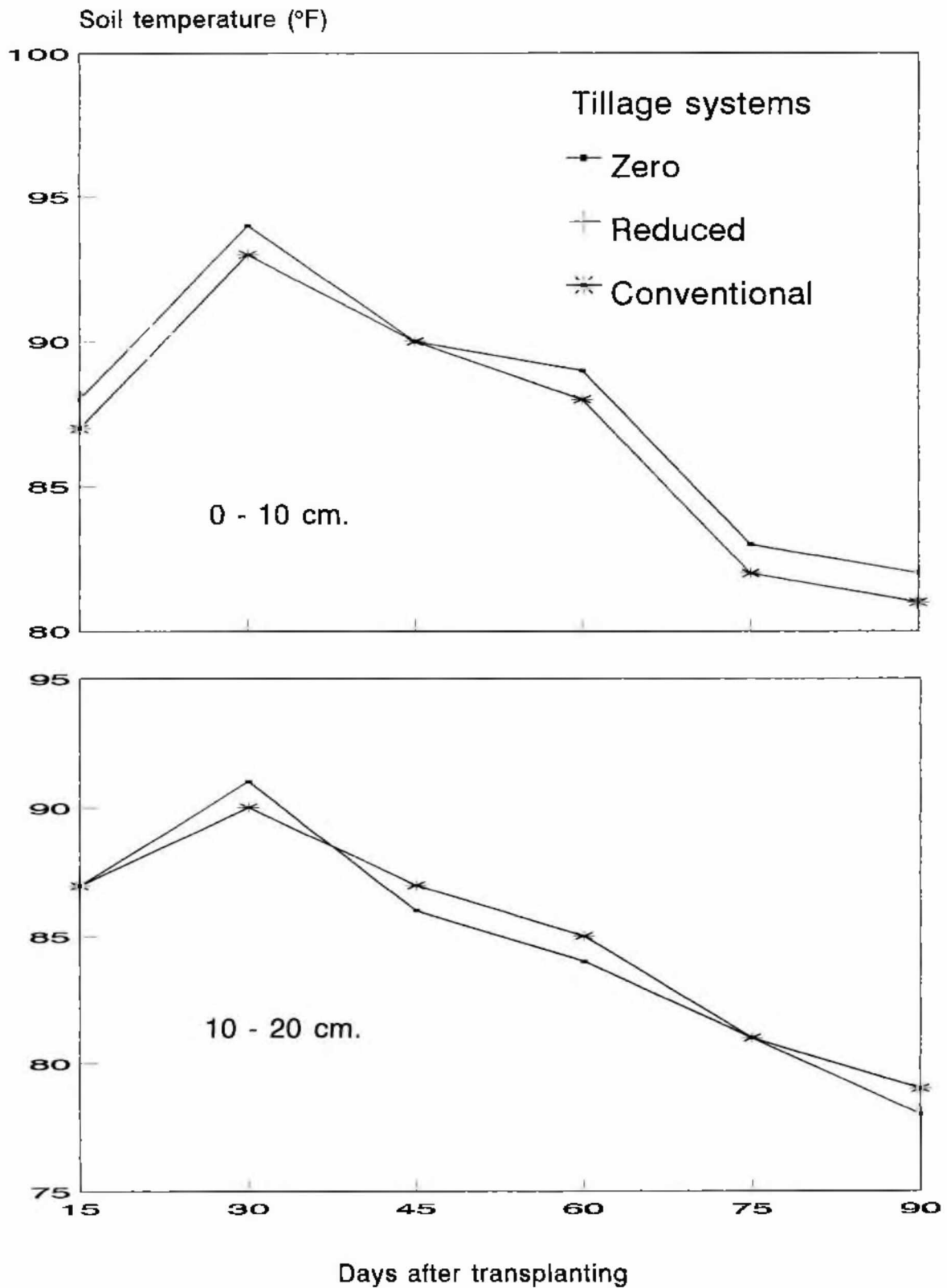


Fig. 19. Effect of tillage on the changes in soil temperature at two depth during the growing period in wet season.

4.3.2.7. Soil drying after drainage

Figure 20 (Appendix Table 7.1 – 7.6) show the moisture content of soil in the 0-10 cm layer as a function of time after the plots were drained. At any time during the post-drainage period, the soil moisture content was higher under CT than under RT or ZT in that order. The puddled soil maintained a higher moisture content because it had a higher water retention capacity than non puddled soil. The puddled soil started cracking by the second week after drainage. Surface cracking under ZT was less severe than that under puddling (CT). Mambani *et al.* (1990) also reported such findings.

4.3.3. Grain and straw yields of rice

Moisture regimes influenced the grain and straw yield of rice. Irrespective of tillage systems irrigated plots produced higher grain and straw yield than those of rainfed plots (Table 17 and Appendix Table 7.7 – 7.8). The differences in the grain and straw yields among ZT, RT and CT under both irrigated and rainfed conditions were not statistically significant. Results reported by earlier investigators in this respect are inconsistent. Ogunremi *et al.* (1986), Lal (1986) and Mambani *et al.* (1990) found increased rice yield with increasing tillage intensity while Griffith *et al.* (1986) and Sharma *et al.* (1988) reported no significant effect of tillage on the dry matter yield of rice.

Table 17. Grain and straw yield (t/ha) of BR11 rice as affected by moisture regimes average over tillage systems.

Moisture regimes	Grain yield	Straw yield
Irrigated	3.70a	4.62a
Rain fed	3.37b	4.26b

Column means followed by common letter do not differ significantly at 5% level by DMRT.

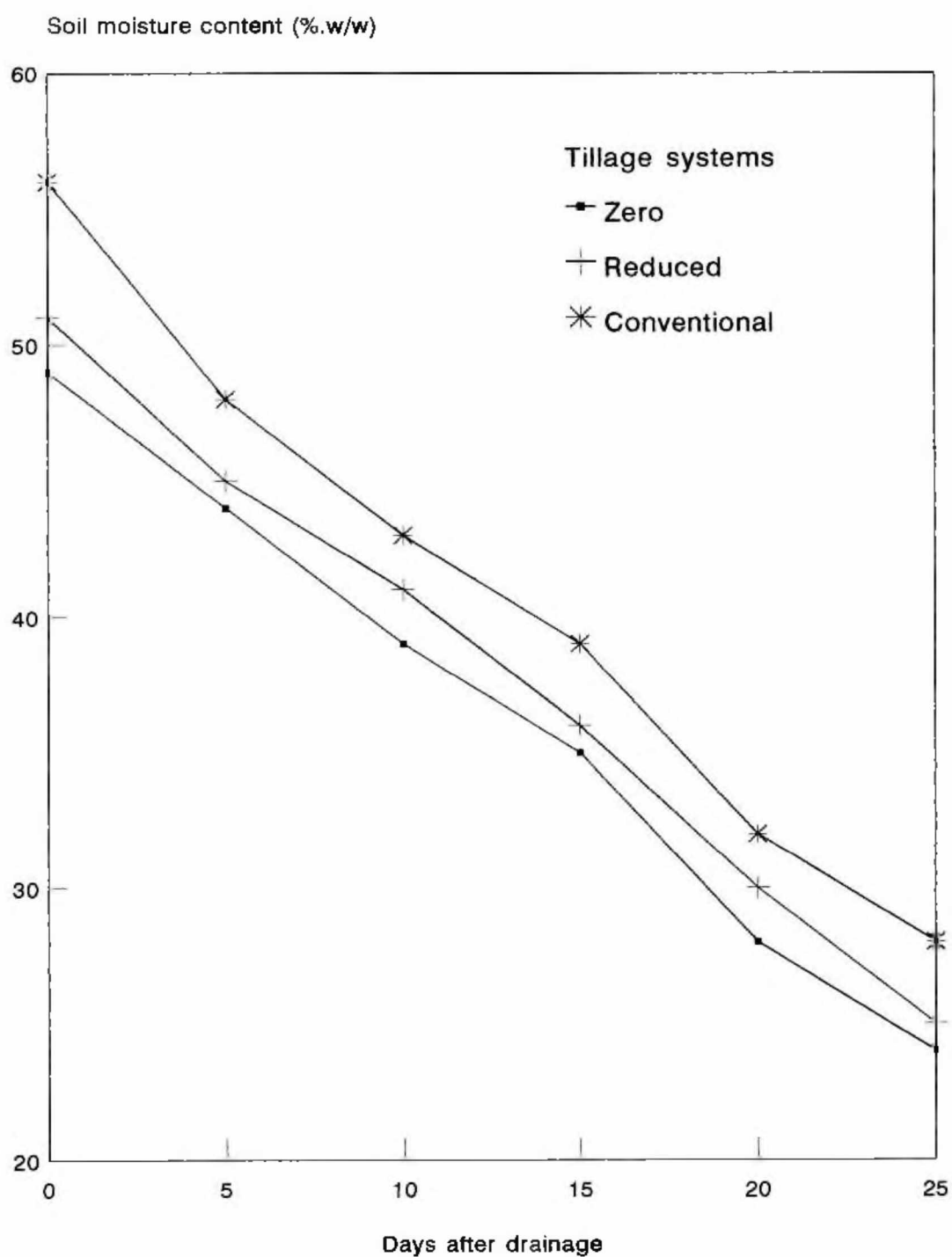


Fig.20. Effect of tillage on soil drying in the 0-10cm soil layer after drainage of water at harvest of T. Aman rice.

4.3.4. Mineral nutrition of rice

4.3.4.1. Nutrient concentration

The effects of moisture regimes and tillage systems on the N, P, K, Ca and Mg content in the straw and grain of BR11 rice are presented in Table 18a and ANOVA in Appendix Table 7.9 – 7.18. The N content of straw was lower in plants in puddled plots than in unpuddled plots regardless of moisture regime. Irrespective of N levels, the grain N content was higher and straw N content was lower under irrigated condition than under rainfed situation. The P, K, and Ca contents of straw and grain were not affected by moisture regimes and tillage levels. Irrespective of moisture regime, an increase in tillage intensity decreased the straw Mg content, but the grain Mg content was not affected by moisture regime or tillage level.

The micro nutrient (Fe, Mn, Zn and Cu) concentrations in the straw and grain of BR11 rice as affected by moisture regimes and tillage methods are shown in Table 18b and ANOVA in Appendix Table 7.19 – 7.26. The concentrations of Fe, Mn, Zn and Cu were higher in straw than in grain. Moisture regime or tillage level did not effect the Fe, Mn and Cu concentrations in straw and grain. However, moisture regime and tillage interactions significantly influenced the Zn concentration in straw. Under both irrigated and rainfed condition, the straw Zn concentration was lower for CT than for ZT or RT. Moisture regimes did not affect the straw Zn content under ZT or RT, but under CT the Zn content was higher under irrigated condition than that under rainfed condition. An increase in tillage intensity decreased the Zn concentration in grain regardless of moisture regime.

Table 18a. Effect of moisture regimes and tillage on the N, P, K, Ca and Mg contents of straw and grain of BR11 in T.Aman.

Tillage system	Straw			Grain		
	Rainfed	Irrigated	T-mean	Rainfed	Irrigated	T-mean
<i>Nitrogen(%)</i>						
Zero	0.47	0.43	0.45 a	0.92	0.98	0.95
Reduced	0.45	0.37	0.40 b	0.90	0.95	0.92
Conventional	0.43	0.37	0.40 b	0.89	0.93	0.91
W- mean	0.45 A	0.39 B		0.90 B	0.95 A	
<i>Phosphorus(%)</i>						
Zero	0.04	0.05	0.05	0.24	0.25	0.24
Reduced	0.05	0.05	0.05	0.25	0.25	0.25
Conventional	0.05	0.05	0.05	0.26	0.24	0.25
<i>Potassium(%)</i>						
Zero	2.44	2.59	2.50	0.32	0.31	0.31
Reduced	2.64	2.59	2.60	0.30	0.31	0.32
Conventional	2.69	2.76	2.72	0.33	0.31	0.32
<i>Calcium(%)</i>						
Zero	0.17	0.14	0.15	0.06	0.05	0.06
Reduced	0.14	0.14	0.14	0.08	0.05	0.06
Conventional	0.15	0.17	0.16	0.06	0.06	0.06
<i>Magnesium(%)</i>						
Zero	0.18	0.17	0.18 a	0.12	0.13	0.12
Reduced	0.16	0.18	0.17 ab	0.12	0.13	0.13
Conventional	0.14	0.17	0.16 b	0.13	0.13	0.13

For each element, means in a column followed by common small letter(s) and in a row followed by common capital letter (s) do not differ significantly at 5% level by DMRT.

Table 18b. Effects of moisture regimes and tillage methods on the micronutrient concentrations in the straw and grain of BR11 in T.Aman.

Tillage system	Straw			Grain		
	Rainfed	Irrigated	T-mean	Rainfed	Irrigated	T-mean
<i>Iron(ppm)</i>						
Zero	5	55	55	106	55	117
Reduced	58	55	56	107	127	117
Conventional	49	55	52	91	126	109
<i>Manganese (ppm)</i>						
Zero	269	353	361	39	42	41
Reduced	342	372	357	44	45	44
Conventional	304	375	340	40	43	41
<i>Zinc(ppm)</i>						
Zero	81 aA	83 aA	82	23	25	24 a
Reduced	77 aA	77 bA	77	23	23	23 ab
Conventional	67 bB	78 abA	72	22	18	20 b
<i>Copper(ppm)</i>						
Zero	3.4	3.4	3.4	2.6	2.8	2.7
Reduced	3.8	3.4	3.6	2.8	3.0	2.9
Conventional	3.6	3.6	3.6	2.7	3.0	2.9

Means in a column followed by common small letter(s) and in a row followed by common capital letter(s) do not differ significantly at 5% level by DMRT.

4.3.4.2. Nutrient uptake

Uptake of nutrients were calculated from percent concentration and dry matter production. The influences of tillage and moisture regime on N, P, K, Ca, Mg, Fe, Mn, Zn and Cu uptake by rice plant are presented in Tables 19a and 19b and ANOVA in Appendix Tables 7.27-7.35. Tillage treatments did not affect the uptake of most nutrients. However, a significantly higher amount of N, P, K, Mg, Fe, Mn and Zn were taken up by the rice plants under irrigated condition than under rainfed situation at different tillage levels. The effect of tillage and moisture regime interaction was found significant on Ca uptake by rice. Under ZT and RT condition irrigated plot extracted higher amount of Ca than rainfed plots while under CT moisture regime did not influence the Ca uptake. Tillage treatment did not affect the Ca uptake under rainfed condition, while under irrigated situation higher amount of Ca was absorbed by rice plant in CT plot than those of other tillage treatments. There was higher uptake of Zn by rice grown in no-tilled soil than the tilled soil, irrespective of moisture regime. Neither moisture regime nor tillage level influenced the Cu uptake of rice.

Rice grown in irrigated plots had generally taken up higher amount of nutrients than the rainfed plots under different tillage treatments (Table 19a and 19 b). This was obviously due to more favorable soil moisture condition in the irrigated plots. Relatively higher soil moisture content and lower soil bulk density during growing season may have improved the soil physical condition for root growth and increased nutrient availability irrespective of tillage levels. A possible greater mobility of nutrients in soil under irrigated condition may facilitate easier absorption of nutrients by the plant roots, whereas under rainfed condition the plant roots probably had to spend more energy to extract a unit amount of nutrients. Besides improved dry matter production with improved moisture condition may also be the reason of greater nutrient uptake under irrigated condition.

Table 19a. Effect of moisture regime and tillage on total N, P, K, Ca and Mg uptake (kg/ha) by BR11 in T.Aman.

Tillage treatment(T)	Moisture regimes(I)		T-mean	Diff.
	Rainfed	Irrigated		
N uptke				
Zero	49.25	53.95	51.60	-4.70
Reduced	47.88	54.51	51.19	-6.63
Conventional	48.84	51.63	50.23	-2.79
I-Mean	48.65 B	53.36 A	51.01	-4.71
CV (b) = 3.1%				
P uptake				
Zero	9.87	11.39	10.63	-1.52
Reduced	10.56	11.29	10.93	-0.73
Conventional	10.98	11.37	11.17	-0.39
I-Mean	10.47 B	11.35 A	10.91	-0.88
CV (b) = 6.2%				
K uptake				
Zero	114.03	128.45	121.24	-14.41
Reduced	121.55	132.82	127.18	-11.27
Conventional	126.90	139.30	133.10	-12.40
I-Mean	120.83 B	133.52 A	127.17	-12.69
CV (b) = 8.7%				
Ca uptake				
Zero	9.15 a	8.36 b	8.75	0.79
Reduced	8.57 a	8.38 b	8.47	0.20
Conventional	8.56 a	9.85 a	9.20	-1.29
I-Mean	8.76	8.86	8.81	-0.10
CV (b) = 5.4%				
Mg uptake				
Zero	11.68	12.68	12.18	-0.99
Reduced	10.84	12.90	11.87	-2.05
Conventional	10.75	12.27	11.51	-1.52
I-Mean	11.09 B	12.61 A	11.85	-1.52
CV (b) = 6.79%				

For each element, means in a column followed by common small letter (s) and in a row followed by common capital letter (s) are not significantly different at the 5% level by DMRT.

Table 19b. Effect of moisture regime and tillage on total Fe, Mn, Zn and Cu uptake (kg/ha) by BR11 rice in T.Aman.

Tillage treatment(T)	Moisture regimes(I)		T-mean	Diff.
	RF	Irrigated		
Fe				
Zero	0.64 a	0.78 a	0.71 a	-0.15
Reduced	0.65 a	0.78 a	0.71 a	-0.13
Conventional	0.56 a	0.78 a	0.67 a	-0.22
I-Mean	0.61 B	0.78 A	0.70	-0.17
CV (b) = 10.6%				
Mn				
Zero	1.70 a	1.78 a	1.74 a	-0.08
Reduced	1.60 a	1.92 a	1.76 a	-0.32
Conventional	1.44 a	1.89 a	1.67 a	-0.45
I-Mean	1.58 B	1.86 A	1.72	-0.29
CV (b) = 12.6%				
Zn				
Zero	0.42 a	0.47 a	0.45 a	-0.05
Reduced	0.40 ab	0.44 ab	0.42 b	-0.04
Conventional	0.37 b	0.43 b	0.40 b	-0.06
I-Mean	0.40 B	0.45 A	0.42	-0.05
CV (b) = 5.1%				
Cu				
Zero	0.02	0.03	0.02	-0.00
Reduced	0.03	0.03	0.03	0.00s
Conventional	0.02	0.03	0.03	-0.01
I-Mean	0.02	0.02	0.03	-0.00
CV (b) = 20.5%				

For each element, means in a column followed by common small letter (s) and in a row followed by common capital letter (s) are not significantly different at the 5% level by DMRT.

4.4. Experiment 4. Effect of moisture regimes, tillage systems and N levels on soil physical properties and on the growth, yield and mineral nutrition of post-rice wheat.

4.4.1. Cumulative water added

Figure 21 show the cumulative water added (irrigation and rainfall) and evapotranspiration occurred during the growing period of wheat from sowing to maturity. At sowing, 35 mm water was applied to each plot for uniform seed germination. Besides this, each irrigated plot received a total of 110 mm irrigation water during the crop growing period out of which 50 mm was applied at 25 DS and 60 mm at 55 DS. The rainfed plots did not receive any irrigation water. Both irrigated and rainfed plots received a total of 83 mm of rain water each out of which 65.2 mm was received at 72 DS, 8 mm at 82 DS and the remaining 9.8 mm at 96 DS. During the period from sowing to maturity, a total of 228 mm water was added to irrigated and 118 mm to rainfed plots. The estimated evapotranspiration was the same for all plots, which was 241 mm during the growing period from sowing to maturity.

4.4.2. Physical properties of soil

4.4.2.1. Infiltration

Infiltration refers to the process of water entry into the soil, generally by downward flow through all or part of the soil surface. The rate of this process determines how much water will enter the root zone, and how much if any, will be lost by runoff. In the present investigation, the infiltration rate (IR) and the cumulative infiltration (CI) were studied. Tillage practices influenced the IR (Fig.22). During the initial 1 minute, the lowest IR (25.5 mm min⁻¹) was observed in the CT plots and the highest rate was observed in the ZT plots. In general, IR decreased with increasing tillage intensity. With the progress of time, IR decreased rapidly in all tillage treated plots. Initially the IR through the soil profile was faster in all tillage treated plots which decreased linearly up to 50 minutes and thereafter decreased very slowly. The time of attaining steady IR was also different for different tillage treatments. In the CT, the steady rate of IR was attained earlier compared with the RT or ZT plots. At the end of 400 minutes IR ranged between 0.29 mm min⁻¹ in CT and 0.43 mm min⁻¹ in ZT (Fig.22).

Initial 1 min condition ?

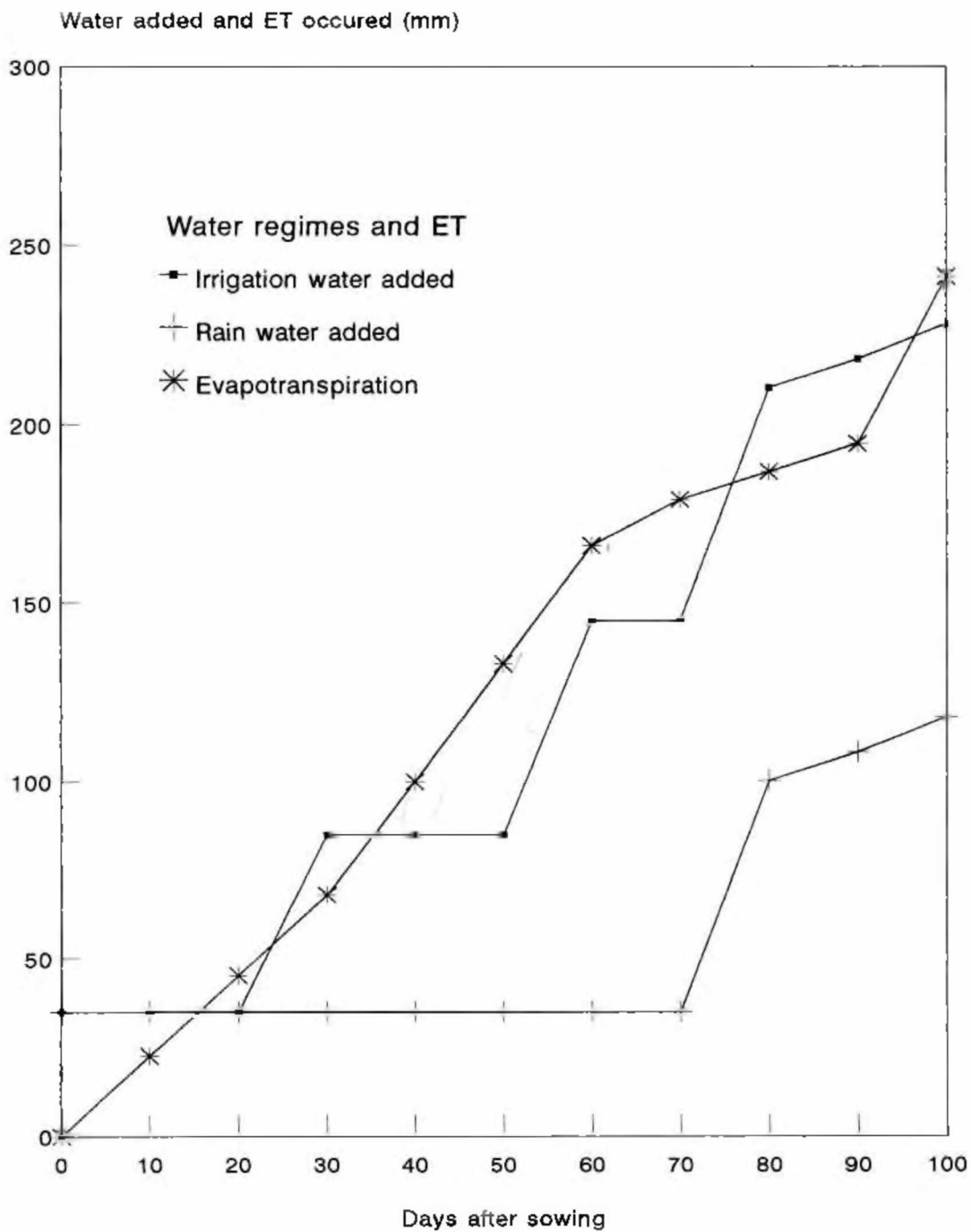


Fig.21. Cumulative water added and evapotranspiration occurred (mm) with time during the growing period of wheat in rabi, 94.

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or
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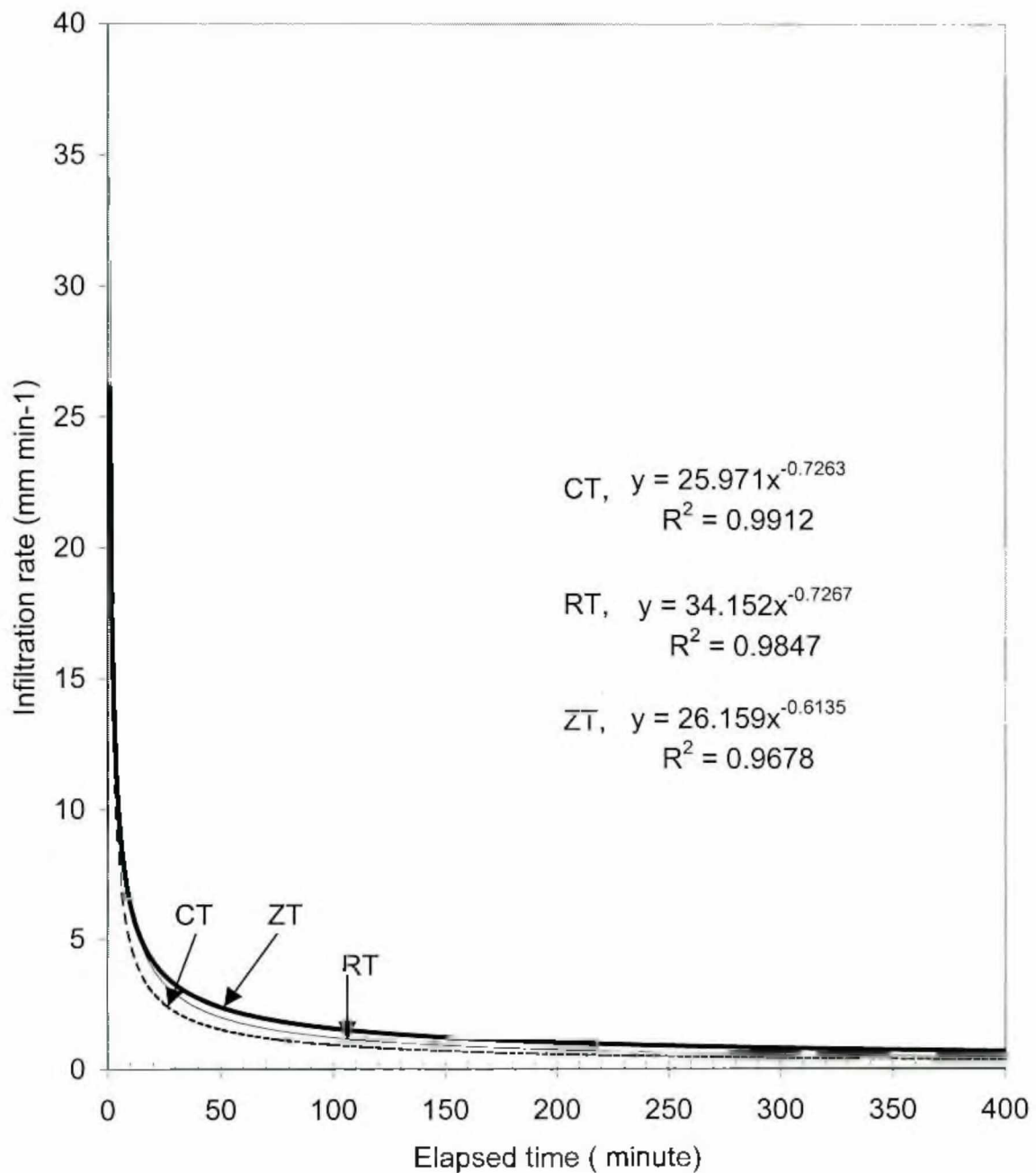


Fig. 22. Influence of tillage practices on the infiltration rate (mm min⁻¹) as a function of time during wheat season in a silty clay soil.

The relationship between the IR of the soil and elapsed time was obtained as

$$\text{CT: IR} = 25.971 t^{-0.7263} \quad (R^2 = 0.9912)$$

$$\text{RT: IR} = 34.152 t^{-0.7267} \quad (R^2 = 0.9847)$$

$$\text{ZT: IR} = 26.159 t^{-0.9678} \quad (R^2 = 0.9678)$$

In all cases, the value of R^2 was close to unity indicating that relationship between IR and elapsed time would be well represented by the function $I = at^{-n}$

Where IR= infiltration rate, a= intercept, t= elapsed time and n= slope

Tillage practices also influenced the CI of the soils (Fig. 23). It was evident from the figure that the CI at a given time decreased with tillage intensity in the order CT < RT < ZT. After 400 minutes, CI ranged from 36.95 cm in CT to 60.67 cm in ZT. The relationship between CI and elapsed time was found to be opposite that between IR and elapsed time. For CT, RT and ZT the relationship was obtained as

$$\text{CT: CI} = 3.0006 t^{0.4318} \quad (R^2 = 0.9944)$$

$$\text{RT: CI} = 3.5521 t^{0.4615} \quad (R^2 = 0.9874)$$

$$\text{ZT: CI} = 3.0659 t^{0.5059} \quad (R^2 = 0.9976)$$

In this case too, the value of R^2 was very high and close to unity implying that CI was functionally related to elapsed time as $CI = at^n$

where, "CI" is the cumulative infiltration, "t" is the elapsed time and "a" is the intercept and "n" is the slope. The magnitude of "a" indicated the infiltration at $t = 1$ and "n" its rate of increase. It was observed that the value of "a" varied for different tillage treatments and the value of "n" decreased with increasing tillage intensity. In general, there was no definite trend in the variation of "a" and "n" values for different tillage treatments.

The CI and IR decreased with increasing tillage intensity. Although the initial IR was higher and differed in different tillage treatments, it decreased with time to be more or less comparable in all the treatments at the end of the study period. The ZT and RT plots were observed to have cracks from the soil surface to the plough pan and the initial higher IR and CI were probably due to intake of water through the cracks. Besides this, the higher IR and CI in the ZT compared to RT and CT were attributed to higher number of bio channels (Blevins *et al.* 1984), higher porosity and more intensive microflora activity (Ghuman and Lal, 1984) in no tilled soil than those of RT and CT soil.

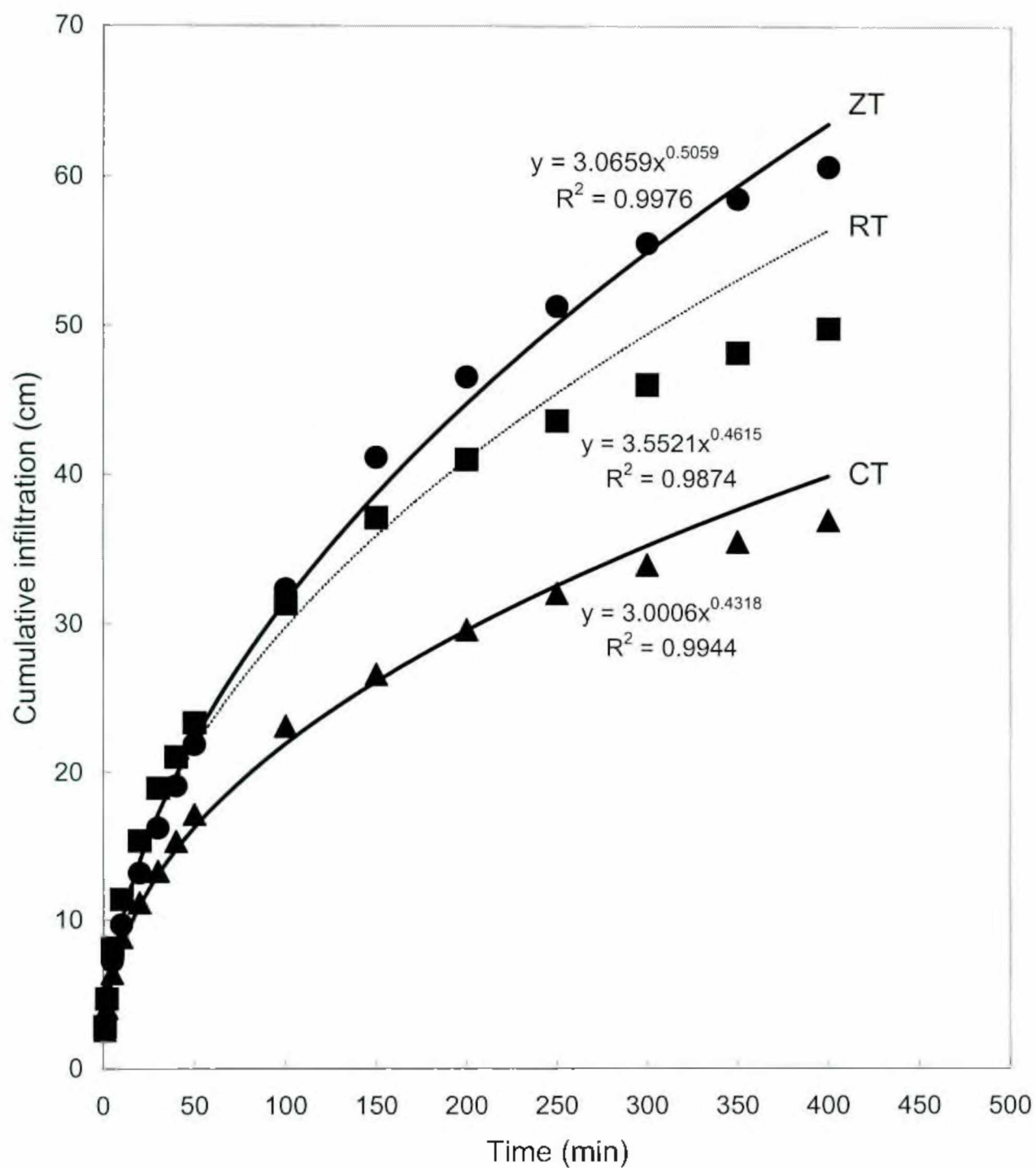


Fig. 23. Influence of different tillage systems on cumulative infiltration (cm) as a function of time during wheat season in a silty clay soil.

Restricted movement of water to tilled zone and the disruption of continuity of soil pores due to tillage practices (Goss *et al.* 1978) may also be the reason of higher IR and CI in no tilled soil. These results were also in agreement with the findings of Maurya (1984), Brar *et al.* (1983), Radcliffe *et al.* (1988) and Ghuman and Lal (1984) where they observed higher IR and CI of water under ZT as compared to normal cultivation.

4.4.2.2. Soil moisture content.

The changes in soil moisture content with time in two soil layers are shown in Figure 24. In the 0-10 cm soil layer, soil moisture content fluctuated widely over time under both irrigated and rainfed conditions. Very little differences in soil moisture content among the tillage treatments were observed, especially in the upper soil layer (0- 10 cm). The soil moisture content remained below field capacity through out the crop growing season except when irrigation was applied or rainfall occurred. At sowing and early growth stage (21 DS) the irrigated and rainfed plots had almost similar soil moisture content irrespective of tillage system, but later the irrigated plots had a higher soil moisture content than the rainfed plots under all tillage system. A higher soil moisture content in the irrigated plots indicates the replenishment of depleted water by irrigation. On the other hand the soil moisture content in the rainfed plots depleted with plant growth starting from sowing to 71 DS and was replenished with rain water only at 73 DS but again the soil moisture content decreased with time up to maturity. Under the rainfed condition the wheat plants suffered from moisture stress during the vegetative and early reproductive stage from 42 DS to 71 DS and this was ultimately reflected in dry matter production.

The soil moisture content in the 10-20 cm layer depleted with plant growth up to 63 DS and then increased at 84 DS and again declined at maturity in both irrigated and rainfed conditions. The increased soil moisture content at 84 DS was due to rainfall that occurred at 72 and 82 DS. The irrigated and rainfed plots had almost similar moisture content in the 10-20 cm soil layer throughout the wheat growing season. The fluctuation in moisture content with time in the 10-20 cm soil layer was less than that in the 0-10 cm layer. Also, unlike in the 0-10 cm layer, some effect of tillage on soil moisture content was observed in the lower (10-20 cm) soil layer. A higher soil moisture content was observed in the more intensely tilled plots during the period from 20 DS to maturity of the crop.

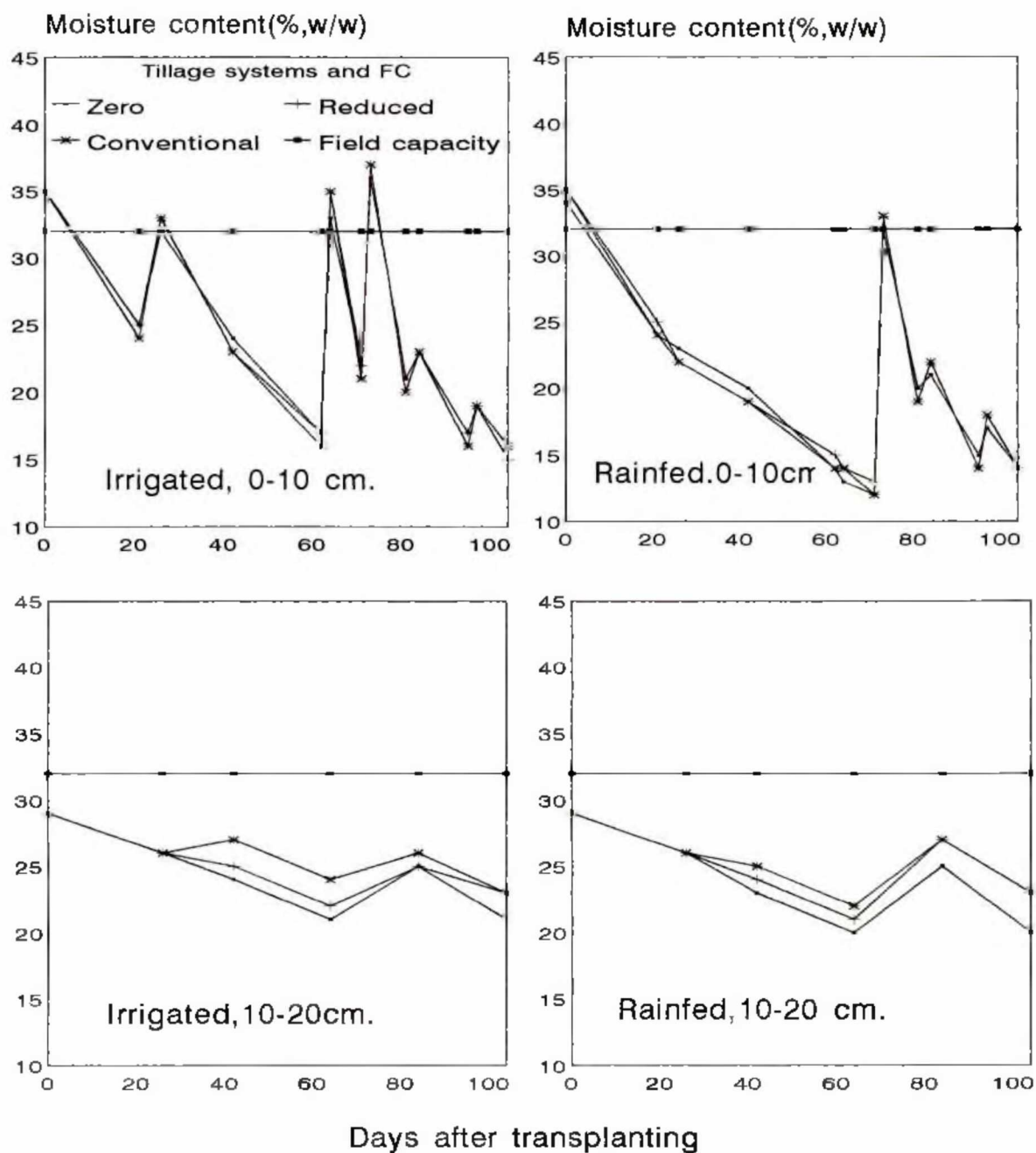


Fig. 24. Tillage effects on the changes in soil moisture content with time at two soil depth under irrigated and rainfed condition during the growing period of wheat.

appropriate?

4.4.2.3. Soil bulk density

The bulk density (BD) of soil generally increased gradually with time from the day of sowing to 60 DS, then fell sharply at 80 DS, and again increasing sharply until maturity of the crop (Fig.25). This was true for both irrigated and rainfed conditions. At sowing and 25 DS the irrigated and rainfed plots had almost similar soil BD under any tillage system, but after 25 DS the rainfed plots had a higher soil BD than the similar irrigated plots. A higher soil BD in the rainfed plots than in the irrigated plots was due to the lower soil moisture content in the former than in the later. At all growth stages of wheat, the soil BD was generally higher with the lower tillage intensity. For example, the BD density was always higher under ZT than that under RT or CT. Decreased soil BD with intensified tillage tillage was also reported by Hallowang and Dexter (1991), and Yoshida *et. al.* (1993).

4.4.3. Wheat growth and agronomic characteristics

4.4.3.1. Plant height

Plant height of wheat was increased gradually with time up to maturity at all treatment levels. Tillage and nitrogen levels variously affected plant height under irrigated and rainfed conditions at different growth stages (Table 20 and Appendix Table 8.1 – 8.4). In general, N fertilization increased the plant height at all growth stages. At the maximum tillering stage N fertilization increased the plant height under all tillage systems and water levels except RT under rainfed situation where applied N did not exert any influence on plant height. Under irrigated condition applied N up to 100 kg/ha under ZT and 140 kg/ha under RT or CT increased the plant height significantly over zero N. Under rainfed situation, plant height under ZT was increased with 140 kg/ha applied N and under CT with 100 kg/ha. Compared with ZT, CT decreased the plant height at 100 kg/ha applied N under irrigated condition while under rainfed situation CT decreased the plant height from RT when N fertilizer was not applied. Irrigation increased the plant height with applied N 100 kg/ha under ZT, with 140 kg/ha under RT and without N under CT.

At the booting stage, the increasing levels of applied N up to 140 kg/ha under CT increased the plant height under irrigated condition while under the other tillage systems in both irrigated and rainfed conditions the plant height was increased with 100 kg/ha applied N.

Table 20. Plant height (cm) of wheat as affected by moisture regimes, tillage systems and N levels at different growth stages.

Applied N (kg/ha)	Growth stages					
	Maximum tillering		Booting		Maturity	
	Irrigated	Rainfed	Irrigated	Rainfed	Irrigated	Rainfed
<i>Zero tillage</i>						
0	27 bA	25 bA	45 bA	42 bA	83 bA	73 cA
100	36 aA	26 bB	63 aA	50 aB	101 aA	86 bB
140	34 aA	31 aA	62 aA	56 aA	102 aA	94 aA
<i>Reduced tillage</i>						
0	25 cA	28 aA	39 cA	40 bA	72 bA	73 cA
100	31 bA	30 aA	62 aA	52 aB	96 aA	87 aA
140	36 aA	28 aB	59 bA	53 aA	96 aA	83 bB
<i>Conventional tillage</i>						
0	27 bA	20 cB	44 cA	45 cA	82 cA	67 cB
100	28 bA	31 aA	55 bA	56 aA	87 bA	93 aA
140	32 aA	27 bA	61 aA	48 bB	102 aA	87 bB
CV for sub plot (b) = 11.4%			CV for (b) = 3.0%		CV for (b) = 6.3%	
CV for sub-sub plot (c) = 10.3%			CV for (c) = 10.1%		CV for (c) = 6.4%	

Under each growth stage and tillage system, means in a column followed by common small letter(s) and in a row followed by common capital letter(s) do not differ significantly at 5% level by DMRT.

Growth stages	Comparison	LSD (.05)
Max. tillering	2-T means at each I X N	5.00
Booting	2-T means at each I X N	6.00
Maturity	2-T means at each I X N	8.00

Conventional tillage decreased the plant height from ZT or RT at 100 kg/ha applied N under irrigated condition and at 140 kg/ha under rainfed situation. Irrigation increased the plant height with 100 kg/ha applied N under ZT and RT and with 140 kg N/ha under CT. At maturity, plant height were similar with 100 and 140 kg/ha N and significantly greater than with no-N treatment under ZT or RT while under CT plant height increased with increasing level of N supply up to 140 kg/ha under irrigated condition. Under rainfed situation, applied N up to 100 kg/ha increased plant height which decreased with additional supply of N under RT or CT, but under ZT increasing level of N up to 140 kg/ha increased plant height significantly. In the absence of N fertilization, ZT and CT had similar plant height which was significantly greater than that under RT under irrigated condition, while under rainfed situation tillage levels did not influence plant height. At 100 kg N/ha, ZT and RT had statistically similar plant height which was greater than that under CT in irrigated condition, but in rainfed situation tillage did not influence plant height. At 140 kg N/ha, tillage systems did not differ in respect of plant height under irrigated condition while under rainfed situation ZT had the tallest plants followed by CT and RT. The plants were taller in irrigated plots than those in the rainfed plots with 100 kg applied N/ha under ZT and with 0 and 140 kg/ha under CT.

4.4.3.2. Tiller number.

The numbers of tillers as affected by moisture regime, tillage system, N fertilization and their interactions are presented in Table 21 and ANOVA in Appendix Table 8.4-8.6. Production of tillers decreased gradually with time from maximum tillering stage to maturity. At the maximum tillering stage, tiller production was influenced by moisture regime x tillage system and moisture regime x N level interactions. The tiller number decreased with increasing tillage intensity under irrigated condition while under rainfed situation tillage systems did not influence tiller production. Compared with rainfed situation, the tiller number was higher with irrigation under ZT while under other tillage systems moisture regime did not show any effect on tiller production. The moisture regimes x N level interactions indicated that increasing level of N supply increased the tiller number under irrigated condition, but under rainfed situation N fertilization had no effect on tiller number.

Table 21. The number of tillers/m² at different growth stages of wheat as influenced by moisture regime, tillage system, N level and their interactions.

A. *W X T and W X N Table of means for tillers at maximum tillering stage.*

Tillage systems	Moisture regimes		Applied N (kg/ha)	Moisture regimes	
	Irrigated	Rainfed		Irrigated	Rainfed
Zero	867 aA	582 aB	0	630 cA	576 aA
Reduced	667 bA	715 aA	100	763 bA	665 aA
Conventional	740 abA	605 aA	140	880 aA	661 aB
CV for sub plot = 25.2% and for sub-sub plot = 16.1%					

B. *W X T and T X N Table of means for tillers at booting stage.*

Tillage systems	Moisture regimes		Applied N kg/ha)	Tillage systems			
	Irrigated	Rainfed		Zero	Reduced	Conventional	N-mean
Zero	670 aA	487 aB	0	541	459	548	516 b
Reduced	511 bA	567 aA	100	583	586	541	570 ab
Conventional	585 abA	544 aA	140	610	573	605	596 a
CV for sub plot = 19.5% and for sub-sub plot = 16.6%							

C. *T X N Table of means for tillers at maturity*

Applied N (kg/ha)	Tillage systems			
	Zero	Reduced	Conventional	N-mean
0	509	489	500	499 b
100	501	578	577	552 a
140	533	532	539	535 ab
CV for sub plot = 10.3% and for sub-sub plot = 13.4%				

Under each section (A,B,C) means in a column followed by common small letter(s) and those in a row followed by common capital letter(s) do not differ significantly at 5% level by DMRT.

During booting stage, N fertilization alone, and moisture regime x tillage system interaction significantly influenced the tiller number. Under irrigated condition, ZT produced the highest number of tillers followed by CT and RT while under rainfed condition tillage systems did not affect tiller production. Irrigation produced higher number tillers compared with rainfed situation under ZT, but under the other tillage systems moisture regime did not affect the tiller number. Irrespective of moisture regime applied N 140 kg/ha produced the highest number of tiller followed by 100 kg/ha and no-N treatment. Tiller number at maturity was not influenced by moisture regime and tillage's system. Irrespective of moisture regime and tillage system, applied N at 100 kg/ha significantly increased the tiller number over no-N treatment, and then no further increase was observed with additional N.

4.4.3.3. Yield components

The yield components of wheat as affected by tillage systems and N levels under irrigated and rainfed conditions are shown in Table 22 and ANOVA in Appendix Table 8.7-8.10. Irrespective of moisture regime or tillage system, applied N at 100 kg/ha significantly increased the number of panicles per unit area and then declined with a further increase in N application. Nitrogen fertilization increased the number of grains per panicle over no-N treatment. Regardless of tillage system and moisture regime, increasing level of applied N beyond 100 kg/ha decreased the weight of 1000 filled grain. Irrespective of tillage systems and applied N levels, irrigated plots had higher number of panicles/m², grains/panicle and 1000 grain weight than that of rainfed plots. Under irrigated condition, applied N at the rate of 100 and 140 kg/ha decreased grain sterility percentage (GSP) while under rainfed situation GSP decreased with 100 kg/ha applied N and again increased with a further increase in the N dose. Compared with irrigated plots, GSP in rainfed plots was higher at the higher level of N application (140 kg/ha). Tillage x N level interaction indicated that, under ZT, N fertilization decreased GSP; under RT, GSP decreased with the application of N up to 100 kg/ha, and then increased with a further increase in the N dose while under CT no effect of applied N was observed. Increasing tillage intensity increased GSP at the highest level of N supply (140 kg/ha), while at other N levels no effect of tillage practices was observed.

Table 22. Effect of moisture regimes, tillage systems, N levels and their interactions on yield component of wheat grown after T.Aman rice.

A. *W X N Table of means for panicles/m², grains/panicle and 1000 grain weight.*

Applied N(kg/ha)	Moisture regimes		N mean	Moisture regimes		N mean	Moisture regimes		N mean
	Irrigated	Rainfed		Irrigated	Rainfed		Irrigated	Rainfed	
	Panicle/m ²			Grain/panicle			1000 grain weight (g)		
0	517	429	473 b	16	13	15 b	50.23	48.61	49.42a
100	581	470	526 a	23	22	22 a	50.19	47.69	48.94ab
140	524	474	499ab	26	21	23 a	48.40	47.47	47.94b
W-mean	541A	458B		22A	19B		49.61A	47.92B	
CV for sub plot (b) = 11.9%			CV for (b) = 16.7%			CV for (b) = 4.3%			
CV for sub-subplot (c) = 14.3			CV for (c) = 15.6%			CV for (c) = 4.1%			

B. *W x N and T x N Table of means for % unfilled grains.*

Applied N (kg/ha)	Moisture regimes		Tillage systems		
	Irrigated	Rainfed	Zero	Reduced	Conventional
0	3.6 a A	2.9 a A	3.9 a A	2.8 aA	3.0 aA
100	2.0 b A	2.2 b A	1.7 b A	2.1 bA	2.5 aA
140	2.3 b B	3.2 a A	2.1 b B	3.4 aA	2.7 aAB
CV for (b) = 48.5% and CV for (c) = 34.6%					

Under each section (A,B,C) means in a column followed by common small letter(s) and those in a row followed by common capital letter(s) do not differ significantly at 5% level by DMRT.





4.4.4. Grain and straw yields

Irrigation, tillage and applied N significantly influenced the grain and straw yields of wheat (Fig.26 and Appendix Table 8.11-8.12). Under irrigated condition the grain and straw yield were not influenced by tillage systems at any N levels. While under rainfed situation, the CT plots produced higher straw and grain yield than those of ZT and RT plots at 100 kg N/ha. Under irrigated condition relatively higher soil moisture content (Fig.24) and lower soil bulk density (Fig. 25) during growing season may have improved the soil physical condition for root growth and increased nutrient availability irrespective of tillage condition. These may have masked the effect of tillage treatments under irrigated condition, and hence no significant yield differences among the tillage treatments were observed.

Under irrigated condition in the ZT system, the grain and straw yields increased with applied N up to 100 kg/ha over zero N while in the RT and CT systems this trend of increasing yield with applied N continued up to 140 kg/ha. Under rainfed situation, the grain and straw yield under ZT and RT systems increased with increasing dose of N up to 140 kg/ha while in the CT systems the yields increased up to 100 kg/ha applied N and then decreased with a further increase in the N dose. Considering grain yield with zero N application as 100%, the yield increase under irrigated condition amounted to 78% with 100 or 140 kg/ha in the ZT system (Table 23). The highest yield increases due to N application (100, 140 kg/ha) were found under RT (88 and 92%) and the lowest under CT (73 and 77%). This indicates decreased N fertilizer effect under more intensive tillage systems. One of the reasons for this was that N fertilizer applied in minimum tillage remained in the surface layer of the soil where most of the roots were confined. If tillage is performed using a plough, the N fertilizers granules are distributed deeper into the soil and diluted. Moreover, intensified tillage may have enhanced mineralization increasing soil N availability and decreasing the effect of applied N fertilizer on the crop. Nyborg and Malhi (1989) and Videonovic *et al.* (1986) also reported reduced fertilizer N effect under more intense tillage.

Yield increase due to N fertilization was relatively greater under rainfed condition than irrigated condition. These were 82 and 126% in ZT, 79 and 106% in RT and 145 and 123 in CT with 100 and 140 kg N/ha, respectively (Table 23). Grain yield under ZT increased with increasing N doses at a faster rate than that under RT or CT. This reflects a relatively favorable growing condition under no-tillage in rainfed condition.

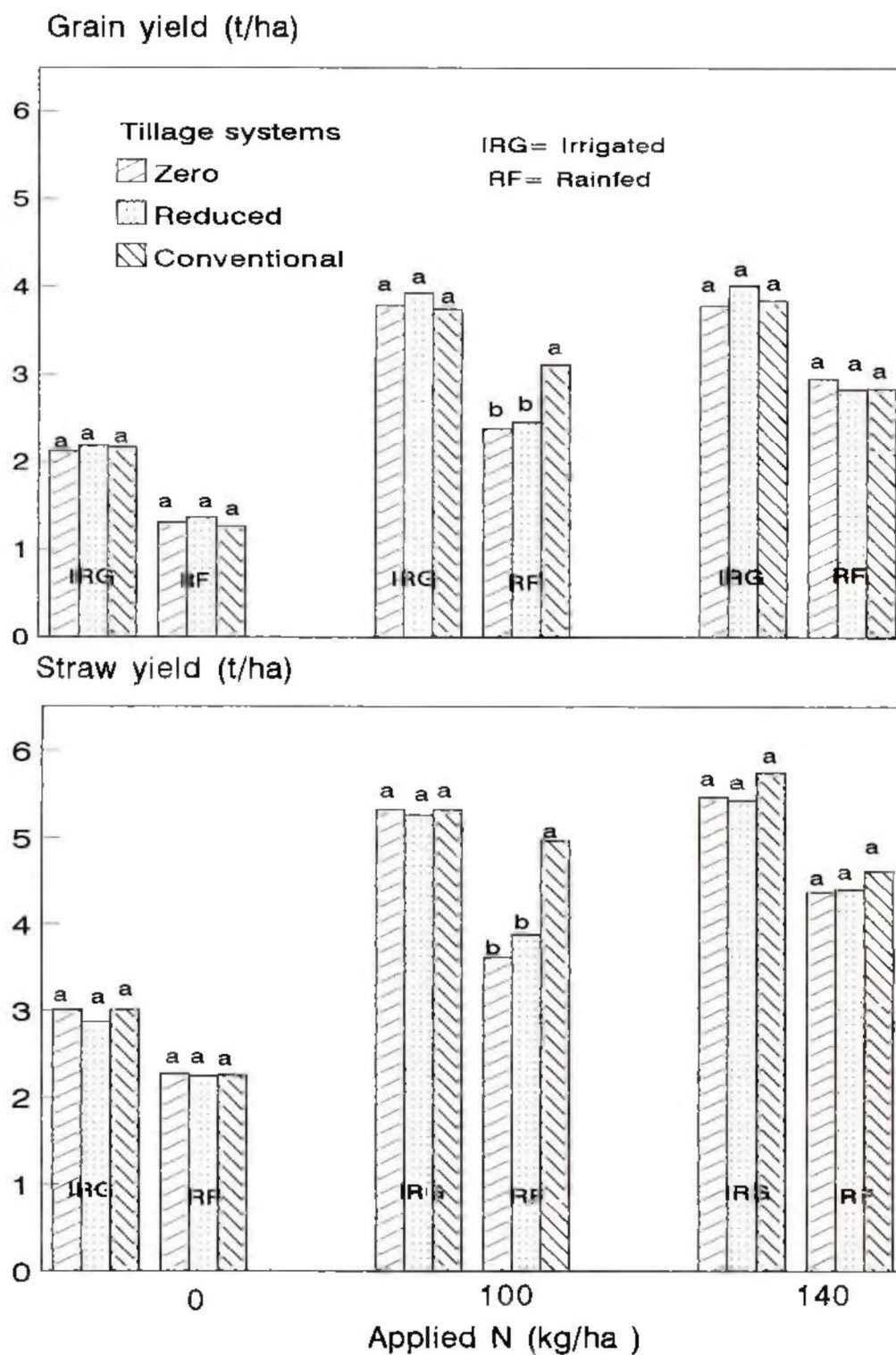


Fig.26. Effect of water regimes, tillage systems, N levels and their interactions on the grain and straw yields of wheat.

A likely explanation is that, soil moisture becomes more yield-limiting in tilled soil than in ZT making it possible for grain yield under ZT to reach higher levels with additional fertilizer N.

Under irrigated condition, the grain yield achieved with 140 kg N/ha in ZT was less than that achieved with 100 kg N/ha in RT (Table 23). Under rainfed condition applied N at 100 kg/ha in CT produced more yield than 140 kg/ha applied N in ZT or RT. These observations shows that tillage increased the N use efficiency. Tillage x N interactions indicate that a higher N rate may be required under ZT to produce wheat yield similar to that under RT or CT. Similar findings were also reported by Phillips *et. al.* (1980) and Wells (1984). The irrigated plots generally produced significantly higher grain and straw yields than the rainfed plot under the different tillage and N levels. This was obviously due to a more favorable soil moisture condition in the irrigated plots. The zero N treatment under irrigation produced higher yield than rainfed condition. For the same yield level a lower N dose was required in irrigated condition compared with rainfed situation. Similar findings were reported by Behera and Sharma (1991) and Gajri *et. al.* (1992).

Table 23. Grain yield increase due to N fertilization under different moisture regimes and tillage systems¹.

Applied N (kg/ha)	Grain yield increase (%) due to N fertilization					
	Irrigated			Rainfed		
	ZT	RT	CT	ZT	RT	CT
100	178	188	173	182	179	245
140	178	192	177	226	206	223

¹Grain yield at zero N = 100%

4.4.5. Mineral nutrition of wheat

4.4.5.1. Nitrogen

Applied N up to 100 kg/ha under ZT and up to 140 kg/ha under RT increased the N concentration in straw while under CT no effect of N fertilization was observed in this regard

(Table 24 and Appendix Table 8.13). At 140 kg/ha applied N, the highest concentration of N in straw was observed under RT, while at other N levels, tillage systems exerted no effect on the straw N content. The N concentration in grain (Table 24 and Appendix Table 8.14) was increased with increasing dose of N up to 140 kg/ha regardless of irrigation and tillage system. A relatively lower concentration of N in straw of wheat under the ZT x O-N treatment combination supported the contention that N is less available in no-till soil (Locke and Hons, 1988).

4.4.5.2. Phosphorus

The P concentration in grain was influenced by T x N and W x T interaction (Table 24 and Appendix Table 8.15 and 8.16)). Irrespective of moisture regimes, increasing level of N application upto 140 kg/ha decreased the P content in grain under zero tillage system, while under RT and CT systems, applied N at 100 kg/ha decreased the P content over no-N treatment, and then no further decrease was observed with additional N. Increasing tillage intensities increased the P content in grain under irrigated condition regardless of N levels, while under rainfed situation the P content was found inconsistent. Inconsistent effect of tillage on the P content in dry matter of cereal crops was reported by several investigators. According to Malhi *et. al.* (1992) conventional tillage resulted in a slightly lower P concentration in barley than zero tillage while, Ellis *et. al.* (1981) pointed out no effect of tillage on the P content in spring barley and winter wheat.

4.4.5.3. Potassium

Nitrogen fertilization did not influence the K content in straw under any moisture regime or tillage system (Table 25 and Appendix Table 4.17 – 4.18). On the other hand, tillage systems did not influence the K content under irrigation when N was not applied, but with applied N, RT had significantly higher K content than ZT or CT. Under rainfed condition, tillage systems did not influence the K content in straw. The straw K content in N treated plots was higher under irrigated condition than under rainfed condition in RT, but in the other tillage system moisture regime did not affect the straw K content. Increasing tillage intensities increased the K content in grain at all N levels under irrigated condition, while under rainfed condition a decreasing trend in K content was observed with increasing tillage intensity. In the ZT and RT systems, the

grain K content was found to be lower under irrigated condition than that under rainfed condition, but in the CT it was the other way round.

Table 24. Interaction effect of moisture regimes, tillage systems, and applied N levels on N and P contents in the straw and grain of wheat grown after T Aman rice.

A. *T X N and W X N Table of means for N content in straw and grain.*

Applied N (kg/ha)	Tillage systems			Moisture regimes		
	ZT	RT	CT	Irrigated	Rainfed	N-mean
Straw(%)				Grain(%)		
0	0.27 bA	0.30 bA	0.32 aA	2.07	2.21	2.14 c
100	0.35 aA	0.32 bA	0.31 aA	2.27	2.25	2.26 b
140	0.32 aB	0.38 aA	0.32 aB	2.38	2.43	2.40 a

B. *T X N and W X T Table of means for P content in grain.*

Tillage systems	Applied N (kg/ha)			Moisture regimes	
	0	100	140	Irrigated	Rainfed
Grain					
Zero	0.47 aA	0.42 aB	0.38 bC	0.41 bB	0.43 aA
Reduced	0.43 bA	0.40 aB	0.40 abB	0.42 abA	0.40 bA
Conventional	0.47 aA	0.42 aB	0.43 aB	0.45 aA	0.43 aA

Under each section(A,B,C), means in a column followed by common small letter(s) and those in a row followed by common capital letter(s) do not differ at 5% level by DMRT.

Table 25. Effect of moisture regime, tillage system, N level and their interactions on the K content in straw and grain of wheat grown after T.aman rice.

Applied N (kg/ha)	Straw-K (%)		Grain- K (%)	
	Irrigated	Rainfed	Irrigated	Rainfed
<i>Zero tillage</i>				
0	1.56 aA	1.37 aA	0.35 aA	0.37 aA
100	1.56 aA	1.47 aA	0.32 bB	0.36 aA
140	1.59 aA	1.43 aA	0.30 bB	0.33 bA
<i>Reduced tillage</i>				
0	1.57 aA	1.37 aA	0.38 aA	0.36 aA
100	1.95 aA	1.51 aB	0.34 aA	0.34 aA
140	1.96 aA	1.59 aB	0.33 aA	0.34 aA
<i>Conventional tillage</i>				
0	1.58 aA	1.34 aB	0.38 aA	0.34 aB
100	1.61 aA	1.59 aA	0.36 aA	0.32 aB
140	1.59 aA	1.56 aA	0.35 aA	0.33 aA

Means in a column followed by common small letter(s) and in a row followed by common capital letter(s) do not differ significantly at 5% level by DMRT.

Component	Comparison	LSD(.05)
Straw	2-T means at each I X N	0.16
Grain	2-T means at each I X N	0.02

4.4.5.4. Micronutrients

The Fe content in wheat straw and grain was the highest under RT followed by that under CT and ZT irrespective of moisture regime and N level (Table 26 and Appendix Table 8.19 – 8.22). Tillage intensity increased the Fe content in grain under irrigated condition and decreased under rainfed condition. Nitrogen x moisture regime interaction effects indicated that applied N at 100 kg/ha increased the grain Fe content which decreased with a further increase in the N dose under irrigated condition, while under rainfed condition the higher level of applied N (140 kg/ha) increased the grain Fe over 0 and 100 kg/ha N. The grain Fe content was significantly higher under irrigated condition than that under rainfed at 100 kg N/ha, but at the other N levels no effect of moisture regime in this regard was observed.

The concentration of Zn in straw decreased with increasing tillage intensity under irrigated condition while under rainfed situation the Zn content increased from ZT to RT but declined with CT (Table 26). Nitrogen fertilization did not influence the Zn content in straw under irrigated condition, but under rainfed condition N application significantly decreased the same from the no-N treatment. Regardless of N fertilization, increasing tillage intensity increased the grain Zn content under irrigated condition but under rainfed situation no effect of tillage was observed. Compared to irrigated plots, wheat in rainfed plots had a higher grain Zn content under ZT, but under RT or CT moisture regime did not influence the grain Zn content.

Under irrigated condition N application significantly increased the Mn concentration in straw with all tillage system, but generally an opposite effect of N was observed in this regard under rainfed condition (Table 27 and Appendix Table 8.23 – 8.24). Tillage systems did not affect the straw Mn content at any N level under irrigated condition, while under rainfed condition, increasing tillage intensity in absence of applied N decreased the straw Mn content. The concentration of Mn in grain was influenced by tillage x N interactions (Table 26). Nitrogen application decreased the Mn concentration in grain irrespective of tillage system. The highest grain Mn content was observed under ZT, which decreased consistently with increasing tillage intensity. Nitrogen application significantly increased the Cu content in straw under irrigated condition, while under rainfed condition straw Cu content decreased with increasing N dose (Table 28 and Appendix Table 8.25 – 8.26).

Table 26. Interaction effects of moisture regimes, tillage systems and N levels on the Fe and Zn contents (ppm) in straw and grain of wheat grown after T.Aman rice.

A. Table of means for Fe content in straw and grain (ppm).

Tillage systems	Moisture regimes			Moisture regimes		Applied N (kg/ha)	Moisture regimes	
	Irrigated	Rainfed	T-mean	Irrigated	Rainfed		Irrigated	Rainfed
	Straw			Grain			Grain	
Zero	174	178	176 b	43 bB	56 aA	0	45 bA	47 bA
Reduced	221	215	218 a	58 aA	46 bA	100	57 aA	45 bB
Conventional	184	185	185 b	52 abA	46 bA	140	51 abA	56 aA

B. W X T and W X N Table of means for Zinc content in straw and grain (ppm).

Tillage systems	Moisture regimes		Moisture regimes		Applied N (kg/h)	Moisture regimes	
	Irrigated	Rainfed	Irrigated	Rainfed		Irrigated	Rainfed
	Straw		Grain			Straw	
Zero	34 aA	30 bA	44 bB	53 aA	0	32 aB	36 aA
Reduced	32 abB	40 aA	53 aA	49 aA	100	32 aA	32 bA
Conventional	31 bA	30 bA	52 aA	50 aA	140	34 aA	31 bA

For each element and component (straw and grain), means in a column followed by common small letter(s) and in a row followed by common capital letter(s) do not differ significantly at 5% level by DMRT.

Table 27. Effect of moisture regime X tillage system X N level interactions on Mn content in straw and effect of T X N interactions in grain Mn content of wheat grown after T.Aman rice.

A. *W X T X N Table of means for Mn in straw (ppm)*

Tillage	Applied N (kg/ha)	Moisture regimes	
		Irrigated	Rainfed
Zero	0	17 bB	31 aA
	100	18 bA	20 bA
	140	25 aA	19 bB
Reduced	0	25 bA	23 cA
	100	24 bA	29 aA
	140	28 aA	26 bA
Conventional	0	20 cA	22 aA
	100	23 bA	21 aA
	140	27 aA	21 aB

B. *T X N Table of means for Mn in grain(ppm)*

Applied N (kg/ha)	Tillage systems		
	Zero	Reduced	Conventional
0	49 aA	44 aA	49 aA
100	46 aA	44 aA	41 bA
140	46 aA	45 aA	39 bB

Under A and B, means in a column followed by common small letter(s) and in a row followed by common capital letter(s) do not differ significantly at 5% level by DMRT.

Component	Comparison	LSD (.05)
Straw	2-T means at each W X N	8

Compared to irrigated treatment, the rainfed treatment had a significantly higher concentration of Cu in straw at 0 or 100 kg/ha N, but at the higher N no significant difference between the moisture regimes was observed. Under irrigated condition the Cu concentration in grain increased with increasing tillage intensity, but under rainfed condition a decreasing trend was observed. With ZT, the grain Cu content was significantly lower under irrigated condition than rainfed condition, but under RT or CT, the moisture regimes differed minimally in terms of grain Cu content.

Table 28. Effect of moisture regime, tillage system, N level and their interactions on the Cu content in straw and grain of wheat grown after T.Aman rice.

Applied N (kg/ha)	Moisture regimes		Tillage systems	Moisture regimes	
	Irrigated	Rainfed		Irrigated	Rainfed
Straw (ppm)			Grain(ppm)		
0	3.04 bB	3.59 aA	Zero	3.65 bB	4.93 aA
100	3.00 bB	3.33 bA	Reduced	4.45 aA	4.59 aA
140	3.27 aA	3.18 bA	Conventional	4.87 aA	4.36 aA

Under each component (straw and grain), means in a column followed by common small letter(s) and in a row followed by common capital letter(s) do not differ significantly at 5% level by DMRT.

4.4.6. Total N uptake and use efficiency

4.4.6.1. Total N uptake

Averaged over tillage systems successive increases in the N dose up to 140 kg/ha significantly increased the total N uptake under both irrigated and rainfed conditions (Table 29 and Appendix Table 8.27 – 8.30). A significantly higher amount of N was taken up by the wheat plants under irrigated condition than under rainfed condition at all applied N levels.

Table 29. Effect of moisture regimes, tillage systems, N levels and their interactions on the N uptake, percent N recovery and N use efficiency of wheat grown after T.Aman rice.

A. W X N Table of means for N uptake (kg/ha) and physiological efficiency of N (kg grain/kg absorbed N).

Applied N (kg/ha)	Moisture regimes		Moisture regimes		
	Irrigated	Rainfed	Irrigated	Rainfed	N-means
	N uptake		physiological efficiency of N		
0	51 cA	36 cB	41	37	39 a
100	104 bA	74 bB	37	36	37 b
140	112 aA	85 aB	36	34	35 c
W-mean			38 A	36 B	
CV for sub plot (b) = 15.1%			CV for (b) = 10.3%		
CV for sub-sub plot (c) = 11.4%			CV for (c) = 6.1%		

B. W X N and T X N Table of means for % N recovery (kg N uptake/100 kg applied N).

Applied N (kg/ha)	Moisture regimes		Moisture regimes		
	Irrigated	Rainfed	Zero	Reduced	Conventional
100	53 aA	38 aB	42 aB	42 aB	52 aA
140	43 bA	35 aB	40 aA	42 aA	36 bA
CV for (b) = 39.6% and CV for (c) = 25.6%					

C. W X T X N Table of means for agronomic efficiency of fertilizer N (kg grain/kg applied N)

Tillage systems	Applied N (kg/ha)	Moisture regimes	
		Irrigated	Rainfed
Zero	100	17ab	11 ab
	140	12 bA	12 aA
Reduced	100	20 aA	11 aB
	140	15 bA	11 aB
Conventional	100	17 aA	19 aA
	140	13 bA	11 bA

CV for (b) = 34.2% and CV for (c) = 21.1%

Under each section (A,B,C), means followed by common small letter(s) in a column and by capital letter(s) in a row do not differ significantly at 5% level by DMRT.

Component	Comparison	LSD(.05)
kg grain/kg applied N	2-T means at each W X N	4

The total N extraction (kg/ha) ranged from 51 to 112 in irrigated condition, and 36 to 85 in rainfed condition. An increase in the N dose increased the N uptake, because the increase in the supply of N not only increased the N concentration in plant but also resulted in a higher dry matter production. These results agree well with those of Gordon and Rickerl (1992).

A reduction in N uptake with water deficit can be attributed to (i) decreased plant demand as a result of reduced growth and (ii) decreased transpiration which is correlated with nutrient uptake (O'Toole and Baldia 1982). The maximum N uptake at the highest level of N supply coupled with irrigation was also reported by Sharma *et al.* (1992).

4.4.6.2. Nitrogen use efficiency

Increasing level of N application decreased the physiological efficiency of N (kg grain/kg absorbed N) irrespective of moisture regime and tillage system. Irrigated plots had higher physiological efficiency of N than that of rainfed situation regardless of tillage systems and N levels (Table 29). The percent recovery of added N (kg absorbed N/100 kg applied N) was influenced by water x N and tillage x N interactions. An increase in the N dose from 100 to 140 kg/ha significantly decreased the percent N recovery under irrigated condition while under rainfed condition the N levels did not affect N recovery (Table 29). The N recovery was greater under irrigated condition than under rainfed condition at all N levels. Increased dry matter production with improved moisture condition may be the reason of greater N recovery under irrigated condition. Similar findings were also reported by Guer *et al.* (1992). Under ZT or RT, the N use efficiency (NUE) in terms of kg grain per kg applied N was significantly lower at the 140 kg/ha N than 100 kg/ha N under irrigated condition, but under rainfed condition, no difference between the two N doses was observed, while under CT, NUE was higher at the lower N dose (Table 29). Irrespective of tillage systems, NUE was generally higher under irrigated condition than under rainfed condition. Greater yield potential and improved N mobility in the soil under irrigated condition may explain the result. Increased NUE and percent N recovery under adequate moisture over water deficit were also reported by Guer *et al.* (1992).

4.5. Experiment 5. Tillage and Nitrogen effect on wetland rice performance

4.5.1. Physical properties of soil

4.5.1.1. Percolation

Percolation of the soil is one of the most important physical properties (Parr and Bertrand, 1960). Percolation has been reported to vary from 0.1 to several hundred mm day⁻¹ (Sharma and De Datta, 1992) and is influenced by a variety of environment and soil related factors (Wickham and Sing, 1978). The magnitude of the decline in percolation depends on soil texture, structure, clay mineralogy and organic matter content. Lal (1985) observed that percolation of water through rice soil is essential. In general low percolation rate (<2mm day⁻¹) was observed in all treated plots in this study (Table 30). Tillage practices influenced the percolation rate of the soil. The percolation rate of the soil was maximum in ZT plots while the minimum percolation rate was recorded in CT plots. In the puddled soils, percolation rate increased with increasing tillage depth. Compaction and shearing by farm implements may create a compact subsurface zone often called plough pan (Moormenn and vanBreeman, 1978). In addition, settling and consolidation of dispersed clay particles may occur (Sharma and De Datta, 1985 and Adachi, 1992). Both compaction and clay translocation may reduce the percolation rate in puddled soil, while partial breaking of dense impervious pan by deep tillage may enhance the percolation rate.

Table 30. Effect of tillage level on percolation rate of a silty clay soil during T. Aman rice culture.

Tillage practices	Depth of ponding water (cm)	Number of observation (days)	Percolation rate (mm day ⁻¹)
Zero Tillage	5-7	25	1.84
Conventional Tillage	5-7	25	1.45
Deep Tillage	5-7	25	1.66
LSD (.05)			0.17

4.5.1.2. Bulk density

At transplanting, bulk density (BD) values varied considerably for different tillage treatments in surface and subsurface soil layer up to 15-20 cm soil depth. Conventional tillage influenced the BD up to 10-15 cm layer and DT influenced the same up to 15-20 soil layer while no remarkable influence was observed under ZT treatment with increasing depth of profile (Fig. 27). The highest BD in the layers up to 15-20 cm soil depth was observed in plots having ZT followed by CT and DT plots. Bulk density under CT was almost similar as that under DT but was lower than that under ZT up to 10-15 cm soil depth. With increasing depth of profile, BD increased considerably as compared to corresponding values in surface layer under all tillage treatments. Bulk density under CT increased gradually from 0.90 g/cm³ at 5-10 cm layer to 1.15g/cm³ at 10-15 cm layer and then sharply to 1.55g/cm³ at 15-20 cm soil depth. Bulk density under DT, increased gradually with the increased of soil depth from 0.85 g/cm³ at 0-5cm layer to 1.05g/cm³ at 15-20 cm soil layer and then sharply to 1.53g/cm³ at 20-25 cm soil depth. The differences among tillage treatment narrowed down at lower soil depth below 10-15 cm soil layer under ZT and CT and 15-20 cm soil layer under DT.

At harvest, BD in the 0-15 cm soil layers under CT and in the 0-20 cm soil layers under DT increased substantially as compared to corresponding values at planting. Like the BD values at planting, the highest value of the soil BD at harvest was observed in plots having ZT followed by CT and DT up to 15-20 cm soil depth and then with further increase of profile depth, the differences among tillage levels narrowed down to almost nil. Unlike the planting time, the differences in BD at harvest ranged with in narrow limits in different tillage treated plots. The results presented above indicated that different tillage treatments had considerable influence on bulk density, both in the surface and subsurface layers of the profile. The decrease in BD in tilled plots may be attributed to tillage which made the soil loose and porous. The increased bulk density in the surface and subsurface layers of the profile at harvest as compared to corresponding values at planting may be due to settling of soil particles with time. Saito (1995) and Ganur (1989) also reported the increased BD in puddled soil with time. At transplanting the increased BD in ZT (1.58g/cm³) and in CT (1.55g/cm³) at 15-20 cm soil layer may indicate the presence of compact layer. Working with soils of different regions of Bangladesh Rahman *et al.* (1992), Hannan (1995) and Mollah (1995) also reported the

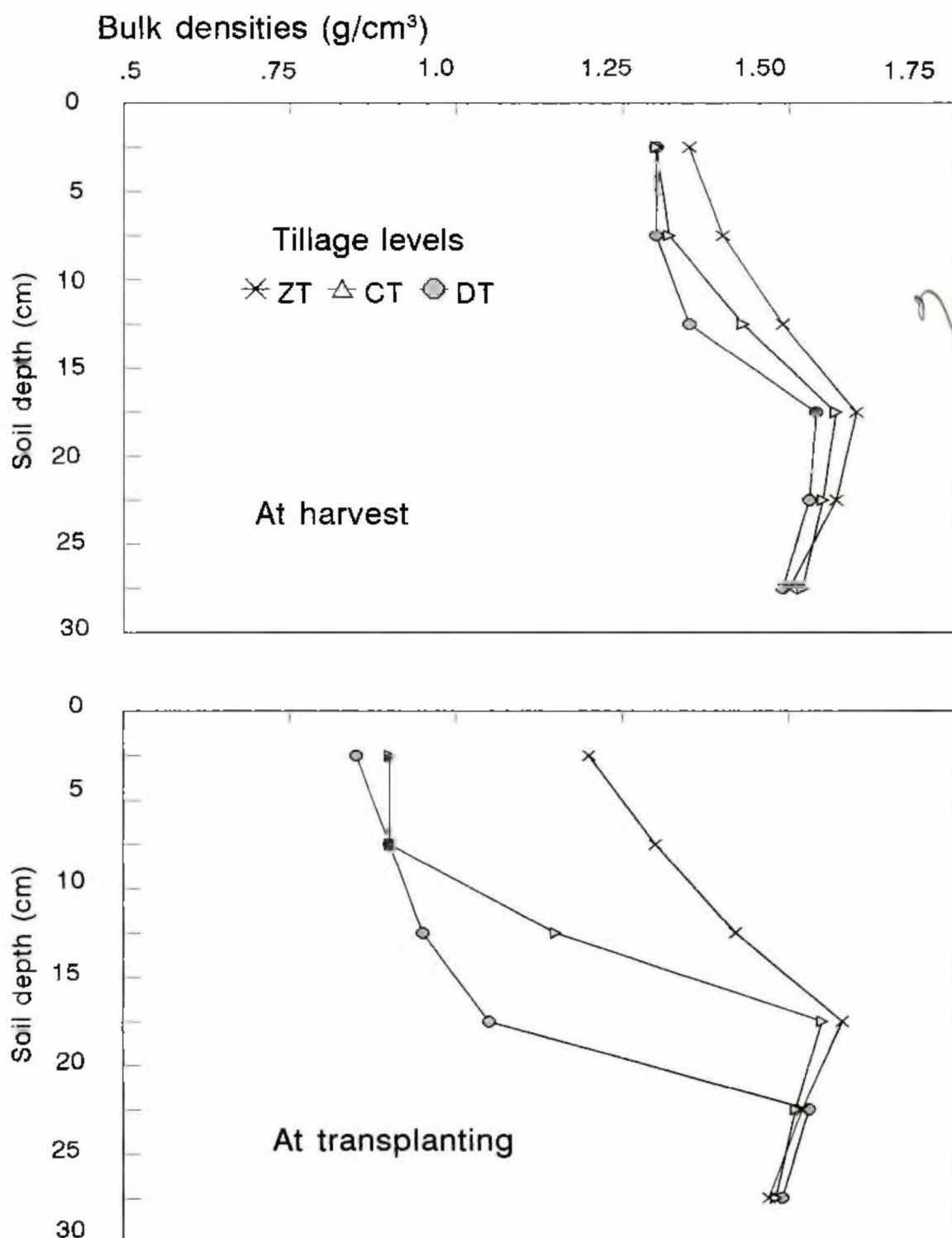


Fig.27. Effect of tillage levels on soil bulk densities at different depth of wet season rice soil.

presence of compact layer of high BD formed at shallow depth (10-15 cm) below the surface in almost all the soils.

4.5.2. Yield components

Application of N fertilizer increased the panicle number irrespective of tillage treatment. Panicle number increased with the increase of N levels up to 100 kg N/ha in ZT, while under CT and DT, panicle number increased up to 80 kg N/ha (Table 31 and Appendix Table 9.1). Regardless of N levels, tilled plots produced higher number of panicles than no tilled plots. Tillage levels did not significantly influence the number of filled grain per panicle but there was a significant positive effect of N fertilization (Table 30 and Appendix Table 9.2). Irrespective tillage levels, application of 60 kg N/ha significantly increased the number of spikelets per panicle over N control, but further increase was not observed beyond this level. Tillage levels and N level either singly or in combination had no significant effect on the weight of 1000 filled grain of rice (Table 31 and Appendix Table 9.3).

Tillage levels and N fertilization significantly influenced the percent unfilled grain of BR11 rice (Table 31 and Appendix Table 9.4). Irrespective of tillage levels, application of 80 kg N/ha significantly increased the sterility percentage over N control but further increase was not observed beyond this N level. Regardless of N levels, tillage treatment reduced the grain sterility percentage over no tillage treatment. The total spikelet volume in which starch may accumulate and the amount of starch which actually accumulates in spikelets; are the two factors which may determine the yield of rice (Tanaka *et al.* 1964). The former is generally increased by N application, but the latter does not necessarily increase with an increase in N level. This may be the reason of higher grain sterility percentage at higher N levels.

Table 31. Effect of Tillage practices and N levels on Yield component of T. Aman rice.

Applied N (kg/ha)	Tillage systems			
	ZT	CT	DT	N-Mean
No. of panicles/m²				
0	187	207	194	196
60	192	220	212	208
80	207	223	241	224
100	217	216	218	217
T-Mean	201	216	216	211
No. of filled grains/panicle				
0	80	88	91	86
60	95	105	108	103
80	96	102	104	101
100	103	104	106	104
T-Mean	94	100	102	98
1000 grain weight (gram)				
0	22	23	23	22
60	23	22	23	23
80	23	23	22	23
100	22	23	23	22
T-Mean	22	23	23	22
Percent unfilled grain				
0	26.7	24.3	25.3	25.4
60	28.0	25.7	27.0	26.9
80	31.3	26.9	28.0	28.4
100	30.0	28.6	29.0	29.2
T-Mean	29.0	26.4	27.3	27.6

Parameters	CV (b)	Comparison	S.E.D	LSD (5%)
No. of panicles/m²	5.9%	2-N means at each T	10.0	21.0
		2-N means	6.0	12.0
Filled grain/panicle	11.0%	2-N means at each T	9.0	18.0
		2-N means	5.0	11.0
1000 grain weight	3.1%	ns		
% unfilled grain	7.3%	2-N means at each T	1.6	3.4
		2- N means	0.9	2.0

4.5.3. Grain and straw yield

Tillage and applied N levels influenced the grain and straw yield of rice (Fig. 28 and Appendix Table 9.5 and 9.6). The quadratic response model gave the best fit of grain and straw yield to N rate under all tillage systems. At all tillage methods, application of 60 kg N/ha significantly increased the grain and straw yield over N control, but no appreciable yield increase was observed at higher N levels. Irrespective of N levels, CT produced the highest yield followed by DT and ZT. The yield gap between tilled and no tilled plots was wider at 60 kg N/ha and then the differences narrowed down with further increase of N levels. Though the CT and DT plots produced better yield but the values were statistically similar with the yield obtained with ZT.

The application of N fertilizer led to better nutrition of the rice crop throughout its growth period enhancing vegetative growth, increasing the number of panicles per unit area and spikelets per panicle (Table 31) finally resulting increased grain and straw yields. A higher yield on tilled soil than on untilled soil when no N fertilizer was used probably resulted from release of more available N when the soil was tilled (Fig. 2.). A higher yield on tilled soil than on no-tilled soil when N fertilizer was applied suggest that a higher fertilizer N dose would be required on a no-till than on a tilled soil to obtain comparable yield . Similar findings were also observed in Experiment 1. Relatively favorable soil physical conditions for root proliferation as indicated by low soil bulk density in CT and in DT in comparison with ZT (Fig. 27) may also explain the better rice yield in CT and DT. The better rice yields either with CT or with DT due to favorable soil physical condition for root proliferation were also reported by Choudhury *et al.*, (1985) and Rahman and Islam, (1987).

Considering the grain yield with ZT system as 100%, the yield increase due to tillage practice ranged between 3% and 16% (Table 32.). The highest yield increase was found under CT (16%) with 60 kg applied N/ha and the lowest (3%) under DT with 80 kg N/ha. Nitrogen fertilization influenced the benefit of yield increase due to tillage practice. At all N levels, yield increase due to tillage systems was found lower in DT than that of CT. The benefit of yield increase due to tillage increased with applied N up to 60 kg/ha and then decreased with further increase of N levels. It is assumed that the N requirements of T. Aman rice is relatively low.

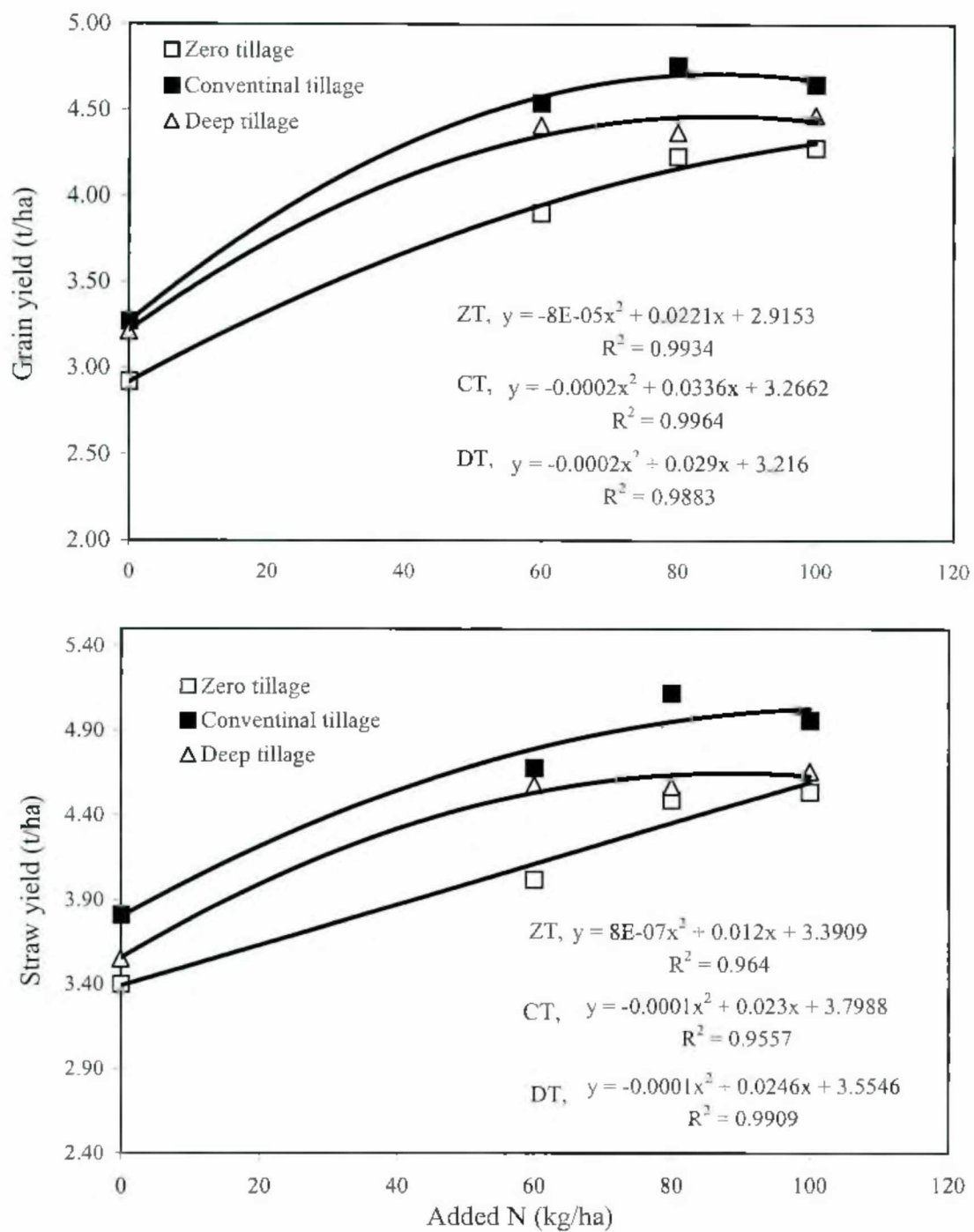


Fig. 28. Fitted regression depicting the effect of Tillage and N levels on grain and straw yield of wet season rice.

The increased N availability due to enhanced mineralization in tilled soil in combination with 60 kg N/ha may fulfil the N requirements of T. Aman rice to produce optimum yield. Higher level of applied N beyond 60 kg/ha in combination with increased available N in tilled soil may provide more than enough N for T. Aman rice.

Table 32. Grain yield increase (%) due to tillage treatment at different applied N levels¹.

Tillage systems	Applied N (kg /ha)			
	0	60	80	100
CT	112	116	112	108
DT	110	113	103	104

¹ Grain yield at ZT= 100%

The luxuriant N supply finally decreases the N use efficiency. This may explain the result of lower benefit of yield increase due to tillage levels at higher N levels. When N fertilizer was applied in DT fertilizer granules were distributed to a larger volume of soil in comparison with CT resulting in the dilution effect of the N fertilizer which may explain the lower yield benefit in DT as compared with CT at all N levels.

4.6. Experiment 6. Tillage and irrigation effects on some soil physical properties and the performance of post- rice wheat.

4.6.1. Physical properties of soil

4.6.1.1. Infiltration

The infiltration rate (IR) and cumulative infiltration (CI) were studied during the wheat growing period. Tillage treatments influenced the IR (Fig.29). During the initial 1 minute, the fastest IR ($27.00 \text{ mm min}^{-1}$) was observed in the MT and the lowest rate ($24.50 \text{ mm min}^{-1}$) in the CT plots, the IR for DT being in between (mm min^{-1}). With time, IR decreased rapidly in all tillage treated plots. At the end of 400 minutes, IR ranged between 0.28 mm min^{-1} for CT and 0.42 mm min^{-1} for DT. The time of attaining a steady IR was also different for different tillage treatment. The steady IR was obtained earlier for DT than that for DT or MT. The relationships between the IR through the soil profile and elapsed time were obtained as:

$$\text{DT : IR} = 18.672 t^{-0.5379} \quad (R^2=0.9276)$$

$$\text{CT : IR} = 21.043 t^{-0.6930} \quad (R^2=0.9853)$$

$$\text{MT : IR} = 34.246 t^{-0.7356} \quad (R^2=0.9826)$$

In all cases the value of R^2 was close to unity indicating that the relationship between IR and elapsed time would be well represented by the function $I = at^{-n}$. Both the values of 'a' and 'n' varied with tillage levels and decreased with depth of tillage.

Tillage treatments also influenced the CI of the soil (Fig.30.). Initially CI was the highest for MT but after 100 minutes CI become the highest for DT. At any time CI was the lowest for CT. After 400 minutes, CI values ranged from 62.4 cm for DT to 34.4 cm for CT. The relationship between CI and elapsed time was found to be opposite that between IR and elapsed time. For DT, CT and MT the relationships obtained were:

$$\text{DT : CI} = 2.3130 t^{0.5573} \quad (R^2=0.9954)$$

$$\text{CT : CI} = 2.5678 t^{0.4446} \quad (R^2=0.9975)$$

$$\text{MT : CI} = 3.6968 t^{0.548} \quad (R^2=0.9801)$$

In this case too, the value of R^2 was very high and close to unity implying that CI was functionally related to elapsed time as: $CI = at^n$

minimum
Tillage = MT ?
Fig 29
Is it
true?

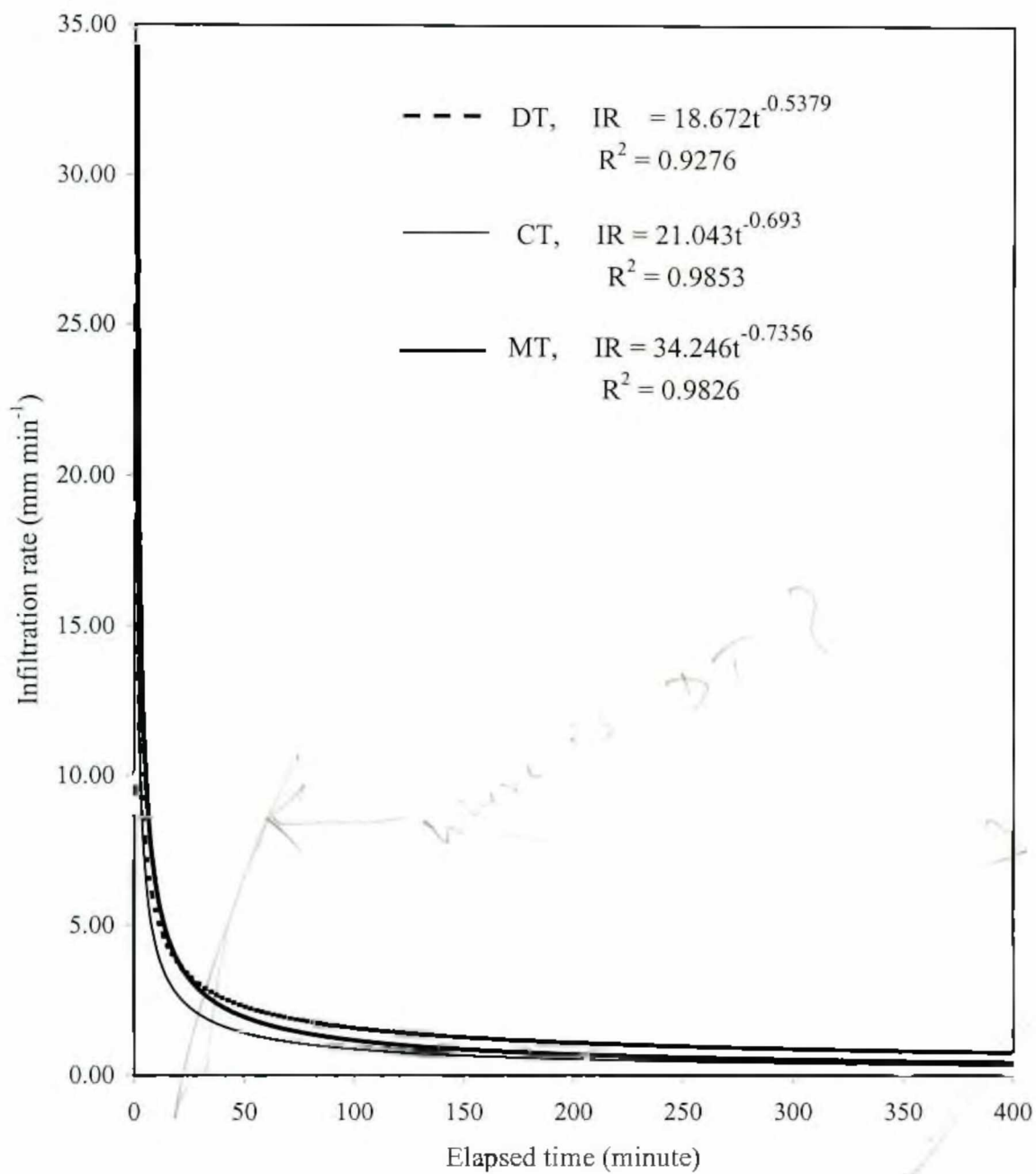


Fig.29. Effect of different tillage treatments on the infiltration rate (mm min^{-1}) as a function of time during wheat season in silty clay soil.

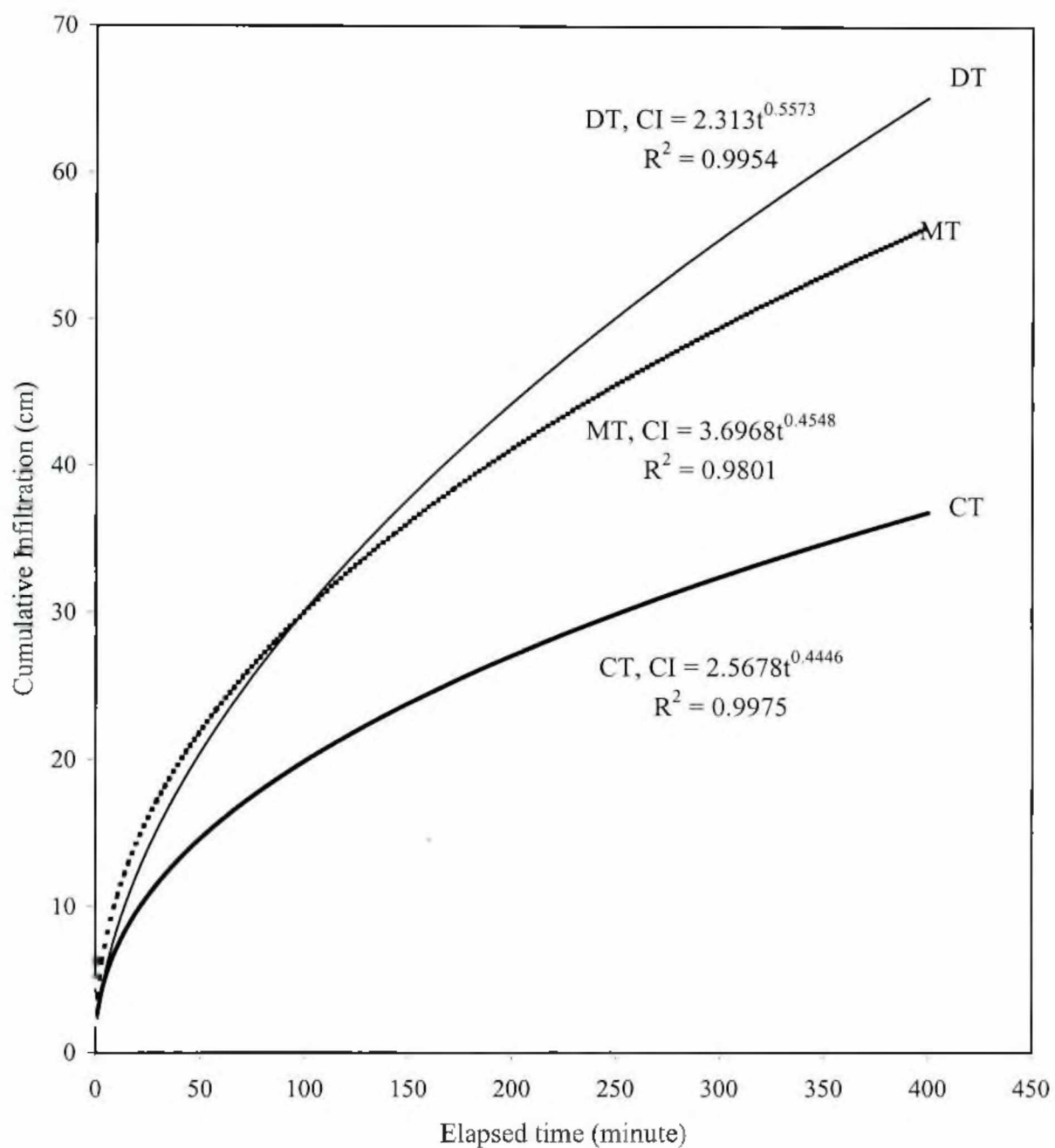


Fig.30. Effect of different tillage treatments on cumulative infiltration (cm) as a function of time during wheat season in silty clay soil.

The magnitude of 'a' indicated the cumulative infiltration at $t = 1$ and 'n' its rate of increase. It was observed that the value of 'a' varied for different tillage treatment and the value of 'n' increased with deep tillage.

The higher IR for DT compared with MT and CT are attributed to change in soil bulk density and breaking of dense impervious pan by deep tillage. Lindstorm *et al.*, (1984) also found greater infiltration in the tilled clay loam soil than in no tilled plots. These findings were also in agreement with the findings of Karim *et al.*, (1983) and Reddy *et al.*, (1983) where they observed increased water intake in deep ploughing. Infiltration rates might increase with deep ploughing due to decementation of the profile by deep cultivation (Vital *et al.*, 1983).

4.6.1.2. Soil moisture depletion of the profile

The cumulative moisture depletion (CMD) of the profile during wheat growing season as influenced by tillage treatments and moisture regimes is presented in fig.31. Under any tillage level, CMD increased with time throughout the growing season under both irrigated and rainfed situation. Under any tillage level, the moisture content in the profile depleted slowly at the early growth stage of wheat and sharply at the vegetative and reproductive stages and again gradually at ripening stage regardless of moisture regimes. The rate of moisture depletion was faster in irrigated plots than in rainfed plots. With the passage of time the differences in CMD among the tillage treatments increased under both irrigated and rainfed conditions. For example at 30 days after sowing (DAS) the CMD for MT, CT and DT were 15.5, 18.0 and 18.0 mm; at 60 DAS the CMD for MT CT and DT were 37.0, 44.0 and 49.0 mm; and at 90 DAS the CMD for MT CT and DT were 49.0, 56.0 and 66.0 mm under rainfed condition. Under irrigated condition, the CMD at 30 DAS for MT, CT and DT were 22.5, 21.5 and 24 mm, at 60 DAS the CMD for MT, CT and DT were 61.5, 63.5 and 69.0 mm and at 90 DAS the CMD for MT, CT and DT were 93.0, 98.0 and 107.0 mm.

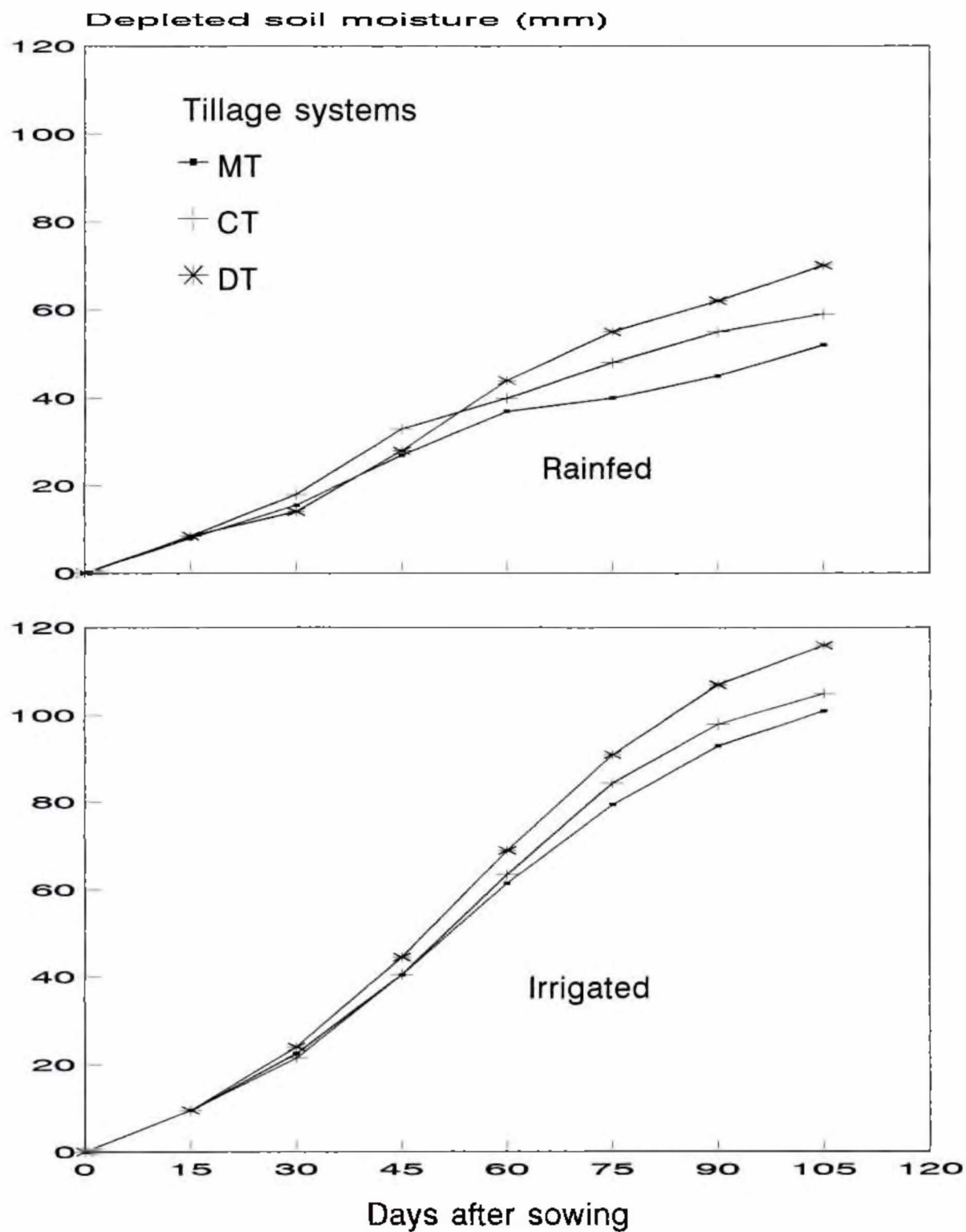


Fig.31. Depletion of cumulative profile moisture contents in the upper 60 cm layer as influenced by tillage levels under irrigated and rainfed condition during wheat growing period.

Higher rate of soil moisture depletion during vegetative and reproductive stage may indicate higher extraction of soil profile moisture by wheat during these growth stages. Moisture depletion was higher in plots having deep tillage. This may be due to higher vegetative growth and better root proliferation in deep-tillage plots which might have encouraged increased absorption of water by the crop. Higher moisture depletion in DT compared to MT was also observed by Karim *et al.*, (1983), Lindstorm *et al.*, (1984), and Nyborg and Malhi (1989). The higher cumulative soil moisture depletion by wheat grown under DT indicates that deep tillage may be a useful practice for wheat to utilize considerably greater residual moisture from the soil profile and thus grow and yield well even in rainfed condition.

4.6.1.3. Tillage effect on moisture retention characteristics

The effect of tillage on moisture retention characteristics in the top 0-10 cm soil layer is shown in figure 32. The soil moisture retention curve relates the soil water content to metric potential or metric suction of soil. The moisture content of soil decreased due to the draining of larger pores initially and progressively followed by smaller pores, causing an increased in tension above 0 bar on MPa. Thus the shape of the moisture retention curve shows the picture with which the water is extracted from the soil for any applied suction and gives the content of moisture retained in the soil against the suction. In this study the tillage treatment did not remarkably influence the soil moisture retention characteristics at any suction.

The moisture retention curve in general, indicated that the soil remain near saturation up to about in Pa value of 0.10, which corresponded to a tension of 100 cm of water. This implied that the soil was devoid of large pores as could be expected for alluvial soil where coarse sand are practically absent. Moisture content of the soil decreased sharply with increasing suction applied to the soil up to 5 MPa and then decreased gradually with further increase of suction. The lack of evidence on the influence of tillage treatments on moisture retention characteristics may be attributed to the fact that measurement of moisture retention was made at the end of cropping season, about 100 days after sowing. It might be possible that during this period the soil particles settled down and thereby nullified the influence of tillage treatment on moisture retention characteristics.

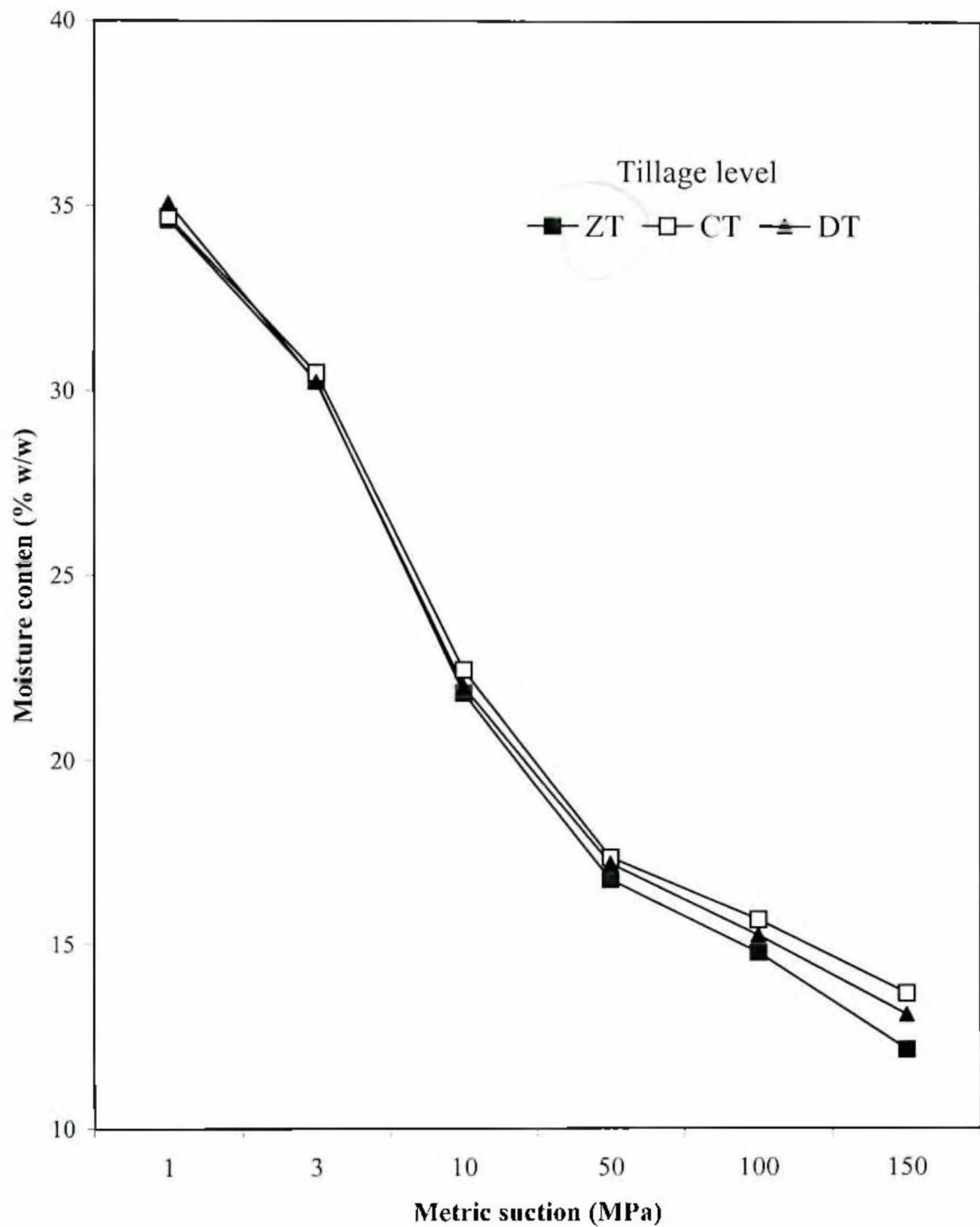


Fig. 32. Influence of tillage on moisture retention characteristics of a silty clay soil under various metric suction in rabi season.

4.6.1.4. Total water use

The total water use by wheat during the rabi season as influenced by tillage and moisture regimes is presented in Table 33. Under both irrigated and rainfed conditions, different tillage considerably influence the total water use by wheat. Under both moisture regimes, the highest value of water use was obtained in the DT plots and the lowest values in the MT plots. Conventional tillage showed intermediate values. In general, total water use increased with increasing depth of tillage in both the moisture regimes. Higher water use in plots having deep tillage may be explained by increased water retention in the profile. A comparison of water use under similar tillage treatments in the two moisture regimes revealed that water use was comparatively higher for crops grown under irrigated condition than those grown under rainfed plots. This was obviously due to a more favorable soil moisture condition in the irrigated plots. Besides, comparatively better vegetative growth and better root proliferation under irrigated condition might have encouraged increased absorption of water by the wheat root system. This present findings were in agreement with the findings of Rahman and Islam (1987) where they observed higher values of total water use in deep-tilled plots compared to conventionally tilled ones.

Table 33. Influence of different tillage levels and moisture regimes on the total water use by wheat crop during rabi season in silty clay soil.

Tillage practices	Irrigation water applied (cm)	Profile moisture depletion (cm)	Rain fall during crop growing period(cm)	Total water use (cm)
Rainfed				
MT	Nil	5.2	Nil	5.2
CT	Nil	5.9	Nil	5.9
DT	Nil	7.0	Nil	7.0
Irrigated				
MT	14.5	10.1	Nil	24.9
CT	14.5	10.5	Nil	25.3
DT	14.5	11.6	Nil	26.4

Based on what?
 Page 118

4.6.2. Growth parameters and yield components

4.6.2.1. Root growth

Tillage treatments and moisture regimes markedly influenced root length density (RLD) of wheat in different soil layers (Table 34). Roots present per unit volume of soil was considerably greater in the upper soil layer than at greater depth. Regardless of tillage level and moisture regime, about 80% of the total root length was distributed in the 0-30 cm soil layer. The roots did not grow very deep but were still present at 50-60 cm soil depth although minimally. Root penetration was significantly higher in the DT plots than in the CT or MT plots. Irrespective of moisture regime, the growth of wheat roots was mostly restricted to the 0-20- cm soil layer under MT or CT and to the 0-30 cm soil layer under DT plots. Regardless of tillage treatments, the rainfed plots gave lower RLD values than irrigated plots. The application of irrigation water increased the RLD up to 20 cm soil depth in MT and CT and up to 30 cm soil depth in DT plots.

Table 34. Effect of tillage levels and moisture regimes on root length density (cm cm^{-3}) of wheat at different soil depth.

Soil depth (cm)	Minimum tillage		Conventional tillage		Deep tillage	
	Irrigated	Rainfed	Irrigated	Rainfed	Irrigated	Rainfed
0-10	1.52	1.08	1.61	1.32	1.38	1.18
10-20	1.26	1.20	1.56	1.42	1.68	1.43
20-30	0.80	0.74	1.01	0.94	1.16	1.25
30-40	0.48	0.45	0.46	0.43	0.48	0.55
40-50	0.28	0.26	0.22	0.20	0.30	0.28
50-60	0.12	0.10	0.09	0.08	0.14	0.12

Regardless of tillage treatments, the rainfed plots gave lower RLD values than irrigated plots. The application of irrigation water increased the RLD up to 20 cm soil depth in MT and CT and up to 30 cm soil depth in DT plots. Neither moisture regime nor tillage level affected the RLD in the deeper soil layer. Deep tillage encouraged vertical penetration of wheat roots in the soil. Loosening of the soil in deep tillage through breaking the hardpan showed a favorable effect on the vertical penetration of roots. Similar effects of deep tillage on root growth have been reported by Ehlers et al, (1983) and Chaney *et al.* (1985).

4.6.2.2. Plant height and tiller production

The plant height and the number of tillers at maturity as affected by moisture regimes and tillage systems are presented in Table 35 and ANOVA in Appendix Table 10.1-10.2. Tillage level did not influence the plant height under any moisture regime. A comparison of plant height under the two moisture regimes for any given tillage treatment revealed that, irrigation significantly increased the plant height over the rainfed situation. Tillage level and moisture regime significantly influenced the number of tillers at maturity. Under both irrigated and rainfed conditions, the DT plots produced significantly higher number of tillers than either MT or CT treatment. A comparison of tiller production in the two moisture regimes under similar tillage treatment revealed that, at all tillage system irrigation significantly increased the number of tillers as compared with rainfed situation.

Table 35. Effect of tillage treatments and moisture regimes on plant height and number of tillers at maturity

Tillage practices	Moisture regimes		
	Rainfed	Irrigated	Diff.
Plant height (cm)			
MT	66.8 a	74.0 a	- 7.3**
CT	68.3 a	77.0 a	- 8.8**
DT	69.5 a	76.5 a	- 7.0**
Number of tillers per m ²			
MT	242 b	321 b	-79 **
CT	238 b	331 b	-94 **
DT	264 a	373 a	-109 **

** = Significant at 1% level.

For each yield parameter means in a column followed by a common letter are not significantly different at the 5% level by DMRT.

<u>Parameters</u>	<u>CV (%)</u>	<u>Comparison</u>	<u>S.E.D.</u>	<u>LSD (5%)</u>
Plant height	4.0	2- T x M means	2.1	4.4
		2- M means	1.2	2.5
No. of tillers	3.8	2- T x M	8.0	17.0

4.6.2.3. Yield component

The yield components of wheat as affected by tillage and moisture regimes are shown in Table 36 and ANOVA in Appendix Table 10.3-10.6. The number of panicles/m², number of grains/panicle and 1000 grain weight increased with an increase in tillage depth. The highest number of panicles/m², grains/panicles and maximum 1000 grain weight were observed for deep tillage under rainfed condition. Under irrigated condition, MT and CT produced statistically similar and significantly lower number of panicles/m² compared with DT plots. On the other hand, CT and DT gave statistically similar and significantly higher number of panicles/m² and 1000 grain weight than MT. Irrigated plots produced significantly higher number of panicles/m² and grains per panicle under all tillage treatments than the rainfed plots. Regardless of tillage level, irrigation significantly decreased the percentage of unfilled grain. Irrespective of moisture regime, increasing tillage depth decreased the percentage of unfilled grains. The highest percent of unfilled grain was observed with MT and the lowest percent was noted with DT.

4.6.3. Grain and straw yields of wheat

Moisture regime and tillage level significantly influenced the grain and straw yield of wheat (Table 37 and ANOVA in Appendix Table 10.7-10.8.). Under both irrigated and rainfed conditions, wheat yield was higher with deep tillage. Under rainfed condition, the grain and straw yields of wheat increased with an increase in the depth of tillage, while under irrigated situation, the influence of MT and CT on grain yield was identical and DT produced significantly higher grain yield. The straw yield of wheat under irrigated condition also increased with increasing tillage depth. The breaking of hard pan by deep tillage provided a larger soil volume available to the roots. Favorable soil physical properties, greater nutrient absorbing surface area, greater root density in deeper layer and, good harvest and better utilization of soil profile moisture by the wheat plant under deep tillage could be the reason of enhanced grain yield under deep tillage. The results indicated that DT could be a useful practice for growing wheat under rainfed condition by enabling the wheat plants to exploit the residual soil moisture in the deeper soil layers.

Table 36. Effect of Tillage practices and moisture regimes on the yield component of wheat.

Tillage practices	Moisture regimes		
	Rainfed	Irrigated	Diff.
No. of panicles /m ²			
MT	178.0 c	253.8 b	- 75.8**
CT	188.5 b	258.3 b	- 69.8**
DT	208.3 a	290.8 a	- 82.5**
No. of filled grains /panicle			
MT	23.25 c	27.00 b	- 3.75**
CT	24.50 b	28.50 a	- 4.00**
DT	27.50 a	28.75 a	- 1.25**
1000 grain weight (gram)			
MT	34.09 c	35.73 b	- 1.64ns
CT	32.97 b	36.10 a	- 3.13**
DT	32.33 a	35.53 a	- 3.20**
Percent unfilled grain			
			T-mean Diff.
MT	3.83	3.65	3.74 a 0.18ns
CT	3.73	3.53	3.63 ab 0.20ns
DT	3.65	3.48	3.56 b 0.18ns
M-mean	3.73	3.55	3.64 0.18**

**= Significant at 1% level; *= Significant at 5% level ; ns= Not significant.

For each parameter means in a column followed by a common letter are not significantly different at the 5% level by DMRT.

<u>Parameters</u>	<u>CV (%)</u>	<u>Comparison</u>	<u>S.E.D.</u>	<u>LSD (5%)</u>
No. of panicles/m ²	2.9	2- Tx M means	4.8	10.2
		2- T means	3.4	7.2
		2- M means	2.8	5.9
No. of grains/panicle	2.7	2- Tx M means	0.51	1.08
		2- M means	0.59	1.26
1000 grain weight	4.2	2- Tx M means	1.03	2.19
		2- M means	0.59	1.26
Sterility percent	3.8	2- Tx M means	0.10	0.21
		2- M means	0.06	0.12

Table 37. Effect of Tillage depth and moisture regimes on the grain and straw yield (kg/ha) of wheat.

Tillage practices	Moisture regimes		
	Rainfed	Irrigated	Diff.
Grain yield			
MT	1336.00 c	2574.75 b	- 1136.25**
CT	1509.75 b	2618.75 b	- 1109.00**
DT	1879.25 a	2806.75 a	- 927.50**
Straw yield.			
MT	1942.25 c	3469.25 c	- 1527.00**
CT	2038.00 b	3588.00 b	- 1550.00**
DT	2547.75 a	3845.50 a	- 1297.75**

** = Significant at 1% level.

For each yield parameter means in a column followed by a common letter are not significantly different at the 5% level by DMRT.

<u>Parameters</u>	<u>CV (%)</u>	<u>Comparison</u>	<u>S.E.D.</u>	<u>LSD (5%)</u>
Gain yield	4.15	2-Tillage x Moisture	35.49	75.65
Straw yield	5.90	2-Tillage x Moisture	36.61	82.31

Considering grain yield with MT as 100%, the yield increase under irrigated condition amounted 10.90% with DT and 10.17% with CT (Table 38). The highest yield increase (14.06%) due to tillage was obtained with DT under rainfed condition. The higher rainfed wheat yield recorded from deep tillage plots may be attributed to greater cumulative utilization of soil profile moisture, a fact supported by the observed RLD patterns (Table 34). The higher number of panicles per m², number of grains per panicles and 1000 filled grain weight, and decreased percent unfilled grain with increasing tillage depth supported these results. Similar findings were also reported by Karim *et al.*, (1983), Chaudhury *et al.*, (1985) and Rahman and Islam (1987).

The irrigated plots generally produced significantly higher grain and straw yield than the rainfed plots under different tillage levels (Table 37). For example the grain yield for MT, CT and DT were 2574.75, 2618.75 and 2806.75 kg/ha under irrigated condition and 1336.00, 1509.79 and 1779.25 kg/ha under rainfed situation. This was obviously due to more favorable soil moisture condition in the irrigated plots. Relatively higher soil moisture content and lower soil bulk density during growing season may have improved the soil physical condition for root growth and increased nutrient availability irrespective of tillage system may explain the results.

Table 38. Grain yield increase (%) due to tillage systems under irrigated and rainfed condition

Tillage systems	Grain yield increase (%) due to tillage systems	
	Rainfed	Irrigated
Conventional Tillage	11.30	10.17
Deep Tillage	14.06	10.90

4.6.4. Water use efficiency (WUE)

The effectiveness of water use by a crop in increasing the yield of grain and straw is generally described in terms of WUE. It is the ratio of grain yield or straw yield to the water used. The WUE estimated for the wheat crop is presented in Table 39. The effect of tillage and moisture regime interactions on the WUE of wheat crop was found significant. Under rainfed condition, DT significantly increased the WUE of wheat over CT or MT. On the

5. Summary and conclusions

Six field experiments were conducted at the Bangladesh Rice Research Institute, Gazipur on Gray Terrace Soil (Chhiata Series) to study (i) the effect of varying combination of water regime, tillage level and applied N dose on some physico-chemical characteristics and N availability of soil; (ii) the tillage-water-N interaction effects on the growth, yield and mineral nutrition of rice and post-rice wheat. The following treatments were used in different experiments-

- ◆ Expt. 1: three levels of tillage i.e. zero tillage (ZT), reduced tillage (RT) and conventional tillage (CT) and, four levels of N (0, 60, 80 and 100 kg/ha);
- ◆ Expt. 2: four moisture regimes i.e. continuous submergence (CS), and irrigation at 4, 7 and 10 days after disappearance of standing water (4 DW, 7 DW and 10 DW) and, four N levels (0, 40, 80 and 120 kg/ha);
- ◆ Expt. 3; two moisture regimes (irrigated and rainfed) and three tillage levels (ZT, RT and CT);
- ◆ Expt. 4: two moisture regimes (irrigated and rainfed), three tillage levels (ZT, RT and CT) and, three N levels (0, 100 and 140 kg/ha);
- ◆ Expt. 5: three tillage levels i.e. ZT, RT and deep tillage (DT) and four N levels (0, 60, 80 and 100 kg/ha);
- ◆ Expt. 6: three tillage levels i.e. minimum tillage (MT), CT and DT and, two moisture regimes (irrigated and rainfed).

The tillage intensities were no ploughing for ZT, one shallow ploughing which scrapped the surface soil for MT, two ploughings followed by two ladderings for RT, and five ploughings followed by four ladderings for CT. The tillage depths were 3-4 cm for MT, 12-14 cm for CT and 20-22 cm for DT. RT represented the same depth as CT, except the intensity.

The findings of these studies are summarized below:

- Tillage intensification for wetland rice increased the soil pH, CEC, and available NH_4 and $\text{NO}_3\text{-N}$ and decreased the organic matter, available P and exchangeable K in the post rice surface soil (0-10 cm). Reduction of percolation rate and, thus a slower passage of soluble nutrients deeper into the soil profile with tillage intensification may be the causes

of these changes, contrary to slower release of nutrients, accumulation of organic residues and less disturbance of the plough layer under ZT.

- During the early period of wet season rice i.e. 0-15 DAT, the $\text{NH}_4\text{-N}$ concentration in soil increased and remained at the peak from 15 to 30 DAT. The $\text{NH}_4\text{-N}$ concentration decreased sharply between 30 and 60 DAT, and then gradually upto maturity, irrespective of tillage intensity and N doses. The sharp reduction in $\text{NH}_4\text{-N}$ content from 30 to 60 DAT may be due to an increased uptake of $\text{NH}_4\text{-N}$ by the vigorously growing plants and may indicate a higher requirements of N fertilization during this growth stage.
- Continuous submergence maintained a higher $\text{NH}_4\text{-N}$ concentration in rice soil throughout the growing period. Water deficit depressed the $\text{NH}_4\text{-N}$ content of the soil, and the effect was more prominent at a higher level of applied N. It is obvious that under aerobic condition the $\text{NH}_4\text{-N}$ is oxidized to $\text{NO}_3\text{-N}$ and under anaerobic condition the resulting $\text{NO}_3\text{-N}$ is lost through denitrification, since $\text{NO}_3\text{-N}$ accumulated during water deficit rapidly disappeared after flooding.
- Increasing tillage intensity decreased soil bulk density (BD) which varied with soil depth at different tillage treatments. Relatively compact layer of high bulk density ($1.52\text{-}1.60\text{ g/cm}^3$) of 5-7 cm thickness was observed at 15-25 cm below the soil surface indicating the presence of a hard pan situation. The soil bulk density increased with time during the rice growing season may be due to settling of soil particles with time.
- Increasing tillage intensity decreased the soil penetration resistance (SPR) in wet soil while in dry condition previously puddled (CT) soil had a higher SPR than unpuddled (ZT) soil resulting physical limitations for the establishment of post rice crops.
- Puddling (CT) decreased the soil temperature in the 0-10 cm soil layer, attributed to a decrease in thermal conductivity associated to porosity. Lower organic matter content in the top soil of CT, compared to NT plots, has also contributed to a decrease in soil temperature.
- Puddled (CT) soil held more water at a given soil moisture tension compared to RT and ZT treatments.
- Soil puddled for transplanted Aman rice cultivation took longer period to dry after drainage of water at harvest and attained higher bulk density and penetration resistance in dry condition than the no-till soil, causing adverse situation for subsequent wheat crop.

- The CT treatment decreased the percolation rate compared with the RT and ZT treatments. In the puddled soil, the percolation rate increased with increasing tillage depth. It is assumed that the sealing of micropores with fine particles translocated during puddling predominantly caused formation of a semipermeable layer just beneath the puddled top soil. This semipermeable layer was mostly responsible for the low percolation rate of the puddled soil. However, breaking of dense impervious pan by DT enhanced the percolation rate.
- Both the cumulative infiltration (CI) and infiltration rate (IR) through the soil profile during wheat growing period decreased with CT and increased with an increase in tillage depth in the order of DT>MT>CT, presumably due to breaking of dense impervious pan and decementation of the profile by deep cultivation.
- The DT plots showed a slightly greater depletion of soil profile moisture than other tillage treated plots during wheat growing season because of higher vegetative growth and better root proliferation in deep tilled soil. The rate of soil moisture depletion was faster in the irrigated plots than the rainfed plots, obviously due to better vegetative growth and better root proliferation under irrigated condition.
- The soil profile moisture content depleted rapidly at vegetative and reproductive phases of wheat indicating a greater water requirements during these growth stages.
- Rainfed wheat utilized water more efficiently than irrigated wheat. The maximum WUE values were observed in DT plots under rainfed condition. Thus it may be assumed that deep tillage enables wheat to be grown under rainfed condition utilizing more soil profile residual moisture.
- Tillage treatments had a positive influence on root growth of wheat. Loosening of the soil in DT through breaking of the hardpan showed a favorable effect on the vertical penetration of roots.
- Water deficit decreased root growth of rice and wheat. The increase in soil strength due to bulk density effect in water deficit plots may be considered as a contributory factor for this decrease in root growth. Rice roots were mostly confined to the 0-10 cm soil layer while about 80% of the total root length of wheat was distributed within 30 cm soil depth, rice being a shallow rooted compared to wheat which is relatively a deep rooted cereal

crop. However, in case of rice plant, nitrogen fertilization had a positive influence on root growth.

- In general, the tilled plots produced relatively higher yield than no-tilled plots. The RT or MT produced similar yield of rice and wheat as CT plots.
- The grain and straw yield of wheat increased with an increase in the depth of tillage, while rice yield was not influenced by tillage depth. As the wheat is relatively a deep rooted crop than rice, the breaking of hardpan by deep tillage provided a larger soil volume available to the wheat roots. Thus favorable soil physical properties, greater nutrient absorbing surface area, greater root density in deeper layer and better utilization of soil profile moisture by the wheat plant under DT could be the reason for this enhanced grain yield of wheat. The result also indicated that DT could be a useful practice for growing wheat under rainfed condition for the exploitation of residual soil profile moisture in the deeper soil layers.
- The application of N fertilizer led to better nutrition of the rice and wheat throughout the growing period enhancing vegetative growth and yield contributing parameters. Increasing N application upto 60 kg/ha in T.Aman and 120 kg/ha in Boro increased the grain and straw yield of rice but upto 140 kg/ha increased the wheat yield.
- The yield increase due to tillage treatments was higher at the zero or lower level of applied N compared to higher N doses; under rainfed condition compared to irrigated condition, particularly for wheat yield. Tillage did not influence wheat yield under irrigated condition at any N level while under rainfed situation the CT plots produced higher yield at 100 kg applied N/ha indicating increased N use efficiency in tilled soil under rainfed condition. Favorable soil physical condition for root growth and increased nutrient availability under irrigated condition may have masked the tillage effect resulting no yield differences among tillage treatments in irrigated plots.
- Increasing tillage intensity increased the P content in grain, and decreased the Zn content in straw of wheat under irrigated condition and K content in grain under rainfed situation.
- A lower concentration of N in wheat under the ZT X O-N treatment combination supported the contention that N is less available in no-till soil.

- Nitrogen application increased the N, K, Mg, Mn and Zn concentration and decreased the P concentration in rice and wheat. The application of fertilizer N established good crop growth and root system, which aids the extraction of larger proportion of soil nutrients.
- Water deficit decreased the P, K, Mg, Ca, Fe and Zn and increased the Mn and Cu concentration in rice and wheat.
- Rice plant absorbed more N from puddled (CT) soil than from unpuddled (ZT) soil. Tillage intensity increased the N recovery percent and decreased the physiological efficiency at any applied N level because of increased total N uptake by crop with "till" than "no-till" soil. Increasing applied N up to a certain limit increased the total N uptake by both rice and wheat crop because the increase in N supply not only increased the N content in plant but also resulted a higher dry matter production. But increasing N dose decreased the agronomic and physiological efficiency and N recovery percent of the applied N fertilizer.
- Irrigated rice extracted more N, P, K, Mg, Ca, Fe, Mn and Zn from the soil than crops without irrigation due to exploitation of a larger volume of a soil by plant roots in association with a favorable soil physical condition and increased nutrient availability, causing increased grain and straw yield under irrigated condition. Dry matter production with improved soil moisture increased the agronomic and physiological efficiency and N recovery percent of applied N.

The following conclusions were drawn from the results of the study:

1. Increasing the tillage intensity beyond two ploughings may not be needed for wetland rice in silty clay soils.
2. The zero tillage practice for transplanted rice is more suitable than CT (puddled soil) in terms of some physical properties of soil e.g. water retention capacity, moisture content, soil bulk density and soil penetration resistance for growing wheat after rice in a rice-wheat cropping system.
3. Deep tillage may enable wheat to grow well under rainfed condition utilizing soil profile residual moisture in silty clay soil. Intensive tillage may not be advisable for wheat after transplanted aman rice.
4. Nitrogen doses of 60 kg/ha in T.Aman, 120 kg/ha in Boro for rice and 140 kg/ha for wheat may be adequate resembling the experimental conditions.

5. Rice may utilize applied N more efficiently in "no-till" than "till" soil. Under rainfed condition wheat may require more N in zero or reduced tillage than under conventional tillage to produce similar grain yield.
6. In the dry season, continuous submergence of soil for a transplanted modern variety of rice may be beneficial under conditions of liberal supply of water to achieve a target yield of 6 t/ha. Intermittent irrigation of the rice crop, where irrigation is provided 4 days after disappearance of standing water, can be practiced under conditions of limited water supply to obtain a target yield of 5.5 t/ha.
7. The present study opens avenues for investigation with different soil types and the evaluation of long-term effects of different tillage practices under varying cropping patterns.

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APPENDICES

Appendix Table 1. Morphological characteristics of soil profile of experimental site (Chhiata series)

Location: West byde, Block B, Plot 33

Coordinates: Lat. 23° 59' 09" and Long. 90° 24' 03"

Soil/Series: Chhiata

Taxonomic classification: Aeric Haplaquept

Date of Examination: May 3, 1999

Physiographic position: Mid terrace

Slope: 2%

Vegetation/Land use: Rice and wheat plot

Parent material: Madhupur clay

Drainage: Poorly drained

Depth of groundwater: 150 cm.

Evidence of erosion: None

Flooding/Inundation (Depth & duration): Seasonally flooded by rain water upto 15 cm for 2-3 days.

Horizon	Depth (cm)	Description
A p1	0-18	Grayish brown (10 YR 5/2) moist, silty clay, very firm, sticky and plastic; weak fine and medium sub angular blocky structure; many fine distinct clear strong brown (7.5 YR 5/6) mottles (iron stain along root channels); common fine continuous vertical and oblique inped tubular pores; many fine and medium roots; pH 6.9; gradual smooth boundary.
A p2g	18-35	Gray (10 YR 5/1) moist, heavy clay, very firm, very sticky and very plastic; weak medium and coarse sub angular blocky structure; many fine and medium faint diffuse light olive brown (2.5 Y 5/4) mottles; few fine continuous vertical inped tubular pores; common fine roots; pH 6.9; gradual smooth boundary.

ABg	35-70	Light gray (10 YR 6/1) moist, silty clay; very firm, very sticky and very plastic; weak medium and coarse sub angular blocky structure; many fine distinct clear strong brown (7.5 YR 5/8) mottles; many very fine and fine continuous vertical inped tubular pores; few soft + hard embedded calcareous gravel, very few fine roots; pH 7.0; sharp smooth boundary.
2 C1	70-80	With thin (0.5 cm) layer of micaceous silt (whitish) on top of the horizon. Gray (10 YR 6/1) moist, silty clay; firm, sticky and plastic; weak medium sub angular blocky structure; many fine distinct clear yellowish red (5 YR 5/8) mottles; many fine continuous vertical inped tubular pores; few small hard spherical Fe-Mn concretions; very few fine roots; clear smooth boundary; pH 6.9.
2 C2	80-90	Gray (10 YR 6/1) moist, silty clay, firm, sticky and plastic; weak medium and coarse sub angular blocky structure; many fine distinct clear yellowish red (5 YR 5/8) mottles (iron stain along root channels); common fine continuous vertical inped tubular pores; very few fine roots; clear smooth boundary; pH 6.8.
C3	90-118	Light gray (10 YR 6/1) moist, silty clay; slightly firm, sticky and plastic, weak medium and coarse breaking to fine sub angular blocky structure; many fine distinct clear strong brown (7.5 YR 5/8) mottles; many fine continuous vertical inped tubular pores; very few fine roots; gradual smooth boundary; pH 6.5.
C4	118 cm. and below	Light gray (2.5 YN 6/) moist, silty clay; slightly firm, sticky and plastic; very weak medium and coarse angular and sub angular blocky structure; many fine and medium distinct clear yellowish brown (10 YR 5/8) mottles; many soft and hard spherical Fe-Mn concretions; pH 6.5.

Appendix Table 2. Correlation of the experimental field soil with different classification systems

Soil Series	General soil Type (Brammer's classification)	Agro Ecological Zones (AEZ)	FAO/ UNESCO	USDA Systems (7 th approximation)			
				Sub Group	Great group	Sub-order	Order
Chhiata	Grey Terrace Soil	Modhupur Tract	Dystric Gleysol	Aeric Haplaquepts	Haplaquepts	Aquepts	Inceptisol

Appendix Table 3. Average monthly potential evapotranspiration (mm/day) for Dhaka region of Bangladesh, (From Karim and Akhand, 1992).

Region	Jan	Feb	March	April	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
Dhaka	2.87	3.92	5.44	6.25	6.06	4.42	4.66	4.52	4.28	3.87	3.31	3.02

Appendix Table 4. Crop co-efficient (Kc) for rice and wheat, (From Karim and Akhand, 1992).

Crop	Jan	Feb	March	April	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
Aus	-	-	-	1.10	1.15	1.30	1.00	-	-	-	-	-
T.Aman	-	-	-	-	-	-	-	1.10	1.5	1.30	1.00	
Boro	1.15	1.25	1.00	-	-	-	-	-	-	-		1.00
Wheat	1.15	0.20	-	-	-	-	-	-	-		0.50	0.75

Appendix Table 5. Analysis of variance of experiment 1 with split-plot design ; main plot is tillage and sub plot is N level.

Sources of variation	Degree of freedom	Sum of squares	Mean square	F-value
NH₄-N				
5.1. 15 DT				
Replication (R)	3	0.54432	0.18144	<1
Tillage (T)	2	23.15365	11.57683	2.83 ns
Error (A)	6	24.58780	4.09797	
Nitrogen (N)	3	43.96990	14.65663	14.59**
T x N	6	5.72856	0.95476	<1
Error (B)	27	27.13034	1.00483	
Total	47	125.11457		
5.2. 30 DT				
Replication (R)	3	5.30712	1.76904	1.12 ns
Tillage (T)	2	26.46245	13.23122	8.37*
Error (A)	6	9.48553	1.58092	
Nitrogen (N)	3	88.72952	29.57650	62.63**
T x N	6	3.47193	0.57865	1.23 ns
Error (B)	27	12.75086	0.47225	
Total	47	146.20743		
5.3. 45 DT				
Replication (R)	3	57.99805	19.33268	23.91**
Tillage (T)	2	2.83508	1.41754	1.75 ns
Error (A)	6	4.85191	0.80865	
Nitrogen (N)	3	44.77205	14.92401	25.40**
T x N	6	5.12511	0.85418	1.45 ns
Error (B)	27	15.86200	0.58748	

(Contd. Appendix Table 5)

Sources of variation	Degree of freedom	Sum of squares	Mean square	F-value
5.4. 60 DT				
Replication (R)	3	2.85464	0.95154	1.66 ns
Tillage (T)	2	4.45820	2.22910	2.70 ns
Error (A)	6	4.94229	0.82371	
Nitrogen (N)	3	40.34377	13.44792	32.54**
T x N	6	2.41766	0.40294	<1
Error (B)	27	11.15741	0.41223	
Total	47	66.17399		
5.5. 75 DT				
Replication (R)	3	4.76800	1.58933	2.14 ns
Tillage (T)	2	3.05776	1.52888	2.06 ns
Error (A)	6	4.45250	0.74208	
Nitrogen (N)	3	11.62437	3.87479	31.88**
T x N	6	3.86798	0.64466	5.3**
Error (B)	27	3.28168	0.12154	
Total	47	31.05232		
5.6. 90 DT				
Replication (R)	3	3.82303	1.27434	4.15 ns
Tillage (T)	2	0.08686	0.04343	<1
Error (A)	6	1.84335	0.30722	
Nitrogen (N)	3	3.75303	1.25101	5.10**
T x N	6	1.38615	0.24523	<1
Error (B)	27	6.62128		
Total	47	17.51373		
5.7. 105 DT				
Replication (R)	3	1.14917	0.38305	<1
Tillage (T)	2	4.10510	2.05255	3.02 ns
Error (A)	6	4.07839	0.67973	
Nitrogen (N)	3	10.64297	3.54765	19.19**
T x N	6	5.09239	0.84873	4.59**
Error (B)	27	4.99145	0.18486	
Total	47			

(Contd. Appendix Table 5)

Sources of variation	Degree of freedom	Sum of squares	Mean square	F-value
NO₃-N				
<u>5.8. 15DT</u>				
Replication (R)	3	0.03002	0.01000	1.10 ns
Tillage (T)	2	0.09332	0.04666	5.11 ns
Error (A)	6	0.05482	0.00913	
Nitrogen (N)	3	0.23887	0.07962	18.15**
T x N	6	0.03057	0.00509	1.16ns
Error (B)	27	0.11848	0.00438	
Total	47	0.56609		
<u>5.9. 30 DT</u>				
Replication (R)	3	0.02811	0.00937	2.09 ns
Tillage (T)	2	0.04745	0.02372	5.28*
Error (A)	6	0.02694	0.00449	
Nitrogen (N)	3	0.36830	0.12276	49.08**
T x N	6	0.02371	0.00395	1.58 ns
Error (B)	27	0.06753	0.00250	
Total	47	0.56206		
<u>5.10. 45 DT</u>				
Replication (R)	3	0.13108	0.04369	1.96 ns
Tillage (T)	2	0.04239	0.02118	<1
Error (A)	6	0.13365	0.02275	
Nitrogen (N)	3	1.58690	0.52896	8.30**
T x N	6	0.25853	0.04308	<1
Error (B)	27	1.71988	0.06369	
Total	47	3.87244		
<u>5.11. 60 DT</u>				
Replication (R)	3	0.12164	0.04054	<1
Tillage (T)	2	1.50123	0.75061	13.33**
Error (A)	6	0.33774	0.05629	
Nitrogen (N)	3	2.89342	0.96447	32.21**
T x N	6	1.51906	0.25317	8.46**
Error (B)	27	0.80841	0.02994	
Total	47	7.18152		

(Contd. Appendix Table 5)

Sources of variation	Degree of freedom	Sum of squares	Mean square	F-value
5.12. 75 DT				
Replication (R)	3	0.65861	0.21953	2.20 ns
Tillage (T)	2	0.55451	0.27725	2.78 ns
Error (A)	6	0.59938	0.09989	
Nitrogen (N)	3	2.26475	0.75491	9.64**
T x N	6	0.25235	0.04205	<1
Error (B)	27	2.11465	0.07832	
Total	47	6.44426		
5.13. 90DT				
Replication (R)	3	0.21390	0.07130	6.48*
Tillage (T)	2	0.00940	0.00470	<1
Error (A)	6	0.06601	0.01100	
Nitrogen (N)	3	0.79227	0.26409	23.49**
T x N	6	0.02749	0.00458	<1
Error (B)	27	0.30356	0.01124	
Total	47	1.41264		
5.14. 105 DT				
Replication (R)	3	1.15200	0.38400	19.75**
Tillage (T)	2	0.47208	0.23604	12.14**
Error (A)	6	0.11666	0.01944	
Nitrogen (N)	3	0.93320	0.31106	35.41**
T x N	6	0.45851	0.07641	8.70**
Error (B)	27	0.23715	0.00878	
Total	47	3.36963		
Plant height				
5.15. 5 WT				
Replication (R)	3	120.50	40.17	12.94**
Tillage (T)	2	8.37	4.19	1.37ns
Error (A)	6	18.62	3.10	
Nitrogen (N)	3	532.17	177.39	51.02**
T x N	6	59.46	9.91	2.85*
Error (B)	27	93.87	3.48	
Total	47	833.00		

(Contd. Appendix Table 5)

Sources of variation	Degree of freedom	Sum of squares	Mean square	F-value
5.16. Maturity				
Replication (R)	3	369.23	123.08	37.00**
Tillage (T)	2	178.04	89.02	26.76**
Error (A)	6	19.96	3.33	
Nitrogen (N)	3	1220.89	406.96	33.34**
T x N	6	22.79	3.80	<1
Error (B)	27	329.56	12.21	
Total	47	2140.48		
Tillers/m²				
5.17. 5 WT				
Replication ®	3	16647.73	5549.24	3.19ns
Tillage (T)	2	16370.17	8185.08	4.70ns
Error (A)	6	10447.83	1741.30	
Nitrogen (N)	3	71428.56	23809.52	294.93**
T x N	6	2860.00	476.67	5.90**
Error (B)	27	2179.68	80.73	
Total	47	119933.98		
5.18. Maturity				
Replication (R)	3	969.56	323.18	1.84ns
Tillage (T)	2	3023.37	1511.68	8.58*
Error (A)	6	1056.62	176.10	
Nitrogen (N)	3	17284.56	5761.52	58.83**
T x N	6	777.62	129.60	1.32ns
Error (B)	27	2644.06	97.93	
Total	47	25755.81		
5.19. Panicle/m²				
Replication (R)	3	732.73	244.24	3.43ns
Tillage (T)	2	1968.17	984.08	13.82**
Error (A)	6	427.33	71.22	
Nitrogen (N)	3	9845.39	3281.80	28.64**
T x N	6	1432.67	238.78	2.08ns
Error (B)	27	3064.19	114.60	
Total	47	17500.48		

(Contd. Appendix Table 5)

Sources of variation	Degree of freedom	Sum of squares	Mean square	F-value
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5.20. Grain/panicle

Replication (R)	3	466.06	155.35	2.79ns
Tillage (T)	2	504.29	252.15	4.52ns
Error (A)	6	334.37	55.73	
Nitrogen (N)	3	4356.06	1452.02	9.79**
T x N	6	266.87	44.48	<1
Error (B)	27	4005.81	148.36	
Total	47	9933.48		

5.21. Percent unfilled grain

Replication (R)	3	20.50	6.83	2.58ns
Tillage (T)	2	1.29	0.64	<1
Error (A)	6	15.87	2.64	
Nitrogen (N)	3	90.57	30.17	17.66**
T x N	6	34.37	5.73	3.35*
Error (B)	27	46.12	1.71	
Total	47	208.67		

5.22. 1000 Grain weight

Replication (R)	3	12.79	4.26	4.93*
Tillage (T)	2	2.24	1.12	1.30ns
Error (A)	6	5.18	0.86	
Nitrogen (N)	3	0.87	0.29	<1
T x N	6	1.98	0.33	1.04ns
Error (B)	27	8.58	0.32	
Total	47	31.65		

5.23. Grain yield

Replication (R)	3	0.424	0.141	2.61ns
Tillage (T)	2	0.247	0.124	2.28ns
Error (A)	6	0.325	0.054	
Nitrogen (N)	3	9.735	3.245	189.79**
T x N	6	0.280	0.046	2.73*
Error (B)	27	0.462	0.017	
Total	47	11.474		

(Contd. Appendix Table 5)

Sources of variation	Degree of freedom	Sum of squares	Mean square	F-value
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5.24. Straw yield

Replication (R)	3	0.555	0.185	3.04ns
Tillage (T)	2	1.575	0.787	12.91**
Error (A)	6	0.366	0.061	
Nitrogen (N)	3	20.924	6.974	396.22**
T x N	6	0.037	0.006	<1
Error (B)	27	0.475	0.017	
Total	47	23.933		

N-Content (%)**5.25. Shoot**

Replication (R)	3	0.087	0.029	<1
Tillage (T)	2	0.430	0.215	4.57*
Error (A)	6	0.280	0.047	
Nitrogen (N)	3	1.315	0.438	12.34**
T x N	6	0.264	0.044	1.24ns
Error (B)	27	0.959	0.035	
Total	47	3.336		

5.26. Grain

Replication (R)	3	0.034	0.011	10.23**
Tillage (T)	2	0.031	0.015	13.73**
Error (A)	6	0.006	0.001	
Nitrogen (N)	3	0.172	0.057	23.47**
T x N	6	0.025	0.004	1.70ns
Error (B)	27	0.066	0.002	
Total	47	0.335		

5.27. Straw

Replication (R)	3	0.0070	0.0023	3.97ns
Tillage (T)	2	0.0031	0.0015	2.62ns
Error (A)	6	0.0035	0.0005	
Nitrogen (N)	3	0.1057	0.0352	59.24**
T x N	6	0.0035	0.0006	<1
Error (B)	27	0.0170	0.0006	
Total	47	0.1399		

(Contd. Appendix Table 5)

Sources of variation	Degree of freedom	Sum of squares	Mean square	F-value
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N Use efficiency**5.28. N-uptake**

Replication (R)	3	234.06	78.02	5.44*
Tillage (T)	2	264.57	132.28	9.22*
Error (A)	6	86.10	14.35	
Nitrogen (N)	3	5293.61	1764.53	250.57**
T x N	6	98.17	16.36	2.32ns
Error (B)	27	190.13	7.04	
Total	47	6166.65		

5.29. Kg grain/kg applied N

Replication (R)	3	81.39	27.13	3.07ns
Tillage (T)	2	27.12	13.56	1.53ns
Error (A)	6	53.04	8.84	
Nitrogen (N)	3	1637.06	545.86	190.57**
T x N	6	65.37	10.89	3.81**
Error (B)	27	77.31	2.86	
Total	47	1941.31		

5.30. kg grain/kg absorbed N

Replication (R)	3	214.79	71.59	15.69**
Tillage (T)	2	135.93	67.96	14.90**
Error (A)	6	27.37	4.56	
Nitrogen (N)	3	2163.61	721.20	92.85**
T x N	6	92.93	15.48	1.99ns
Error (B)	27	209.73	7.76	
Total	47	2844.37		

5.31. kg absorbed N/100 kg applied N

Replication (R)	3	227.83	75.94	2.69ns
Tillage (T)	2	185.17	92.58	5.08 *
Error (A)	6	109.17	18.19	
Nitrogen (N)	3	8455.50	2818.50	177.39**
T x N	6	149.00	24.83	1.56ns
Error (B)	27	429.00	15.89	
Total	47	9555.67		

(Contd. Appendix Table 5)

Appendix Table 6. Analysis of variance of experiment 2 with split-plot design ; main plot is moisture regimes and sub plot is N levels.

Sources of variation	Degree of freedom	Sum of squares	Mean square	F-value
NH₄-N at 45 DT				
6.1. 0-10 cm.				
Replication (R)	3	0.65101	0.21700	<1
Moisture regimes (M)	3	470.776	156.925	176.00**
Error (A)	9	8.02452	0.89161	
Nitrogen (N)	3	902.476	300.825	659.85**
M X N	9	216.305	24.0339	52.72**
Error (B)	36	16.4123	0.45589	
Total	63	1614.64		
6.2. 10-20 cm.				
Replication (R)	3	3.24476	1.08148	5.02*
Moisture regimes (M)	3	21.8246	7.27487	33.79**
Error (A)	9	1.93751	0.21527	
Nitrogen (N)	3	10.3496	3.44988	16.79**
M X N	9	3.31407	0.36823	1.79 ns
Error (B)	36	7.39724	0.20547	
Total	63	48.0678		
NH₄-N at 65 DT				
6.3. 0-10 cm.				
Replication (R)	3	1.37628	0.45842	<1
Moisture regimes (M)	3	24.4923	8.16411	7.93**
Error (A)	9	9.26298	1.02922	
Nitrogen (N)	3	33.0560	11.0186	95.06**
M X N	9	0.66663	0.07407	<1
Error (B)	36	4.17287	0.11591	
Total	63	73.0261		

(Contd. Appendix Table 6)

Sources of variation	Degree of freedom	Sum of squares	Mean square	F-value
6.4. 10-20 cm.				
Replication (R)	3	0.97095	0.32365	1.06 ns
Moisture regimes (M)	3	1.17679	0.39226	1.29 ns
Error (A)	9	2.74723	0.30524	
Nitrogen (N)	3	2.50366	0.83455	7.19**
M X N	9	1.70142	0.18904	1.63 ns
Error (B)	36	4.17703	0.11602	
Total	63	13.2771		
NO₃-N at 45 DT				
6.5. 0-10 cm.				
Replication (R)	3	0.34969	0.11656	2.34 ns
Moisture regimes (M)	3	0.30680	0.10226	2.06 ns
Error (A)	9	0.44763	0.04972	
Nitrogen (N)	3	0.50857	0.16952	1.90 ns
M X N	9	0.28185	0.03131	<1
Error (B)	36	3.21784	0.08938	
Total	63	5.11241		
6.6. 10-20 cm.				
Replication (R)	3	0.42013	0.14004	2.35 ns
Moisture regimes (M)	3	1.67665	0.55888	9.38**
Error (A)	9	0.53610	0.05956	
Nitrogen (N)	3	0.02793	0.00931	<1
M X N	9	0.05090	0.00565	<1
Error (B)	36	1.02966	0.02860	
Total	63	3.74139		
NO₃-N at 65 DT				
6.7. 0-10 cm.				
Replication (R)	3	0.47140	0.15713	<1
Moisture regimes (M)	3	4.54930	1.51643	2.37 ns
Error (A)	9	5.75798	0.63977	
Nitrogen (N)	3	0.88881	0.29627	6.91**
M X N	9	0.41896	0.04655	1.09 ns
Error (B)	36	1.54306	0.04286	
Total	63	13.62954		

(Contd. Appendix Table 6)

Degree of freedom		Sum of squares	Mean square	F-value
6.8. 10-20 cm. $\text{NO}_3\text{-N}$ at 65 DT				
Replication (R)	3	1.71277	0.57092	2.53 ns
Moisture regimes (M)	3	6.05695	2.01898	8.93**
Error (A)	9	2.03471	0.22607	
Nitrogen (N)	3	0.39425	0.13141	1.57 ns
M X N	9	0.13678	0.01519	<1
Error (B)	36	3.00523	0.08347	
Total	63	13.3407		
6.9. Active tillering				
Replication (R)	3	43.4218	14.4739	3.95*
Moisture regimes (M)	3	183.296	61.0989	16.66**
Error (A)	9	33.0156	3.66840	
Nitrogen (N)	3	212.421	70.8072	21.73**
M X N	9	89.5156	9.94618	3.05*
Error (B)	36	117.312	3.25868	
Total	63	678.984		
6.10. Panicle initiation				
Replication (R)	3	28.9218	9.64062	1.00 ns
Moisture regimes (M)	3	118.546	39.5156	4.11*
Error (A)	9	86.5156	9.61284	
Nitrogen (N)	3	1648.67	549.557	92.31**
M X N	9	274.265	30.4739	5.12**
Error (B)	36	214.312	5.95312	
Total	63	2371.23		
6.11. Maturity				
Replication (R)	3	144.546	48.1822	11.72**
Moisture regimes (M)	3	282.171	94.0572	22.87
Error (A)	9	37.0156	4.11284	
Nitrogen (N)	3	1605.17	535.057	116.26**
M X N	9	164.890	18.3211	3.98**
Error (B)	36	165.687	4.60243	
Total	63	2399.48		

(Contd. Appendix Table 6)

Sources of variation	Degree of freedom	Sum of squares	Mean square	F-value
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No. of tillers/m²**6.12. Active tillering**

Replication (R)	3	21202.4	7067.47	4.28*
Moisture regimes (M)	3	1179.67	393.224	<1
Error (A)	9	14876.8	1652.98	
Nitrogen (N)	3	214540	71513.4	694.32**
M X N	9	6372.64	708.071	6.87**
Error (B)	36	3707.93	102.998	
Total	63	261879		

6.13. Panicle initiation

Replication (R)	3	4462.17	1487.39	<1
Moisture regimes (M)	3	6503.29	2167.76	<1
Error (A)	9	34168.0	3796.44	
Nitrogen (N)	3	374337	124779	138.00**
M X N	9	114839	12759.9	14.11**
Error (B)	36	32551.0	904.196	
Total	63	566861		

6.14. Maturity

Replication (R)	3	166.312	55.4375	<1
Moisture regimes (M)	3	3277.06	1092.35	4.95*
Error (A)	9	1985.06	220.562	
Nitrogen (N)	3	159260	53086.9	549.71**
M X N	9	3645.06	405.006	4.19**
Error (B)	36	3476.62	96.5729	
Total	63	171810		

Root length density**6.15. 0-10 cm.**

Replication (R)	3	0.030716	0.015358	<1
Moisture regimes (M)	3	0.119666	0.039888	<1
Error (A)	9	0.468183	0.078030	
Nitrogen (N)	3	0.478383	0.159461	8.79**
M X N	9	0.168850	0.018738	1.03 ns
Error (B)	36	0.43556	0.018148	
Total	63	1.70116		

(Contd. Appendix Table 6)

Sources of variation	Degree of freedom	Sum of squares	Mean square	F-value
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6.16.10-20 cm.

Replication (R)	3	0.000835	0.000418	1.18 ns
Moisture regimes (M)	3	0.002139	0.000713	2.01 ns
Error (A)	9	0.002129	0.000354	
Nitrogen (N)	3	0.007056	0.002352	11.52**
M X N	9	0.001968	0.000218	1.07 ns
Error (B)	36	0.004900	0.000204	
Total	63	0.019031		

6.17. 20-30 cm.

Replication (R)	3	0.001654	0.000827	2.69 ns
Moisture regimes (M)	3	0.004166	0.001388	4.51 ns
Error (A)	9	0.001845	0.000307	
Nitrogen (N)	3	0.001283	0.000427	2.50 ns
M X N	9	0.000816	0.000090	<1
Error (B)	36	0.004100	0.000170	
Total	63	0.013866		

Root mass density**6.18. 0-10 cm.**

Replication (R)	3	0.11141	0.03713	<1
Moisture regimes (M)	3	1.24051	0.41350	3.31 ns
Error (A)	9	1.12480	0.12497	
Nitrogen (N)	3	17.7910	5.93035	106.04**
M X N	9	3.23851	0.35983	6.43**
Error (B)	36	2.01335	0.05592	
Total	63	25.5196		

6.19. 10-20 cm.

Replication (R)	3	0.00467	0.00155	<1
Moisture regimes (M)	3	0.05259	0.01753	9.47**
Error (A)	9	0.01666	0.00185	
Nitrogen (N)	3	0.05722	0.01907	24.76**
M X N	9	0.00836	0.00092	1.21 ns
Error (B)	36	0.02773	0.00077	
Total	63	0.16726		

(Contd. Appendix Table 6)

Sources of variation	Degree of freedom	Sum of squares	Mean square	F-value
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6.20. 20-30 cm.

Replication (R)	3	0.40604	0.13534	<1
Moisture regimes (M)	3	0.31957	0.10652	<1
Error (A)	9	1.35043	0.15004	
Nitrogen (N)	3	0.38128	0.12709	<1
M X N	9	1.33189	0.14798	1.03 ns
Error (B)	36	5.19074	0.14418	
Total	63	8.97999		

Yield components**6.21. Panicles/m²**

Replication (R)	3	448.812	149.604	<1
Moisture regimes (M)	3	713.812	237.937	<1
Error (A)	9	4151.31	461.256	
Nitrogen (N)	3	131296	43765.6	566.98**
M X N	9	2028.81	225.423	2.92*
Error (B)	36	2778.87	77.1910	
Total	63	141418		

6.22. Grains/panicle

Replication (R)	3	127.250	42.4166	<1
Moisture regimes (M)	3	445.125	148.375	4.01*
Error (A)	9	332.625	36.9583	
Nitrogen (N)	3	2374.37	791.458	17.51**
M X N	9	373.000	41.4444	<1
Error (B)	36	1627.62	45.2118	
Total	63	5280.00		

6.23. Wt. of 1000**grain**

Replication (R)	3	2.3056	0.76854	1.30 ns
Moisture regimes (M)	3	14.187	4.72729	8.00 **
Error (A)	9	5.3168	0.59076	54.58**
Nitrogen (N)	3	61.548	20.5160	2.50*
M X N	9	8.5493	0.93993	
Error (B)	36	13.532	0.37590	
Total	63	105.344		

(Contd. Appendix Table 6)

Sources of variation	Degree of freedom	Sum of squares	Mean square	F-value
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6.24. % unfilled grains

Replication (R)	3	44.5625	14.8541	<1
Moisture regimes (M)	3	231.562	77.1875	4.72*
Error (A)	9	147.312	16.3680	
Nitrogen (N)	3	316.062	105.354	19.24**
M X N	9	119.812	13.3125	2343*
Error (B)	36	197.125	5.47569	
Total	63	1026.43		

6.25. Grain yield

Replication (R)	3	2220809	740269	19.87**
Moisture regimes (M)	3	8068161	2689387	72.18**
Error (A)	9	335333	37259	
Nitrogen (N)	3	97681971	32560657	2124.47**
M X N	9	998096	110899	7.24**
Error (B)	36	551753	15326	
Total	63	109856126		

6.26. Straw yield

Replication (R)	3	758337	252779	1.71 ns
Moisture regimes (M)	3	3417269	1139089	7.70**
Error (A)	9	1331284	147920	
Nitrogen (N)	3	89283597	29761199	706.22**
M X N	9	393498	43722	1.04 ns
Error (B)	36	1517102	42141	
Total	63	96701088		

N-content

6.27. Shoot at 45 DT

Replication (R)	3	0.98475	0.49237	3.58 ns
Moisture regimes (M)	3	0.23227	0.07742	<1
Error (A)	9	0.82484	0.12747	
Nitrogen (N)	3	6.64057	2.21352	51.71**
M X N	9	0.70320	0.07813	1.83 ns
Error (B)	36	1.02740	0.04280	
Total	63	10.4130		

(Contd. Appendix Table 6)

Sources of variation	Degree of freedom	Sum of squares	Mean square	F-value
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6.28. Shoot at 65 DT

Replication (R)	3	0.55542	0.27771	3.98 ns
Moisture regimes (M)	3	0.11881	0.03960	<1
Error (A)	9	0.41837	0.06972	
Nitrogen (N)	3	5.83328	1.94442	234.74**
M X N	9	0.17276	0.01919	2.32*
Error (B)	36	0.19880	0.00828	
Total	63	7.29746		

6.29. Straw

Replication (R)	3	0.00053	0.00026	<1
Moisture regimes (M)	3	0.05117	0.01705	1.89 ns
Error (A)	9	0.05424	0.00904	
Nitrogen (N)	3	0.00102	0.00034	<1
M X N	9	0.00800	0.00088	<1
Error (B)	36	0.02515	0.00104	
Total	63	0.14013		

6.30. Grain

Replication (R)	3	0.00761	0.00380	2.01 ns
Moisture regimes (M)	3	0.02295	0.00765	4.05 ns
Error (A)	9	0.01136	0.00189	
Nitrogen (N)	3	0.02858	0.00952	5.65**
M X N	9	0.00933	0.00103	<1
Error (B)	36	0.04050	0.00168	
Total	63	0.12034		

6.31. P in straw

Replication (R)	3	0.00080	0.00040	1.3 ns
Moisture regimes (M)	3	0.01255	0.00418	13.55**
Error (A)	9	0.00185	0.00030	
Nitrogen (N)	3	0.00030	0.00010	1.20 ns
M X N	9	0.00086	0.00009	1.15 ns
Error (B)	36	0.00200	0.00008	
Total	63	0.01837		

(Contd. Appendix Table 6)

Sources of variation	Degree of freedom	Sum of squares	Mean square	F-value
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6.32. P in grain

Replication (R)	3	0.00152	0.00076	7.81*
Moisture regimes (M)	3	0.00995	0.00331	33.89**
Error (A)	9	0.00058	0.00009	
Nitrogen (N)	3	0.00048	0.00016	1.72 ns
M X N	9	0.00075	0.00008	<1
Error (B)	36	0.00228	0.00009	
Total	63	0.01559		

6.33. K in straw.

Replication (R)	3	0.02073	0.01036	<1
Moisture regimes (M)	3	0.26094	0.42031	3.66 ns
Error (A)	9	0.68979	0.11496	
Nitrogen (N)	3	0.41034	0.136780	14.20**
M X N	9	0.49217	0.05468	5.68**
Error (B)	36	0.23113	0.00963	
Total	63	3.10512		

6.34. K in grain

Replication (R)	3	0.00557	0.00278	7.65*
Moisture regimes (M)	3	0.02335	0.00778	21.35**
Error (A)	9	0.00218	0.00036	
Nitrogen (N)	3	0.00030	0.00010	<1
M X N	9	0.00251	0.00027	1.10 ns
Error (B)	36	0.00610	0.00025	
Total	63	0.04004		

6.35. Ca in straw

Replication (R)	3	0.00018	0.00009	<1
Moisture regimes (M)	3	0.00617	0.00205	7.92*
Error (A)	9	0.00155	0.00025	
Nitrogen (N)	3	0.00159	0.00053	1.34 ns
M X N	9	0.00512	0.00056	1.44 ns
Error (B)	36	0.00950	0.00039	
Total	63	0.00950		

(Contd. Appendix Table 6)

Sources of variation	Degree of freedom	Sum of squares	Mean square	F-value
6.36. Ca in grain				
Replication (R)	3	0.00002	0.00001	<1
Moisture regimes (M)	3	0.00041	0.00013	2.70 ns
Error (A)	9	0.00030	0.00005	
Nitrogen (N)	3	0.00005	0.00001	1.90 ns
M X N	9	0.00004	0.000004	<1
Error (B)	36	0.00022	0.000009	
Total	63	0.00106		
6.37. Mg in straw				
Replication (R)	3	0.00398	0.00199	1.39 ns
Moisture regimes (M)	3	0.00349	0.00116	<1
Error (A)	9	0.00856	0.00142	
Nitrogen (N)	3	0.00413	0.00137	2.68 ns
M X N	9	0.00290	0.00032	<1
Error (B)	36	0.01831	0.00051	
Total	63	0.03738		
6.38. Mg in grain				
Replication (R)	3	0.000006	0.000003	<1
Moisture regimes (M)	3	0.004152	0.001384	6.18*
Error (A)	9	0.001344	0.000224	
Nitrogen (N)	3	0.000163	0.000054	<1
M X N	9	0.002696	0.000299	<1
Error (B)	36	0.007920	0.000330	
Total	63	0.016283		
6.39. Fe in straw				
Replication (R)	3	272.375	136.187	1.43 ns
Moisture regimes (M)	3	577.417	192.472	2.02 ns
Error (A)	9	570.958	95.1597	
Nitrogen (N)	3	19.4166	6.47222	<1
M X N	9	805.083	89.4537	1.37 ns
Error (B)	36	1572.00	65.5000	
Total	63	3817.25		

(Contd. Appendix Table 6)

Sources of variation	Degree of freedom	Sum of squares	Mean square	F -value
6.40. Fe in grain				
Replication (R)	3	3007.29	1503.64	<1
Moisture regimes (M)	3	29827.1	9942.39	6.5*
Error (A)	9	9170.70	1528.45	
Nitrogen (N)	3	2711.16	903.722	1.41 ns
M X N	9	8514.66	946.074	1.47 ns
Error (B)	36	15400.7	641.694	
Total	63	68631.7		
6.41. Mn in straw				
Replication (R)	3	15899.0	7949.52	1.84 ns
Moisture regimes (M)	3	385604	128534	29.71**
Error (A)	9	25955.1	4325.85	
Nitrogen (N)	3	10598.0	3532.68	3.53*
M X N	9	25321.3	2813.48	2.81*
Error (B)	36	23995.8	999.826	
Total	63	487373		
6.42. Mn in grain				
Replication (R)	3	14.8125	4.9375	<1
Moisture regimes (M)	3	70.8125	23.6041	4.44*
Error (A)	9	47.8125	5.31250	
Nitrogen (N)	3	22.0625	7.35416	2.49 ns
M X N	9	33.0625	3.67361	1.24 ns
Error (B)	36	70.3750	2.95486	
Total	63	258.937		
6.43. Zn in straw				
Replication (R)	3	525.875	262.937	1.68 ns
Moisture regimes (M)	3	1347.16	449.055	2.87 ns
Error (A)	9	938.958	156.493	
Nitrogen (N)	3	659.833	219.944	3.47*
M X N	9	270.000	30.0000	<1
Error (B)	36	1521.17	63.3819	
Total	63	5263.00		

(Contd. Appendix Table 6)

Sources of variation	Degree of freedom	Sum of squares	Mean square	F-value
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6.44. Zn in grain

Replication (R)	3	0.50000	0.25000	<1
Moisture regimes (M)	3	7.41666	2.47222	3.07 ns
Error (A)	9	4.83333	0.80555	
Nitrogen (N)	3	4.91666	1.63888	<1
M X N	9	12.9166	1.43518	<1
Error (B)	36	46.6666	1.94444	
Total	63	77.2500		

6.45. Cu in straw

Replication (R)	3	23.5050	11.7525	3.71 ns
Moisture regimes (M)	3	80.1983	26.7327	8.44*
Error (A)	9	19.0066	13.1677	
Nitrogen (N)	3	5.82500	1.94166	1.90 ns
M X N	9	3.48666	0.38740	<1
Error (B)	36	24.5283	1.02201	
Total	63	156.550		

6.46. Cu in grain

Replication (R)	3	16.2679	8.13395	3.72 ns
Moisture regimes (M)	3	216.960	72.3202	33.1**
Error (A)	9	13.1087	2.18479	
Nitrogen (N)	3	4.81562	1.60520	1.36 ns
M X N	9	6.32354	0.70261	<1
Error (B)	36	28.24333	1.17680	
Total	63	285.719		

6.47. N-uptake

Replication (R)	3	160.221	80.1107	2.12 ns
Moisture regimes (M)	3	865.610	288.536	7.65*
Error (A)	9	226.266	37.7111	
Nitrogen (N)	3	10129.4	3376.48	1804.37**
M X N	9	58.3056	6.47841	3.46**
Error (B)	36	44.9106	1.87128	
Total	63	11484.7		

(Contd. Appendix Table 6)

Sources of variation	Degree of freedom	Sum of squares	Mean square	F-value
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6.48. Kg grain/kg applied N

Replication (R)	3	14.2916	7.14583	<1
Moisture regimes (M)	3	307.416	102.472	6.32*
Error (A)	9	97.2083	16.2013	
Nitrogen (N)	3	10202.4	3400.80	669.93**
M X N	9	154.750	17.1944	3.39**
Error (B)	36	121.833	5.07639	
Total	63	10897.9		

6.49. Kg grain /kg absorbed N

Replication (R)	3	10.1250	5.06250	<1
Moisture regimes (M)	3	302.500	100.833	1.32 ns
Error (A)	9	459.875	76.6458	
Nitrogen (N)	3	288.333	96.1111	9.18**
M X N	9	501.833	55.7592	5.32**
Error (B)	36	251.333	10.4722	
Total	63	1814.00		

6.50. Kg Nuptake /100kg applied N

Replication (R)	3	21.1250	10.5652	1.48 ns
Moisture regimes (M)	3	174.729	58.2430	8.18*
Error (A)	9	42.7083	7.11806	
Nitrogen (N)	3	11076.7	3692.24	1425.42**
M X N	9	103.354	11.4838	4.43**
Error (B)	36	62.1667	2.59028	
Total	63	11480.8		

Appendix Table 7. Analysis of variance of experiment 3 with split-plot design ; main plot is moisture regimes and sub plot is tillage.

Sources of variation	Degree of freedom	Sum of squares	Mean square	F-value
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Soil drying

(For table 7.1 to 7.6, only tillage treatment were considered for statistical analysis)

7.1. 0DWD

Replication (R)	3	8.66666	2.88888	<1
Tillage (T)	2	82.6666	41.3333	5.46*
Error	6	45.3333	7.55555	
Total	11	136.666		

7.2. 5DWD

Replication (R)	3	8.00000	2.66666	<1
Tillage (T)	2	74.6666	37.3333	4.87 *
Error	6	46.0000	7.66666	
Total	11	128.000		

7.3. 10 DWD

Replication (R)	3	8.66666	2.88888	<1
Tillage (T)	2	50.6666	25.3333	5.18*
Error	6	29.3333	4.88888	
Total	11	88.6666		

7.4. 15DWD

Replication (R)	3	56.8333	18.9444	1.31 ns
Tillage (T)	2	115.083	57.5416	4.00*
Error	6	86.3333	14.3611	
Total	11	258.2493		

7.5. 20DWD

Replication (R)	3	78.0000	26.0000	24.00**
Tillage (T)	2	38.1666	19.08333	17.62**
Error	6	6.50000	1.08333	
Total	11	122.666		

(Contd. Appendix Table7)

Sources of variation	Degree of freedom	Sum of squares	Mean square	F-value
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7.6. 25DWD

Replication (R)	3	7.99856	2.67000	<1
Tillage (T)	2	83.0001	41.5000	5.49*
Error	6	45.3468	7.5578	
Total	11	136.345		

Grain and straw yield**7.7. Grain**

Replication (R)	3	0.40475	0.13485	4.06 ns
Irrigation (I)	1	0.65670	0.65670	20.02**
Error (A)	3	0.09837	0.03279	
Tillage (T)	2	0.00930	0.00465	<1
IxT	2	0.00163	0.00081	<1
Error (B)	12	0.06466	0.00538	
Total	23	1.23526		

7.8. Straw

Replication (R)	3	2.11377	0.70459	10.24**
Irrigation (I)	1	0.78120	0.78120	11.35**
Error (A)	3	0.20637	0.06879	
Tillage (T)	2	0.00232	0.00116	<1
IxT	2	0.03005	0.01502	<1
Error (B)	12	0.21082	0.01756	
Total	23	3.34456		

Nutrient content in straw and grain**7.9. N in straw**

Replication (R)	3	0.0006	0.0002	<1
Irrigation (I)	1	0.0188	0.0188	14.46**
Error (A)	3	0.0039	0.0013	
Tillage (T)	2	0.0160	0.0080	7.53**
IxT	2	0.0003	0.0002	<1
Error (B)	12	0.0127	0.0011	
Total	23	0.0524		

(Contd. Appendix Table 7)

Sources of variation	Degree of freedom	Sum of squares	Mean square	F-value
<u>7.10. N in grain</u>				
Replication (R)	3	0.00854	0.00284	2.34 ns
Irrigation (I)	1	0.01450	0.01450	11.98**
Error (A)	3	0.00364	0.00121	
Tillage (T)	2	0.00763	0.00381	1.15 ns
IxT	2	0.00043	0.00021	<1
Error (B)	12	0.03993	0.00332	
Total	23	0.074695		
<u>7.11. P in straw</u>				
Replication (R)	3	0.00055950	0.00018317	2.11 ns
Irrigation (I)	1	0.00000017	0.00000017	<1
Error (A)	3	0.00025950	0.00008650	
Tillage (T)	2	0.00015008	0.000075404	2.61 ns
IxT	2	0.00012308	0.00006154	2.13 ns
Error (B)	12	0.00034550	0.00002879	
Total	23	0.00142783		
<u>7.12. P in grain</u>				
Replication (R)	3	0.000454	0.000151	1.02 ns
Irrigation (I)	1	0.000035	0.000035	<1
Error (A)	3	0.000442	0.000147	
Tillage (T)	2	0.000335	0.000167	1.01 ns
IxT	2	0.000564	0.000282	1.69 ns
Error (B)	12	0.002000	0.000166	
Total	23	0.003831		
<u>7.13. K in straw</u>				
Replication (R)	3	0.10867	0.03622	<1
Irrigation (I)	1	0.01550	0.01550	<1
Error (A)	3	0.15961	0.05320	
Tillage (T)	2	0.20025	0.10012	2.15 ns
IxT	2	0.03145	0.015729	<1
Error (B)	12	0.55988	0.04665	
Total	23	1.07539		

(Contd. Appendix Table 7)

Sources of variation	Degree of freedom	Sum of squares	Mean square	F-value
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7.14. K in grain

Replication (R)	3	0.001518	0.000506	-
Irrigation (I)	1	0.000120	0.000120	2.92 ns
Error (A)	3	0.000124	0.000041	
Tillage (T)	2	0.000431	0.000215	2.44 ns
IxT	2	0.000066	0.000033	<1
Error (B)	12	0.001066	0.000088	
Total	23	0.003325		

7.15. Ca in straw

Replication (R)	3	0.00111	0.00037	<1
Irrigation (I)	1	0.00013	0.00013	<1
Error (A)	3	0.00326	0.00108	
Tillage (T)	2	0.00132	0.00066	2.47 ns
IxT	2	0.00170	0.00085	3.18 ns
Error (B)	12	0.00321	0.00027	
Total	23	0.01076		

7.16. Ca in grain

Replication (R)	3	0.000145	0.000048	<1
Irrigation (I)	1	0.000937	0.000937	3.47 ns
Error (A)	3	0.000812	0.000270	
Tillage (T)	2	0.000233	0.000116	1.11 ns
IxT	2	0.000700	0.000350	3.32 ns
Error (B)	12	0.001266	0.000105	
Total	23	0.004095		

7.17. Mg in straw

Replication (R)	3	0.00208	0.00069	<1
Irrigation (I)	1	0.00080	0.00080	<1
Error (A)	3	0.00271	0.00090	
Tillage (T)	2	0.00175	0.00087	6.10*
IxT	2	0.00062	0.00031	2.16 ns
Error (B)	12	0.00172	0.00014	
Total	23	0.00971		

(Contd. Appendix Table 7)

Sources of variation	Degree of freedom	Sum of squares	Mean square	F-value
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7.18. Mg in grain

Replication (R)	3	0.0001944	0.0000648	<1
Irrigation (I)	1	0.0000033	0.0000033	<1
Error (A)	3	0.0002471	0.0000823	
Tillage (T)	2	0.0000645	0.0000323	<1
IxT	2	0.0001592	0.0000796	2.44 ns
Error (B)	12	0.0003922	0.0000327	
Total	23	0.001060		

7.19. Fe in straw

Replication (R)	3	4625.00	1541.67	<1
Irrigation (I)	1	3952.67	3952.67	<1
Error (A)	3	214.333	71.4444	
Tillage (T)	2	368.583	184.291	1.15 ns
IxT	2	249.083	124.541	<1
Error (B)	12	1915.66	159.639	
Total	23	11325.7		

7.20. Fe in grain

Replication (R)	3	149.125	49.7083	<1
Irrigation (I)	1	9.37500	9.37500	<1
Error (A)	3	1778.12	592.708	
Tillage (T)	2	80.0833	40.0416	1.16 ns
IxT	2	80.2500	45.1250	1.31 ns
Error (B)	12	413.000	34.4166	
Total	23	2591.95		

7.21. Mn in straw

Replication (R)	3	568592.45	189530.82	1.65 ns
Irrigation (I)	1	114678.37	114678.37	<1
Error (A)	3	462865.79	154288.59	
Tillage (T)	2	368532.58	184266.29	1.30 ns
IxT	2	430879.75	215439.87	1.52 ns
Error (B)	12	1705213.0	142101.08	
Total	23	3650761.96		

(Contd. Appendix Table 7)

Sources of variation	Degree of freedom	Sum of squares	Mean square	F-value
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7.22. Mn in grain

Replication (R)	3	48.8333	16.2777	<1
Irrigation (I)	1	95.0000	95.0000	3.15 ns
Error (A)	3	90.3333	30.1111	
Tillage (T)	2	97.0000	48.5000	2.09 ns
IxT	2	16.0000	8.00000	<1
Error (B)	12	278.333	23.1944	
Total	23	625.500		

7.23. Zn in straw

Replication (R)	3	133.791	44.5972	<1
Irrigation (I)	1	108.375	108.375	<1
Error (A)	3	1033.46	344.486	
Tillage (T)	2	371.583	185.791	15.27**
IxT	2	127.750	63.8750	5.25*
Error (B)	12	146.000	12.1666	
Total	23	1920.96		

7.24. Zn in grain

Replication (R)	3	11.0000	3.66667	<1
Irrigation (I)	1	2.66666	2.66667	<1
Error (A)	3	13.0000	4.33333	
Tillage (T)	2	69.0833	34.5417	6.28*
IxT	2	41.5833	20.7917	3.78 ns
Error (B)	12	66.0000	5.50000	
Total	23	203.333		

7.25. Cu in straw

Replication (R)	3	0.9661	0.3220	<1
Irrigation (I)	1	0.0962	0.0962	<1
Error (A)	3	3.7600	1.2533	
Tillage (T)	2	0.2037	0.1018	<1
IxT	2	0.2785	0.1392	<1
Error (B)	12	5.8415	0.4867	
Total	23	11.146		

(Contd. Appendix Table 7)

Sources of variation	Degree of freedom	Sum of squares	Mean square	F-value
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7.26. Cu in grain

Replication (R)	3	0.4262	0.1421	< 1
Irrigation (I)	1	0.9640	0.9640	1.41 ns
Error (A)	3	2.0545	0.6848	
Tillage (T)	2	1.1732	0.5866	2.26 ns
IxT	2	0.1827	0.0914	<1
Error (B)	12	3.1203	.2600	
Total	23	7.9211		

7.27. Total N uptake

Replication (R)	3	41.0170	13.6723	
Irrigation (I)	1	133.0574	133.0575	11.76 **
Error (A)	3	33.9418	11.3139	
Tillage (T)	2	7.8636	3.9318	1.57 ns
IxT	2	14.7457	7.3728	2.95 ns
Error (B)	12	29.9960	2.4996	
Total	23	260.6218		

7.28. Total P uptake

Replication (R)	3	7.6930	2.5643	
Irrigation (I)	1	4.6288	4.6288	5.89 *
Error (A)	3	2.3584	0.7861	
Tillage (T)	2	1.1805	0.5902	1.30 ns
IxT	2	1.3361	0.6680	1.47 ns
Error (B)	12	5.4486	0.4540	
Total	23	22.6457		

(Contd. Appendix Table 7)

Sources of variation	Degree of freedom	Sum of squares	Mean square	F-value
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7.29. Total K uptake

Replication (R)	3	113.8385	37.9461	
Irrigation (I)	1	966.7242	966.7242	12.13 **
Error (A)	3	238.9825	79.6608	
Tillage (T)	2	563.1137	281.5568	2.27 ns
IxT	2	10.1806	5.0903	<1
Error (B)	12	1485.3626	123.7802	
Total	23	3378.2023		

7.30. Total Ca uptake

Replication (R)	3	1.4884	0.4961	
Irrigation (I)	1	0.0580	0.0580	<1
Error (A)	3	15.8491	5.2830	
Tillage (T)	2	2.1712	1.0856	4.76 *
IxT	2	4.5993	2.2996	10.07 **
Error (B)	12	2.7392	0.2282	
Total	23	26.9054		

7.31. Total Mg uptake

Replication (R)	3	7.1981	2.3993	
Irrigation (I)	1	13.8776	13.8776	7.26 *
Error (A)	3	5.7335	1.9111	
Tillage (T)	2	1.7989	0.8994	1.42 ns
IxT	2	1.1236	0.5618	<1
Error (B)	12	7.6161	0.6346	
Total	23	37.3479		

7.32. Total Fe uptake

Replication (R)	3	0.0680	0.0226	
Irrigation (I)	1	0.1650	0.1650	12.99 **
Error (A)	3	0.0382	0.0127	
Tillage (T)	2	0.0097	0.0048	<1
IxT	2	0.0082	0.0041	<1
Error (B)	12	0.0660	0.0055	
Total	23	0.3552		

(Contd. Appendix Table 7)

Sources of variation	Degree of freedom	Sum of squares	Mean square	F-value
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7.33. Total Mn uptake

Replication (R)	3	0.1982	0.0660	
Irrigation (I)	1	0.4902	0.4902	50.00 **
Error (A)	3	0.0294	0.0098	
Tillage (T)	2	0.0364	0.0182	<1
IxT	2	0.1372	0.0686	1.47 ns
Error (B)	12	0.5608	0.0467	
Total	23	1.4524		

7.34. Total Zn uptake

Replication (R)	3	.00503	0.00167	
Irrigation (I)	1	0.01601	0.01601	3.59 *
Error (A)	3	0.01335	0.00445	
Tillage (T)	2	0.00823	0.00411	8.72 **
IxT	2	0.00023	0.00012	<1
Error (B)	12	0.00566	0.00047	
Total	23	0.04853		

7.35. Total Cu uptake

Replication (R)	3	0.000033	0.000011	
Irrigation (I)	1	0.000066	0.000066	2.00 ns
Error (A)	3	0.000100	0.000033	
Tillage (T)	2	0.000025	0.000012	<1
IxT	2	0.000058	0.000029	1.11 ns
Error (B)	12	0.000316	0.000026	
Total	23	0.000600		

Appendix Table 8. Analysis of variance of experiment 4 with split-split plot design; main plot is moisture regimes, sub-plot is tillage and sub-sub plot is N levels.

Sources of variation	Degree of freedom	Sum of squares	Mean square	F-value
Plant height				
8.1. Maximum tillering				
Replication (R)	3	181.611	60.5370	1.18 ns
Moisture regimes (M)	1	193.389	193.388	3.79*
Error (A)	3	152.722	50.9074	
Tillage (T)	2	75.8611	37.9305	3.53 ns
MxT	2	36.8611	18.4305	1.72 ns
Error (B)	12	128.833	10.7351	
Nitrogen (N)	2	503.3611	251.680	28.46**
MXN	2	32.8611	16.4305	1.86 ns
TxN	4	19.6388	4.90972	<1
MxTxN	4	279.388	69.7847	7.89**
Error (C)	36	318.333	8.84459	
Total	71	1922.61		
8.2. Booting stage				
Replication (R)	3	526.597	175.532	2.82 ns
Moisture regimes (M)	1	728.347	728.347	11.73**
Error (A)	3	186.152	62.0509	
Tillage (T)	2	109.777	54.8888	22.98**
MxT	2	19.1111	9.55556	4.00*
Error (B)	12	28.6666	2.38889	
Nitrogen (N)	2	3917.19	1958.60	73.73**
MXN	2	52.6944	26.3472	<1
TxN	4	63.8055	15.9513	<1
MxTxN	4	397.972	99.4930	3.75*
Error (C)	36	956.333	26.5648	
Total	71	6986.65		
8.3. Maturity				
Replication (R)	3	450.333	150.111	1.22 ns
Moisture regimes (M)	1	1334.72	1334.722	10.93**
Error (A)	3	366.500	122.167	

(Contd. Appendix Table 8)

Sources of variation	Degree of freedom	Sum of squares	Mean square	F-value
Tillage (T)	2	330.361	165.180	5.48*
MxT	2	361.833	30.1527	<1
Error (B)	12	5158.86	2579.43	83.52**
Nitrogen (N)	2	103.527	51.7638	1.68 ns
MXN	2	100.222	25.0555	<1
TxN	4	794.889	198.722	6.43**
MxTxN	4	1111.83	30.8842	
Error (C)	36	10164.44		
Total	71			

Tillers/m²**8.4. Maximum tillering**

Replication (R)	3	29244.27	9748.09	<1
Moisture regimes (M)	1	276768.00	276768.00	12.72**
Error (A)	3	65256.33	21752.11	
Tillage (T)	2	32780.77	16390.39	<1
MxT	2	332360.33	166180.16	5.42*
Error (B)	12	367724.22	30643.68	
Nitrogen (N)	2	348068.69	174034.34	13.87**
MXN	2	88254.75	44127.37	3.52*
TxN	4	58153.89	14538.47	1.16 ns
MxTxN	4	120981.66	30245.42	2.41 ns
Error (C)	36	451575.67	12543.77	
Total	71	2171168.61		

8.5. Booting stage

Replication (R)	3	99215.9	33071.79	17.08**
Moisture regimes (M)	1	57347.55	57347.55	29.62**
Error (A)	3	5810.55	1936.85	
Tillage (T)	2	18957.25	9478.62	<1
MxT	2	172992.36	86496.18	7.27*
Error (B)	12	142776.39	11898.03	
Nitrogen (N)	2	80633.58	40316.79	4.68*
MXN	2	3934.19	1967.09	<1
TxN	4	36614.66	9153.67	1.06 ns
MxTxN	4	39748.39	9937.09	1.15 ns
Error (C)	36	310295.17	8617.19	
Total	71	968249.50		

(Contd. Appendix Table 8)

Sources of variation	Degree of freedom	Sum of squares	Mean square	F-value
8.6. Maturity				
Replication (R)	3	43121.15	14373.71	<1
Moisture regimes (M)	1	70642.01	70642.01	3.04 ns
Error (A)	3	69627.48	23209.16	
Tillage (T)	2	7551.08	3775.54	1.26 ns
MxT	2	5821.02	2910.52	<1
Error (B)	12	35828.11	2985.67	
Nitrogen (N)	2	34827.25	17413.62	3.45*
MXN	2	11558.69	5779.34	1.14 ns
TxN	4	25632.67	6408.17	1.27 ns
MxTxN	4	7006.89	1751.73	<1
Error (C)	36	181848.50	5051.34	
Total	71	493464.87		

Yield components

8.7. Panicle/m²				
Replication (R)	3	29299.15	9766.38	<1
Moisture regimes (M)	1	123753.12	123753.12	5.85*
Error (A)	3	63443.04	21147.68	
Tillage (T)	2	8775.52	4387.76	1.23 ns
MxT	2	4147.25	1073.62	<1
Error (B)	12	42662.55	3555.21	
Nitrogen (N)	2	33549.52	16774.76	3.30*
MXN	2	11010.25	55.5.12	1.08 ns
TxN	4	37798.47	9449.61	1.86 ns
MxTxN	4	12104.75	3026.18	<1
Error (C)	36	182737.00	5076.03	
Total	71	547280.65		

(Contd. Appendix Table 8)

Sources of variation	Degree of freedom	Sum of squares	Mean square	F-value
Nitrogen (N)	2	15.199	7.599	8.78**
MXN	2	8.273	4.136	4.78*
TxN	4	14.552	3.638	4.20*
MxTxN	4	6.378	1.594	1.84 ns
Error (C)	36	31.153	0.865	
Total	71	105.183		

Grain and straw yield

8.11. Grain

	3			
Replication (R)	1	3579224.15	1193074.72	18.84**
Moisture regimes (M)	3	17053773.35	17053773.35	270.60**
Error (A)		189092.71	63030.90	
Tillage (T)	2	94563.69	47281.85	2.43 ns
MxT	12	247922.86	123961.43	6.37*
Error (B)	2	233509.89	19459.16	
Nitrogen (N)	2	42279928.69	21139964.35	444.67**
MXN	4	536748.69	268374.35	5.65**
TxN	4	443141.81	110785.45	2.33 ns
MxTxN	36	811474.97	202867.74	4.27**
Error (C)	71	1711460.50	47540.57	
Total		67180837.32		

8.12. Straw

	3			
Replication (R)	3	5669723.4	1889907.8	5.56*
Moisture regimes (M)	1	17199112.5	17199112.5	50.61**
Error (A)	3	1019501.2	339833.7	
Tillage (T)	2	950283.5	475141.8	2.96 ns
MxT	2	205171.8	102585.9	<1
Error (B)	12	1924411.4	160367.6	
Nitrogen (N)	2	82798837.5	41399418.8	249.87**
MXN	2	683805.5	341902.8	2.06 ns
TxN	4	2183271.5	545817.9	3.29*
MxTxN	4	2194054.9	548513.7	3.31*
Error (C)	36	5964656.5	165684.9	
Total	71	120792829.8		

(Contd. Appendix Table 8)

Sources of variation	Degree of freedom	Sum of squares	Mean square	F-value
Mineral nutrition				
8.13. N in straw				
Replication (R)	3	0.05682	0.01894	
Moisture regimes (M)	1	0.00073	0.00073	<1
Error (A)	3	0.00971	0.00323	
Tillage (T)	2	0.00380	0.00190	1.08 ns
MxT	2	0.00726	0.00363	2.07 ns
Error (B)	12	0.02108	0.00175	
Nitrogen (N)	2	0.02501	0.01250	5.57*
MXN	2	0.00173	0.00086	<1
TxN	4	0.02972	0.00743	3.31*
MxTxN	4	0.00722	0.00180	<1
Error (C)	36	0.08090	0.00224	
Total	71	0.24403		
8.14. N in grain				
Replication (R)	3	0.1700	0.0566	
Moisture regimes (M)	1	0.0503	0.0503	2.44 ns
Error (A)	3	0.0618	0.0206	
Tillage (T)	2	0.0982	0.0491	<1
MxT	2	0.0275	0.0137	<1
Error (B)	12	0.7785	0.0648	
Nitrogen (N)	2	0.8305	0.4152	14.38**
MXN	2	0.0744	0.0372	1.29 ns
TxN	4	0.1024	0.0256	<1
MxTxN	4	0.0713	0.0178	<1
Error (C)	36	1.0397	0.0288	
Total	71	3.3006		
8.15. P in straw				
Replication (R)	3	0.0083	0.0027	
Moisture regimes (M)	1	0.0034	0.0034	1.09 ns
Error (A)	3	0.0094	0.0031	
Tillage (T)	2	0.0092	0.0046	1.74 ns
MxT	2	0.0074	0.0037	1.41 ns
Error (B)	12	0.0317	0.0026	
Nitrogen (N)	2	0.0138	0.0069	2.38 ns
MXN	2	0.0087	0.0043	1.50 ns
TxN	4	0.0138	0.0034	1.19 ns
MxTxN	4	0.0179	0.0044	1.55 ns
Error (C)	36	0.1047	0.0029	
Total	71	0.2287		

(Contd. Appendix Table 8)

Sources of variation	Degree of freedom	Sum of squares	Mean square	F-value
8.16. P in grain				
Replication (R)	3	0.00982	0.00327	
Moisture regimes (M)	1	0.00031	0.00031	<1
Error (A)	3	0.00467	0.00155	
Tillage (T)	2	0.01017	0.00508	7.31**
MxT	2	0.00930	0.00465	6.69*
Error (B)	12	0.00834	0.00069	
Nitrogen (N)	2	0.03987	0.01993	28.67**
MXN	2	0.00053	0.00026	<1
TxN	4	0.00997	0.00249	3.59*
MxTxN	4	0.00178	0.00044	<1
Error (C)	36	0.02503	0.00069	
Total	71	0.11983		
8.17. K in straw				
Replication (R)	3	0.0646	0.0215	
Moisture regimes (M)	1	0.6612	0.6612	11.18**
Error (A)	3	0.1798	0.0599	
Tillage (T)	2	0.3250	0.1625	14.43**
MxT	2	0.1797	0.0898	7.98**
Error (B)	12	0.1351	0.0112	
Nitrogen (N)	2	0.3786	0.1893	15.40**
MXN	2	0.0025	0.0012	<1
TxN	4	0.1522	0.0380	3.10*
MxTxN	4	0.1372	0.0343	2.79*
Error (C)	36	0.4425	0.0123	
Total	71	2.6589		
8.18. K in grain				
Replication (R)	3	0.0189	0.0063	
Moisture regimes (M)	1	0.0000	0.0000	
Error (A)	3	0.0001	0.0000	
Tillage (T)	2	0.0018	0.0009	2.58 ns
MxT	2	0.0108	0.0054	15.39**
Error (B)	12	0.0042	0.0004	
Nitrogen (N)	2	0.0133	0.0066	43.79**
MXN	2	0.0011	0.0003	3.55*
TxN	4	0.0013	0.0001	2.09 ns
MxTxN	4	0.0004	0.0002	<1
Error (C)	36	0.0055		
Total	71	0.0574		

(Contd. Appendix Table 8)

Sources of variation	Degree of freedom	Sum of squares	Mean square	F-value
8.19. Fe in straw				
Replication (R)	3	471.61	157.203	
Moisture regimes (M)	1	2.72	2.72	<1
Error (A)	3	2973.61	991.20	
Tillage (T)	2	23301.44	11650.72	5.45*
MxT	2	314.77	157.39	<1
Error (B)	12	25673.11	2139.42	
Nitrogen (N)	2	3374.19	1687.09	<1
MXN	2	3363.69	1681.84	<1
TxN	4	11505.97	2876.49	1.05 ns
MxTxN	4	9637.80	2409.45	<1
Error (C)	36	98469.66	2735.26	
Total	71	179088.61		
8.20. Fe in grain				
Replication (R)	3	1847.48	615.82	
Moisture regimes (M)	1	58.68	58.68	19.45**
Error (A)	3	9.04	3.01	
Tillage (T)	2	140.58	70.29	<1
MxT	2	2225.52	1112.76	5.51*
Error (B)	12	2423.88	201.99	
Nitrogen (N)	2	628.08	314.04	2.55 ns
MXN	2	871.36	435.68	3.54*
TxN	4	1292.58	323.14	2.62 ns
MxTxN	4	288.80	72.20	<1
Error (C)	36	4435.83	123.21	
Total	71	14221.87		
8.21. Zn in straw				
Replication (R)	3	310.50	103.50	
Moisture regimes (M)	1	8.00	8.00	<1
Error (A)	3	393.44	131.14	
Tillage (T)	2	359.19	179.59	19.82**
MxT	2	466.75	233.37	25.76**
Error (B)	12	108.72	9.06	
Nitrogen (N)	2	36.11	18.05	<1
MXN	2	151.00	75.50	3.71*
TxN	4	36.05	9.01	<1
MxTxN	4	209.00	52.25	2.57 ns
Error (C)	36	731.83	20.32	
Total	71	2810.61		

(Contd. Appendix Table 8)

Sources of variation	Degree of freedom	Sum of squares	Mean square	F-value
8.22. Zn in grain				
Replication (R)	3	746.33	248.77	
Moisture regimes (M)	1	10.88	10.88	<1
Error (A)	3	84.55	28.18	
Tillage (T)	2	117.36	58.68	1.85 ns
MxT	2	548.69	274.34	8.63**
Error (B)	12	381.27	31.77	
Nitrogen (N)	2	155.19	77.59	2.71 ns
MXN	2	123.69	61.84	2.16 ns
TxN	4	244.39	61.09	2.13 ns
MxTxN	4	24.22	6.05	<1
Error (C)	36	1031.83	28.66	
Total	71	3468.44		
8.23. Mn in straw				
Replication (R)	3	104.26	34.75	
Moisture regimes (M)	1	6.12	6.12	<1
Error (A)	3	241.37	80.45	
Tillage (T)	2	167.19	83.59	1.64 ns
MxT	2	18.25	9.12	<1
Error (B)	12	612.11	51.00	
Nitrogen (N)	2	198.36	99.18	2.42 ns
MXN	2	549.25	274.62	6.70**
TxN	4	166.88	41.72	1.02 ns
MxTxN	4	467.00	116.75	2.85*
Error (C)	36	1474.50	40.95	
Total	71	4005.32		
8.24. Mn in grain				
Replication (R)	3	481.93	160.64	
Moisture regimes (M)	1	572.34	572.34	28.60**
Error (A)	3	61.48	20.49	
Tillage (T)	2	174.52	87.26	2.25 ns
MxT	2	125.36	62.68	1.62 ns
Error (B)	12	465.00	38.75	
Nitrogen (N)	2	276.02	138.01	9.28*
MXN	2	88.69	44.34	2.98 ns
TxN	4	243.80	60.95	4.10**
MxTxN	4	83.47	20.86	1.40 ns
Error (C)	36	535.33	14.87	
Total	71	3107.98		

(Contd. Appendix Table 8)

Sources of variation	Degree of freedom	Sum of squares	Mean square	F-value
8.25. Cu in straw				
Replication (R)	3	4.11	1.37	
Moisture regimes (M)	1	1.24	1.24	2.88 ns
Error (A)	3	1.30	0.43	
Tillage (T)	2	1.64	0.82	<1
MxT	2	8.63	4.31	3.76 ns
Error (B)	12	13.76	1.14	
Nitrogen (N)	2	0.28	0.14	<1
MXN	2	1.18	0.59	3.39*
TxN	4	0.47	0.12	<1
MxTxN	4	1.62	0.40	2.33 ns
Error (C)	36	6.27	0.17	
Total	71	40.54		
8.26. Cu in grain				
Replication (R)	3	9.62	3.20	
Moisture regimes (M)	1	1.66	1.66	<1
Error (A)	3	7.72	2.57	
Tillage (T)	2	1.40	0.70	<1
MxT	2	9.87	4.93	6.50*
Error (B)	12	9.11	0.76	
Nitrogen (N)	2	1.53	0.76	1.64 ns
MXN	2	0.16	0.08	<1
TxN	4	1.10	0.27	<1
MxTxN	4	0.72	0.18	<1
Error (C)	36	16.86	0.46	
Total	71	59.80		
8.27. N uptake				
Replication (R)	3	2299.11	766.37.37	
Moisture regimes (M)	1	10416.05	10416.05	381.25**
Error (A)	3	81.94	27.31	
Tillage (T)	2	25.86	12.93	<1
MxT	2	286.02	143.01	1.06 ns
Error (B)	12	1617.44	134.78	
Nitrogen (N)	2	41149.69	20574.84	267.35**
MXN	2	706.02	353.01	4.59*
TxN	4	685.88	171.47	2.23 ns
MxTxN	4	317.88	79.47	1.03 ns
Error (C)	36	2770.50	76.95	
Total	71	60356.44		

(Contd. Appendix Table 8)

Sources of variation	Degree of freedom	Sum of squares	Mean square	F-value
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8.28. Kg grain/kg absorbed N

Replication (R)	3	11.59	3.86	
Moisture regimes (M)	1	62.34	62.34	25.03**
Error (A)	3	7.48	2.49	
Tillage (T)	2	24.69	12.34	<1
MxT	2	13.02	6.51	<1
Error (B)	12	170.5	14.20	
Nitrogen (N)	2	172.52	86.26	17.09**
MXN	2	30.36	15.18	3.01 ns
TxN	4	17.14	4.28	<1
MxTxN	4	17.63	4.40	<1
Error (C)	36	181.67	5.04	
Total	71	708.98		

8.29. Kg N uptake/100 kg N applied

Replication (R)	3	236.37	78.79	
Moisture regimes (M)	1	1020.01	1020.03	64.92**
Error (A)	3	17.15	15.71	
Tillage (T)	2	60.52	30.26	<1
MxT	2	253.36	126.68	1.02 ns
Error (B)	12	1492.55	124.37	
Nitrogen (N)	2	28983.02	14491.51	278.36**
MXN	2	627.19	313.59	6.02**
TxN	4	551.63	137.90	2.65*
MxTxN	4	311.30	77.82	1.49 ns
Error (C)	36	1874.17	52.06	
Total	71	35457.32		

8.30. Kg grain/kg applied N

Replication (R)	3	69.94	23.31	
Moisture regimes (M)	1	72.00	72.00	194.59**
Error (A)	3	1.11	0.37	
Tillage (T)	2	21.33	10.66	1.07 ns
MxT	2	52.33	26.17	2.61 ns
Error (B)	12	120.11	10.00	
Nitrogen (N)	2	3220.33	1610.17	422.08**
MXN	2	52.33	26.17	6.86**
TxN	4	45.33	11.33	2.97*
MxTxN	4	69.33	17.33	4.54**
Error (C)	36	137.33	3.81	
Total	71	3861.50		

Appendix Table 9. Analysis of variance of experiment 5 with split plot design; main plot is tillage and sub plot is N levels.

Sources of variation	Degree of freedom	Sum of squares	Mean of squares	F- Value
Yield component				
9.1. Number of panicles/m²				
Replication (R)	2	1270.4	635.2	
Tillage (T)	2	2005.6	1002.8	1.48 ns
Error (a)	4	2704.6	676.2	
Nitrogen (N)	3	3813.0	1271.0	8.14 **
T x N	6	1691.8	282.0	1.81 ns
Error b()	18	2809.0	156.1	
Total	35	14294.3		
9.2. Number of filled grains/panicle				
Replication (R)	2	12.06	6.03	
Tillage (T)	2	954.06	477.03	1.66 ns
Error (a)	4	1148.44	287.11	
Nitrogen (N)	3	3742.75	1247.58	10.75 **
T x N	6	1016.83	169.58	1.46 ns
Error b()	18	2088.17	116.01	
Total	35	8962.31		
9.3. Weight of 1000 filled grains				
Replication (R)	2	2.8889	1.4444	
Tillage (T)	2	1.7222	0.8611	< 1
Error (a)	4	5.6111	1.4028	
Nitrogen (N)	3	0.7500	0.2500	< 1
T x N	6	3.1667	0.5278	1.08 ns
Error b()	18	8.8333	0.4907	
Total	35	22.9722		
9.4. Percent unfilled grain				
Replication (R)	2	8.1666	4.0833	
Tillage (T)	2	57.1666	28.5833	2.37 *
Error (a)	4	48.1666	12.0416	
Nitrogen (N)	3	51.2222	17.0740	4.29 *
T x N	6	28.6111	4.7685	
Error b()	18	71.6666	3.9814	
Total	35	265.0000		

(Contd. Appendix Table 9)

Sources of variation	Degree of freedom	Sum of squares	Mean of squares	F- Value
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9.5. Grain yield

Replication (R)	2	0.0304	0.0151	
Tillage (T)	2	1.3478	0.6739	2.19 ns
Error (a)	4	1.2301	0.3075	
Nitrogen (N)	3	11.0522	3.6841	75.13 **
T x N	6	0.1957	0.0326	< 1
Error (b)	18	0.8826	0.0490	
Total	35	14.7389		

9.6. Straw yield

Replication (R)	2	0.0017	0.0008	
Tillage (T)	2	1.6856	0.8428	2.57 ns
Error (a)	4	1.3098	0.3274	
Nitrogen (N)	3	7.8279	2.6093	35.12 **
T x N	6	0.3111	0.0518	< 1
Error (b)	18	1.3374	0.0743	
Total	35	12.4735		

Appendix Table 10. Analysis of variance of experiment 6 with randomized complete block design

Sources of variation	Degree of freedom	Sum of squares	Mean of squares	F- Value
10.1. Plant height				
Replication (R)	3	40.3333	13.4444	1.59 ns
Treatment	5	388.5000	77.7000	9.17 **
Tillage (T)	2	32.2500	16.1250	1.90 ns
Irrigation (I)	1	352.6666	352.6666	41.60 **
T x I	2	3.5833	1.7916	<1
Error	15	127.1666	8.4777	
Total	23	556.0000		
10.2. Number of tillers per m²				
Replication (R)	3	3304.1250	1101.3750	8.98 **
Treatment	5	60737.7083	12147.5416	99.08 **
Tillage (T)	2	6900.0833	3450.0416	28.14 **
Irrigation (I)	1	52922.0416	52922.0416	431.63 **
T x I	2	915.5833	457.7916	3.73 *
Error	15	1839.1250	122.6083	
Total	23	65880.9583		
10.3. Number panicles per m²				
Replication (R)	3	397.8333	132.6111	2.90 ns
Treatment	5	39803.8333	7960.7666	174.03 **
Tillage (T)	2	4985.0833	2492.5416	54.49 **
Irrigation (I)	1	34656.0000	34656.0000	757.60 **
T x I	2	162.7500	81.3750	1.78 ns
Error	15	686.1666	45.7444	
Total	23	40887.8333		
10.4. Number of grains per panicle				
Replication (R)	3	0.8333	0.2777	<1
Treatment	5	99.3333	19.8666	38.87 **
Tillage (T)	2	36.0833	18.0416	35.30 **
Irrigation (I)	1	54.0000	54.0000	105.65 **
T x I	2	9.2500	4.6250	9.05 **
Error	15	7.6666	0.5111	
Total	23	107.8333		

(Contd. Appendix Table 10)

Sources of variation	Degree of freedom	Sum of squares	Mean of squares	F- Value
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10.5. 1000 grain weight

Replication (R)	3	23.3745	7.7908	3.70 *
Treatment	5	49.3120	9.8624	4.68 **
Tillage (T)	2	3.9216	1.9608	<1
Irrigation (I)	1	42.2941	42.2941	20.08 **
T x I	2	3.0963	1.5481	<1
Error	15	31.6000	2.1066	
Total	23	104.2847		

10.6. Percent unfilled grain

Replication (R)	3	0.1250	0.0416	2.19 ns
Treatment	5	0.3283	0.0656	3.46 *
Tillage (T)	2	0.1258	0.0629	3.31 ns
Irrigation (I)	1	0.2016	0.2016	10.61 **
T x I	2	0.0008	0.0004	<1
Error	15	0.2850	0.0190	
Total	23	0.7383		

10.7. Grain yield

Replication (R)	3	18124.458	6041.486	2.40 ns
Treatment	5	7888766.875	1577753.375	626.34 **
Tillage (T)	2	639489.250	319744.625	126.93 **
Irrigation (I)	1	7151508.375	7151508.375	2839.00 **
T x I	2	97769.250	48884.625	19.41 **
Error	15	37785.292	2519.019	
Total	23	7944676.625		

10.8. Straw yield

Replication (R)	3	7650.79	2550.26	<1
Treatment	5	13902445.38	2780489.08	932.41 **
Tillage (T)	2	1065677.25	532838.63	178.68 **
Irrigation (I)	1	12758958.38	12758958.38	4278.61 **
T x I	2	77809.75	38904.88	13.05 **
Error	15	44730.46	2982.03	
Total	23	13954826.63		