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Effects of Irrigation and Nitrogen Fertilization on Root Growth and Root Characteristics of Wheat on a Clay Terrace Soil of Bangladesh

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A field research was conducted at the university farm of Bangabandhu Sheikh Mujibur Rahman Agricultural University, Bangladesh, during November 1997 to March 1998 in order to study the effects of irrigation and nitrogen fertilization on the root growth and root characteristics of wheat. The experiment was executed in the split–plot design comprising the combination of the five levels of irrigation arranged as a main plot and the four rates of N application distributed to a sub–plot. The treatments for the study were the same as before. Both irrigation and N application have created a remarkable impact on root length density, root weight density and root–to–shoot ratio of wheat. Root length density and root diameter in the surface layer increased with the increasing level of irrigation or N application. Root growth in the subsurface layers increased when either irrigation or N application was limited while the other was in the optimum level. Root–to–shoot ratio was negatively correlated with the frequency and amount of irrigation and N application. Higher frequency of irrigation has remarkably reduced soil strength in the surface layer, but N application could not create any impact on it.

INTRODUCTION

Irrigation water and N fertilizer are the major inputs governing growth and development of wheat plant. Plant roots have an important role on growth and development of plant as they contribute absolutely to stand establishment and extraction of water and nutrients. Wheat roots were found to have the positive and significant association with the uptake of nutrients by the plants (Parmar and Sharma, 1998). The growth and development of roots depend to a great extent on the nutrient status and physical conditions of the soil, such as moisture, texture and compaction. High soil moisture and poor aeration limit root growth and the optimum moisture level for the normal root development in a specific soil depth depends on its bulk density (Miah *et al.*, 1990). Water deficit reduced the amount of roots in the surface layer and increased the number of roots in the deeper soil layers (Wang and Ma, 1992), but the amount of roots in the subsoil was very small to contribute to extraction of potentially available water (Barraclough *et al.* 1989). Application of N fertilizer at the optimum level results in the

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maximum root expansion, moisture use and yield of crops, and Awasthi *et al.* (1993) reported that the maximum root expansion, moisture use efficiency and yield of wheat were obtained at the N application rate of 60 kg ha^{-1}. Root growth under a specific soil moisture regime and N status varies with soil types and physical properties of the soil.

The low yield of wheat in Bangladesh is characterized by the sub-optimal soil moisture during most of the growing period and low availability of soil N and other nutrients, and thereby resulting in the restricted root and shoot growth. Irrigation scheduling and optimum N application are therefore important for growth and development of root system to achieve higher yield potential of wheat. The impact of irrigation and N application on above-ground parts of wheat is extensively studied both at home and abroad but little effort has been made on underground parts. The present study was undertaken to clarify the root growth and characteristics of wheat in relation to irrigation and N fertilization on a clay terrace soil of Bangladesh. This is the second paper of the study on wheat production, following the first paper (Rahman *et al.*, 2000).

MATERIALS AND METHODS

The experiment was done at the research farm of Bangabandhu Sheikh Mujibur Rahman Agricultural University (BSMRAU), Gazipur, Bangladesh during November 1997 to March 1998. The soil, climate, test crop, experimental design, fertilizer application, sowing of seeds, and cultural operations of the experiment, and statistical analysis were mentioned in the previous paper (Rahman *et al.*, 2000).

Growth analysis of root

Growth analysis of roots was studied once at the dough stage (90 DAS) after the execution of the last irrigation treatment. Roots with soil were collected from a selected hill of individual treatment by driving vertically a core sampler in three splits of 0–10, 10–20 and 20–30 cm depths. They were watered in an individual polyethylene bag, kept overnight for swelling and loosening of soil, and washed in tap water using a cloth net over the plastic net tray. The weight of the root samples in three splits of depth was noted immediately after cleaning and then a small part of it was oven-dried at 70 °C for determining the oven-dry weight of roots. The rest of the fresh root samples was preserved in refrigerator immediately after cleaning and stained with methyl-violet at least 24 hr before taking the measurement. The length and area of an individual root were measured by a root scanner (Model: NVM12, Japan). The equipment was calibrated using weir of the known length and area for measuring root length and root area, respectively. Root diameter was calculated from the area of roots divided by the total length of the roots.

Root length density. Root length density (RLD) at different soil depths was calculated using the equation as follows:

RLD ($cm\ cm^{-3}$)=L_l/S_v,

where L_l=total length of roots (cm);

S_v=inner volume of the core sampler (cm^3) calculated as $S_v=\pi r^2 h$;

where r=radius of the core sampler (cm) and h=sampling depth (cm).

Root weight density. Root weight density (RWD) was calculated using the

equation as follows:
RWD (g cm^{-3})=W_1/S_v,
where W_1=total weight of roots (collected from the upper 30 cm of soil core) (g).

Root-to-shoot ratio

The above-ground plant-parts of an individual hill were dried in an oven at 70 °C for 72 hr and weighed. The root-to-shoot ratio was calculated by dividing the total weight of roots by that of shoots.

Soil strength

At the time of root sampling a pit up to a depth of at least 30 cm was made in each plot. Soil strength was measured by pushing a pocket-type penetrometer vertically along the inner side of the pit at a regular interval of 10 cm. The measurement was taken in triplicate from each depth and the mean value was calculated.

RESULTS AND DISCUSSION

Root length density

Root length density at different soil depths was influenced by irrigation and N application (Tables 1 and 2). It increased with the increasing number of irrigation up to a depth of 20 cm (Table 1). Sharma and Chaudhary (1983) reported that RLD was greater

Table 1. Effect of irrigation on root length density and root diameter of wheat at different depths of soil (at the dough stage (90 DAS)).

Treatment	Root length density (cm cm^{-3})			Root diameter (mm)		
	0–10 cm	10–20 cm	20–30 cm	0–10 cm	10–20 cm	20–30 cm
I_0	3.39 d	0.35 d	0.28 a	0.54 c	0.31 a	0.30 a
I_1	3.57 d	0.37 cd	0.26 a	0.57 c	0.32 a	0.31 a
I_2	3.87 c	0.39 c	0.22 b	0.64 b	0.33 a	0.31 a
I_3	4.35 b	0.42 b	0.23 b	0.66 b	0.33 a	0.32 a
I_4	4.55 a	0.45 a	0.24 b	0.75 a	0.34 a	0.34 a

Treatments having a common letter in column are not significantly different at 5% level.

Table 2. Effect of N application on root length density and root diameter of wheat at different depths of soil (at the dough stage (90 DAS)).

Treatment	Root length density (cm cm^{-3})			Root diameter (mm)		
	0–10 cm	10–20 cm	20–30 cm	0–10 cm	10–20 cm	20–30 cm
N_0	3.13 d	0.44 a	0.32 a	0.54 c	0.30 b	0.28 b
N_1	3.87 c	0.43 a	0.25 b	0.64 b	0.33 ab	0.33 a
N_2	4.59 a	0.38 b	0.22 bc	0.68 a	0.34 ab	0.33 a
N_3	4.20 b	0.33 c	0.21 c	0.71 a	0.36 a	0.33 a

Treatments having a common letter in column are not significantly different at 5% level.

under irrigated than under non–irrigated conditions. Singh *et al.* (1990) observed deeper root penetration and greater root growth in different soil layers with irrigation at 50% depletion of soil available water than a single irrigation at the crown root initiation stage (CRI), which is close to our findings with the exception of the confinement of root development in the surface layer in our study. Significantly higher RLD in the upper two layers (0–10 and 10–20 cm) was recorded under I_4 that provided irrigation water at CRI, booting and grain filling stages (Table 1). At the lower layer (20–30 cm), however, RLD was comparatively high under minimum or no irrigation (I_1 or I_0). Minimum soil moisture in upper layer might have compelled the roots to penetrate down to explore moisture from the subsurface layer. Wang and Ma (1992) observed that water deficit reduced the amount of roots in the surface layer and increased the number of roots in the deeper soil layers, similar to our observation. Barraclough *et al.* (1989) also reported that the drought wheat rooted more deeply than the irrigated one but that the amount of roots in the deeper subsoil was very small to contribute to extraction of potentially available water.

Under favourable moisture condition root development in a specific soil depth depends on its bulk density (Miah *et al.*, 1990) and the growth of root is suppressed with the increasing depth of soil (Singh and Das, 1986). Due to high bulk density (1.66 to 1.78 g cm^{-3}) (Rahman *et al.*, 2000) and greater resistance (Table 6) in subsoil RLD was drastically reduced below the top layer (0–10 cm) (Table 1). The rate of reduction in RLD was higher at the higher levels of irrigation. Katterer *et al.* (1993) reported that the proportion of deep–rooting (50–100 cm) decreased as a result of frequent irrigation.

Different rates of N application have led to the significant variation in RLD in different depths of soil (Table 2). At the surface layer (0–10 cm) RLD increased with the increasing N application rate up to 120 kg ha^{-1} (N_2) and the further increment led to the decreased RLD. On the contrary, RLD in the subsurface layers (10–20 and 20–30 cm) decreased linearly with the increasing N application rate. Comfort *et al.* (1988) reported that root length was increased in the upper soil layers up to a depth of 30 cm by applying 67 kg N ha^{-1} and that the further increment in N up to 134 kg N ha^{-1} caused similar or decreased root length. They further stated that root growth was suppressed with the increasing soil depth above 30 cm and that the higher N application rate (134 kg ha^{-1}) caused the great suppression in root growth compared to the control or moderate N application rate. Higher soil compaction below 10 cm depth (Rahman *et al.*, 2000) accompanied by higher N application rate might have favoured the confinement of roots within the upper layer of soil (Table 2).

The interaction effect of irrigation and N application on total root length at the depth of 20–30 cm is presented in Table 3. It was observed that at the irrigation level of I_0, total root length increased with the increasing application rate of N. In contrast, at the higher irrigation levels of I_2 through I_4, total root length decreased with the increasing application rate of N. The same tendency was observed for the N treatment in general. The results reveal that root length of wheat at the deeper soil layer increases when one of the factors is limiting while other is in optimum level.

Root diameter

Both irrigation and N application have created a significant impact on root diameter

Table 3. Interaction effect of irrigation and N application on total length of roots in core volume (11 cm in diameter) at a depth of 20–30 cm (at the dough stage (90 DAS)) (cm).

Treatment	I_0	I_1	I_2	I_3	I_4	Mean
N_0	241.2 C d	271.0 A c	314.0 A b	296.7 A b	344.0 A a	293.4 A
N_1	248.1 C b	278.6 A a	222.7 B c	232.3 B bc	198.3 B d	236.0 B
N_2	273.0 B a	276.6 A a	167.3 C b	189.3 C b	177.3 BC b	216.7 C
N_3	301.8 A a	184.5 B b	148.7 C c	167.3 C bc	174.7 C b	195.4 D
Mean	266.0 a	252.7 b	213.2 c	221.4 c	223.6 c	235.4

Treatments having a common capital letter in column and those having a common small letter in row are not significantly different at 5% level.

(RD) of wheat (Tables 1 and 2). Root diameter at the surface layer (0–10 cm) increased linearly with the increasing irrigation level and N application rate. At the surface the maximum value of 0.75 mm was recorded under the highest level of irrigation (I_4). The minimum value of 0.54 mm was recorded under no–irrigation condition (I_0). The highest rate of N application (N_3) has led to the maximum RD (0.71 mm) and it was statistically similar to RD (0.68 mm) recorded in N_2. The results are supported by the findings of Singh and Das (1986), who reported that RD of wheat increased with the increasing irrigation level and specially with the increasing N application rate. Root diameter was drastically reduced in the subsurface layers (10–20 and 20–30 cm) irrespective of irrigation and N treatments (Tables 1 and 2). It might be due to the high soil compaction (bulk density: 1.66 to 1.78 g cm^{-3}) (Rahman *et al.*, 2000) and greater resistance (Table 6) in subsoil. There was no significant variation in RD in the subsurface layers for different irrigation levels, but N application has created a significant impact on RD. Wheat plant fertilized with the higher rates of N maintained greater RD in the subsurface layers.

Root weight and root weight density

The oven–dry weight of roots within the core sampler at a depth of 0–30 cm increased significantly with the increasing irrigation level (Table 4). Root weight density also increased with increase in the irrigation frequency but it was statistically nonsignificant. Singh *et al.* (1990) reported that RWD of wheat was higher for irrigation at 50% depletion of soil available water than for single irrigation at CRI. In our study the response to irrigation was partially interfered by rain (Rahman *et al.*, 2000), but still the increasing trend in RWD was observed with the increasing irrigation level. Nitrogen application at 120 kg ha^{-1} (N_2) has led to the significant increase in root weight and RWD (Table 5). The further increment in N up to 160 kg ha^{-1} (N_3) resulted in the reduction in root weight and RWD, although the values were statistically similar to those obtained in N_2. Singh *et al.* (1990) observed that RWD was highest for N application at 120 kg ha^{-1} and that RWD was positively correlated with N uptake, dry matter accumulation and yield of wheat.

Root–to–shoot ratio

Root–to–shoot ratio (R/S) is an important character that changes under stress condition. In general, water deficit or N deficiency causes increase in R/S. In the present

Table 4. Effect of irrigation on root weight density and root-to-shoot ratio of wheat (at the dough stage (90 DAS)).

Treatment	Total root weight (mg)	Root weight density (mg cm^{-3})	Total shoot weight (g)	Root-to-shoot ratio (mg g^{-1})
I_0	935.8 b	0.99 a	23.47 d	39.88 a
I_1	947.5 b	1.00 a	24.17 d	39.20 a
I_2	1019.2 a	1.06 a	29.96 c	34.02 b
I_3	1006.6 a	1.06 a	32.52 b	30.95 b
I_4	1049.5 a	1.10 a	34.30 a	30.60 b

Treatments having a common letter in column are not significantly different at 5% level.

Table 5. Effect of N application on root weight density and root-to-shoot ratio of wheat (at the dough stage (90 DAS)).

Treatment	Total root weight (mg)	Root weight density (mg cm^{-3})	Total shoot weight (g)	Root-to-shoot ratio (mg g^{-1})
N_0	700.5 c	0.78 c	13.70 d	51.13 a
N_1	1025.0 b	1.08 b	28.54 c	35.91 b
N_2	1152.0 a	1.21 a	36.87 b	31.24 c
N_3	1085.0 a	1.14 ab	37.68 a	28.80 d

Treatments having a common letter in column are not significantly different at 5% level.

Table 6. Effects of irrigation and N application on soil strength at different depths of soil (at the dough stage (90 DAS)) (kg cm^{-2}).

Treatment	Soil depth		
	0–10 cm	10–20 cm	20–30 cm
Irrigation			
I_0	3.79	4.5+	4.5+
I_1	3.19	4.5+	4.5+
I_2	3.25	4.5+	4.5+
I_3	2.08	4.38	4.31
I_4	1.84	3.57	4.08
N application			
N_0	2.86	4.42	4.5+
N_1	2.95	4.5+	4.5+
N_2	2.77	4.5+	4.5+
N_3	2.90	4.5	4.5

study both irrigation and N application made a significant impact on R/S (Tables 4 and 5). No irrigation (N_0) or one irrigation (N_1) has resulted in the high value of R/S as compared to other irrigation treatments. The value of R/S decreased with increase in the N application rate. The highest value (51.13 mg g^{-1}) was recorded from N_0 and the lowest value (28.80 mg g^{-1}) was from N_3. The reduction of R/S is caused either by the decreased root weight or increase in the weight of shoot. Although both root and shoot weights increased in favour of irrigation or N application, the reduction in R/S at higher levels of both factors was due to great increase in shoot weight compared to root weight.

Soil strength

Soil strength or penetration resistance (PR) of the soil was high in the subsurface layers (10–20 and 20–30 cm) compared to the surface layer (0–10 cm) irrespective of irrigation and N treatments (Table 6). Irrigation has created a marked variation in PR in all the layers, but N application did not have any impact on it. In general, PR decreased with increase in the irrigation level and the reduction in PR in the surface layer was greater than that in the subsurface layers.

CONCLUSIONS

Wheat root responds remarkably to both irrigation and N application. Root length density and root diameter at the surface layer increase with the increasing level of irrigation and N application. Root weight density increases slightly with increasing frequency of irrigation, but the increment becomes significantly high by applying N up to 120 kg ha^{-1}. Root–to–shoot ratio decreases with the increasing level of irrigation and N application. Root growth in the subsurface layers increases when one of the factors (irrigation or N) is limited while the other is in the optimum level.

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