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Rahman M., Ataur
MS student, Department of Soil Science, Bangabandhu Sheikh Mujibur Rahman Agricultura University

Karim, Sirajul A. J. M.

Solaiman R. M., A.
Department of Soil Science, Bangabandhu Sheikh Mujibur Rahman Agricultural University

Egashira, Kazuhiko
Laboratory of Soil Science, Division of Soil Science and Plant Production, Department of Plant Resources, Faculty of Agriculture, Kyushu University

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Effects of Irrigation and Nitrogen Fertilization on Nitrogen Uptake and Nitrogen Use Efficiency of Wheat on a Clay Terrace Soil of Bangladesh

M. Ataur Rahman*, A. J. M. Sirajul Karim, A. R. M. Solaiman** and Kazuhiko Egashira*****

Laboratory of Soil Science, Division of Soil Science and Plant Production,
Department of Plant Resources, Faculty of Agriculture,
Kyushu University, Fukuoka 812–8581, Japan
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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 uptake of nitrogen and nitrogen use efficiency 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 significant impact on N content, N uptake, and N use efficiency in wheat. The N content and N uptake of wheat were increased significantly by providing two to three irrigations having irrigation at the grain filling stage (80 days after sowing). Nitrogen application up to 120 kg ha^{-1} also increased the N content and N uptake of wheat. The N content in wheat grain was found to be highly correlated with the leaf N content at the different growth stages. A negative relationship existed between N use efficiency of wheat and the rate of N application.

INTRODUCTION

Efficient N uptake and assimilation are essential for the optimum growth and yield of wheat. Grain protein content correlated with grain N content is of considerable economic importance. Increased N accumulation generally results in the increased grain protein yield. Field and green house studies have shown that N uptake by wheat plant contributes significantly to build–up of grain N (Cooper and Blankeney, 1990; Dhugga and Waines, 1989). Nitrogen uptake and its assimilation in wheat are governed by various agronomic factors. Soil water and N are the two important factors contributing N uptake and grain N yield. Favourable soil water conditions during the growing season are required for the high grain yield and for the positive yield response to N fertilization (Rasmussen and Rohde, 1991). When soil water and N are adequate for wheat, high grain N yield is also achieved (Johnston and Flowler, 1991). In contrast, inadequate soil water during the growing season results in the reduced N accumulation and N use efficiency

* MS student, Department of Soil Science, Bangabandhu Sheikh Mujibur Rahman Agricultural University, Salna, Gazipur 1703, Bangladesh; currently serving at Wheat Research Center, Noshipur, Dinajpur, Bangladesh

** Department of Soil Science, Bangabandhu Sheikh Mujibur Rahman Agricultural University, Salna, Gazipur 1703, Bangladesh

*** Corresponding author (E-mail: kegashi@agr.kyushu-u.ac.jp)

(NUE) of wheat. Excess watering increases the potential for ground water pollution from soil nitrates. Thus watering at right time with right amount is important to increase N accumulation and NUE of wheat.

In wheat and many other crops, high correlation between the amount of applied N and the leaf N content has been reported under the controlled condition. Due to unpredictable influence of climatic and soil conditions, there are some differences among the results related to N content, N uptake and NUE of wheat as influenced by applied N in the field condition. With increase in applied N fertilizer, agronomic efficiency usually declines (Doyle and Holford, 1993). Much work has been done on rice to explore potential N uptake and utilization efficiency of applied N through agronomic management but little effort has been made for wheat. The present study was carried out to examine the effects of irrigation and N fertilization on N uptake and NUE of wheat on a clay terrace soil of Bangladesh. This is the third part of the study on wheat production, following the previous papers (Rahman *et al.*, 2000a, b).

MATERIALS AND METHODS

The experiment was conducted 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.*, 2000a). Sampling of wheat plant was also described in the previous paper (Rahman *et al.*, 2000a). The above-ground plant-parts were segmented into different components and then dried in an oven at 70 °C for 72 hr followed by weighing. Plant and soil N was determined by the Kjeldahl method.

Nitrogen uptake by plants

Nitrogen uptake by leaves was calculated from weight of leaves (kg ha^{-1}) and the leaf N content. Similarly, straw and grain N uptakes were calculated by their weights with respective N contents. Total N uptake by wheat is the summation of N uptake by straw and grain.

Nitrogen use efficiency

Nitrogen use efficiency was calculated as the ratio of grain yield (kg ha^{-1}) to total N uptake (kg ha^{-1}) by wheat for a particular treatment.

Residual soil nitrogen

After the harvest soil samples up to a depth of 20 cm at two equal splits (0–10 and 10–20 cm) were collected from each plot and total N was determined.

RESULTS AND DISCUSSION

Nitrogen content and uptake of leaves

The effects of irrigation and N application on the leaf N content and N uptake by leaves are presented in Tables 1 and 2, respectively. Since all the irrigation treatments

Table 1. Effect of irrigation on leaf N content and N uptake by leaves at the maturity stage (104 DAS) of wheat.

Treatment	N content (%)	N uptake (kg ha^{-1})
I_0	0.97 c	14.26 c
I_1	1.12 b	17.84 b
I_2	1.12 b	18.14 b
I_3	1.46 a	27.26 a
I_4	1.41 a	25.88 a

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

Table 2. Effect of N application on leaf N content and N uptake by leaves at different growth stages of wheat.

Treatment	N content (%)			N uptake (kg ha^{-1})		
	Booting (60 DAS)	Anthesis (70 DAS)	Maturity (104 DAS)	Booting (60 DAS)	Anthesis (70 DAS)	Maturity (104 DAS)
N_0	2.56 d	1.75 d	0.45 d	18.98 d	12.37 d	2.83 d
N_1	3.12 c	2.66 c	0.96 c	56.79 c	43.86 c	14.90 c
N_2	3.57 b	3.54 b	1.40 b	81.01 b	70.37 b	26.86 b
N_3	3.92 a	4.00 a	2.01 a	89.80 a	79.37 a	38.12 a

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

could not be completed before the grain filling stage (80 DAS) of wheat, leaf N content and N uptake for irrigation treatment were determined only at the maturity stage (104 DAS). Irrigation has created a significant impact on the leaf N content and N uptake by leaves (Table 1). The treatment which included irrigation at the grain filling stage (80 DAS) (I_3 and I_4) exhibited the significantly higher leaf N content and N uptake by leaves. Amin (1997) found higher total N in all parts of wheat plant under higher frequency of irrigation.

Leaf N content and N uptake were determined at the booting (60 DAS), anthesis (70 DAS) and maturity (104 DAS) stages of wheat in the study of N application effect (Table 2). The effect of N application on the leaf N content and N uptake was significant. The leaf N content increased linearly with every increase in applied N. Plants receiving N at the rate of 160 kg ha^{-1} (N_3) had the significantly highest leaf N content at all the growth stages. Nitrogen uptake by leaves was also significantly higher under higher dose of N. The results are supported by the findings of Johnston and Flowler (1991), who reported that tissue N content and N yield increased with the increasing rate of N application. The leaf N content varied considerably with growth stages of wheat, being highest at booting and minimum at maturation. The reduction of leaf N content from the booting to maturity stages might be due to translocation of N from leaves to reproductive organs or grains.

Nitrogen content and uptake of grains

Grain N content is considered to be an index of grain quality and protein content. It

was felt important to assess the effects of irrigation and N application on the N content of grains. The main effect of N application as well as the interaction effect of irrigation and N application on the N content of grains was significant (Table 3). The highest average grain N content (2.44%) was found under application of N at the rate of 120 kg ha^{-1} (N_2) that was statistically similar to the content at 160 kg N ha^{-1} (N_3) but different from the contents of other N treatments. It indicates that the grain N content increases with applied fertilizer N up to a certain limit. The result is similar to the findings of Karczmarczyk *et al.* (1993) and Johnston and Flowler (1991). The content of grain N was found to be closely related to the content of leaf N in factors of nitrogen and interaction (Table 4). The correlation between grain and leaf N contents indicates that the treatments which showed the higher leaf N content at different growth stages have produced the higher grain N content. The results are in agreement with the findings of Waldren and Flowerday (1979), who reported that about two–thirds of leaf N were translocated to grains. The response to irrigation was interrupted by rain at the early growth stage of wheat plant (Rahman *et al.*, 2000a). This may be the reason of non–response of the grain N content to irrigation treatment (Table 3).

Nitrogen uptake by wheat grains was significantly influenced by irrigation and N application (Table 5) and found to be highly correlated with N uptake by leaves at different growth stages (Table 6). The treatments which included irrigation at the grain filling stage (80 DAS) (I_3 and I_4) showed the significantly higher uptake of N by grains.

Table 3. Interaction effect of irrigation and N application on N content of wheat grains (%).

Treatment	I_0	I_1	I_2	I_3	I_4	Mean
N_0	2.06 C a	2.10 C a	2.06 C a	2.06 C a	2.00 C a	2.05 C
N_1	2.33 B a	2.15 BC b	2.24 B ab	2.24 B ab	2.32 B a	2.26 B
N_2	2.43 A ab	2.38 AB b	2.38 AB b	2.47 A ab	2.53 A a	2.44 A
N_3	2.37 AB b	2.45 A a	2.44 A a	2.39 A b	2.49 A a	2.43 A
Mean	2.30 a	2.27 a	2.28 a	2.30 a	2.34 a	2.30

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

Table 4. Correlation coefficients between grain and leaf N contents at different growth stages of wheat as influenced by irrigation, N application, and their interaction.

Factor	Growth stage		
	Vegetative (45 DAS)	Anthesis (75 DAS)	Maturity (104 DAS)
Irrigation (n=5)	Nd	Nd	0.558
Nitrogen (n=4)	0.962	0.974	0.910
Interaction (n=20)	Nd	Nd	0.827

Nd: not determined.

Table 5. Interaction effect of irrigation and N application on N uptake by wheat grains (kg ha^{-1}).

Treatment	I_0	I_1	I_2	I_3	I_4	Mean
N_0	18.4 B c	20.7 C a	23.2 C a	26.1 C a	24.0 C a	22.5 C
N_1	76.1 A a	73.0 B a	75.5 B a	77.5 B a	80.1 B a	76.4 B
N_2	82.8 A b	80.5 A b	87.4 A b	99.3 A a	108.6 A a	91.7 A
N_3	77.3 A c	87.2 A b	87.2 A b	93.3 A ab	101.8 A a	89.4 A
Mean	63.7 b	65.4 b	68.3 b	74.0 a	78.6 a	70.0

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

Table 6. Correlation coefficients between grain and leaf N uptakes at different growth stages of wheat as influenced by irrigation, N application, and their interaction.

Factor	Growth stages		
	Vegetative (45 DAS)	Anthesis (75 DAS)	Maturity (104 DAS)
Irrigation (n=5)	Nd	Nd	0.925
Nitrogen (n=4)	0.962	0.943	0.868
Interaction (n=20)	Nd	Nd	0.840

Nd: not determined.

Nitrogen uptake by grains increased with the increasing rate of N application up to 120 kg ha^{-1} (N_2). Doyle and Holford (1993) reported that N uptake increased with increasing the amount of N fertilizer. The highest grain N uptake (108.6 kg ha^{-1}) was recorded in I_4N_2 which was statistically similar to I_4N_3, I_3N_2 and I_3N_3.

Nitrogen content and uptake of straw at harvest and total nitrogen uptake

The effects of irrigation and N application on the N content and N uptake of wheat straw at harvest were significant (Tables 7 and 8). The highest average straw N content (0.73%) was recorded in I_3. There was no significant variation among I_3, I_1 and I_4 in this respect. Significantly higher N uptake by straw as well as total N uptake by wheat plant was noted in the treatments where irrigation was provided at the grain filling stage (80 DAS) (I_3 and I_4). Increment of N dose has led to increase in the N content and N uptake of straw (Table 8). Similar trend was found in case of total N uptake by wheat plant. The results are supported by the findings of Sharma *et al.* (1991), who reported that increasing irrigation frequency and N application rate increased N uptake by wheat plant.

The interaction effect of irrigation and N application on the total N uptake by wheat plant was significant (Table 9). Total N uptake increased with the increasing level of irrigation and N application up to a certain extent. The highest total N uptake (170.4 kg ha^{-1}) was found in I_4N_2 which was statistically similar to I_4N_3, I_3N_2 and I_3N_3. Charanjeet and Das (1985) also reported that N uptake increased with both applied N and irrigation.

Table 7. Effect of irrigation on N content and uptake of straw at harvest, total N uptake, and N use efficiency.

Treatment	N in straw at harvest		Total N uptake (kg ha^{-1})	N use efficiency (kg grain kg^{-1} N uptake)
	Content (%)	Uptake (kg ha^{-1})		
I_0	0.65 bc	32.9 c	96.6 b	31.8 a
I_1	0.69 ab	38.1 b	103.5 b	31.2 a
I_2	0.63 c	36.1 b	104.4 b	33.1 a
I_3	0.73 a	43.6 a	117.6 a	32.4 a
I_4	0.67 ab	42.7 a	121.3 a	32.0 a

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

Table 8. Effect of N application on N content and uptake of straw at harvest, total N uptake, and N use efficiency.

Treatment	N in straw at harvest		Total N uptake (kg ha^{-1})	N use efficiency (kg grain kg^{-1} N uptake)
	Content (%)	Uptake (kg ha^{-1})		
N_0	0.34 d	7.8 d	30.3 c	35.8 a
N_1	0.64 c	36.6 c	113.0 b	34.4 a
N_2	0.83 b	53.2 b	144.9 a	30.0 b
N_3	0.90 a	57.7 a	147.1 a	28.2 b

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

Table 9. Interaction effect of irrigation and N application on total N uptake by wheat plant (kg ha^{-1}).

Treatment	I_0	I_1	I_2	I_3	I_4	Mean
N_0	23.7 C b	28.9 D ab	31.0 C ab	35.7 C a	32.1 C ab	30.3 C
N_1	111.3 B a	111.5 C a	107.9 B a	118.9 B a	115.3 B a	112.9 B
N_2	128.9 A b	130.5 B b	135.8 A b	159.1 A a	170.4 A a	144.9 A
N_3	122.4 A c	146.2 A b	142.8 A b	156.8 A a	167.3 A a	147.1 A
Mean	96.6 b	104.3 b	104.4 b	117.6 a	121.3 a	108.8

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

From the above results it may be concluded that irrigation at the grain filling stage together with the application of higher rate of N (preferably 120 kg ha^{-1}) favours N uptake by wheat on a clay terrace soil of Bangladesh.

Nitrogen use efficiency

There was no significant impact of irrigation treatment on NUE of wheat (Table 7). However, it varied significantly with N treatment, and a negative relationship between NUE and the rate of N application was observed (Table 8). Significantly higher values of

34.4 and 35.8 kg grain kg^{-1} N uptake were recorded under minimum (N_1) and no application (N_0) of N. The reduced values of NUE at higher N doses indicate that grain yield of wheat did not increase proportionately with increased N uptake. The result is similar to the findings of Sharma *et al.* (1990), who reported that NUE of wheat was highest with 60 kg N ha^{-1} and decreased with further increase in the N application rate irrespective of irrigation regimes. The reduction of NUE with increasing the amount of N fertilizer was also reported by Doyle and Holford (1993) and Gauer *et al.* (1992).

Residual soil nitrogen

Residual N of the surface layer (0–10 cm) was found to be influenced by both irrigation and N application (Table 10), but there was no significant impact of irrigation on residual N of the subsurface layer (10–20 cm) (Table 11). The least average soil N in the surface layer (0.06%) was noted in non-irrigated plot (I_0) while the highest value (0.08%) being observed under the highest frequency of irrigation (I_4). Higher volatilization loss of N from drier soil might have reduced the N content in non-irrigated plot. The highest soil N in I_4 might be due to less loss of N through volatilization under higher frequency of irrigation and the treatment allowed irrigation up to field capacity did not permit percolation loss of N.

In general, residual soil N was found to be increased with the increasing rate of N application (Tables 10 and 11). The highest average soil residual N (0.08% in the surface

Table 10. Effects of irrigation and N application on total residual N in the surface layer (0–10 cm) after harvest of wheat (%).

Treatment	I_0	I_1	I_2	I_3	I_4	Mean
N_0	0.04	0.05	0.05	0.05	0.05	0.05 C
N_1	0.07	0.08	0.07	0.08	0.07	0.07 B
N_2	0.07	0.09	0.08	0.09	0.09	0.08 A
N_3	0.07	0.08	0.08	0.09	0.09	0.08 A
Mean	0.06 c	0.07 b	0.07 b	0.07 b	0.08 a	0.07

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

Table 11. Effects of irrigation and N application on total residual N in the subsurface layer (10–20 cm) after harvest of wheat (%).

Treatment	I_0	I_1	I_2	I_3	I_4	Mean
N_0	0.02	0.03	0.03	0.02	0.03	0.03 C
N_1	0.04	0.04	0.05	0.06	0.05	0.05 B
N_2	0.05	0.05	0.05	0.05	0.05	0.05 B
N_3	0.06	0.06	0.05	0.07	0.06	0.06 A
Mean	0.05 a	0.05 a	0.05 a	0.05 a	0.05 a	0.05

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

and 0.06% in the subsurface) was recorded under the highest level of N application in N_3. Alcoz *et al.* (1993) and Sharma *et al.* (1991) reported that residual soil NO_3–N was higher with the higher N application rate, similar to our observation.

CONCLUSIONS

From the experimental findings it may be concluded that the N content and N uptake in wheat increase with the inclusion of irrigation at the grain filling stage. Nitrogen application up to 120 kg ha^{-1} also increases the N content and uptake of wheat. The N content in wheat grains is highly correlated with the leaf N content at different growth stages. A negative relationship exists between NUE of wheat and the rate of N application.

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