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Yield Response of Maize to Irrigation and Nitrogen Fertilization

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ABSTRACT

Background: A field experiment was conducted during November, 2018 to April, 2019 to evaluate the response of maize to irrigation and nitrogenous fertilizer in shallow red brown terrace soil of Madhupur Tract under AEZ-28 in Bangladesh.

Methods: The irrigation was provided as factor A at four distinct rates (irrigation at 20%, 40%, 60% and 80% available water) and nitrogenous fertilizer as factor B at three dosages (75%, 100% and 125% of recommended dose) when each factor was repeated three times. Data relevant to soil and plant parameters were analyzed for variance (ANOVA) using Statistix 10.

Result: The yield and yield contributing characters of maize responded significantly to varying degrees of irrigation and N fertilizer, with the treatment I_4N_2 having the highest cob per plant (1.17), cob yield (16.89 t ha^{-1}), grain yield (9.19 t ha^{-1}), dry matter yield (10.15 t ha^{-1}) and the treatment I_3N_3 provided statistically identical results as I_4N_2. The treatment I_4N_2 also resulted in maximum content of grain N (0.87%), P (0.20%) and K (0.26%). The treatment, irrigation at 80% available water with application of 100% N on recommended dose (I_4N_2) appeared as the most suitable package for maize cultivation in the stated region.

Key words: Irrigation, Maize, Nitrogen, Yield.

INTRODUCTION

The world population is growing day by day. It is expected to reach up to 7.4 billion by 2025. Undernourishment is affecting 850 million people around the world (FAO, 2010). Under this circumstance, food security has been identified as a major concern by different countries especially the underdeveloped countries to contribute to its socio economic stabilization as well as development (Kashem and Faroque, 2011). But the agricultural production is under severe strain to satisfy the food demand due to limited resource and energy, climate change, soil degradation and higher reliance on certain crops. To accomplish the food goal, production per unit area must be raised while resources are well utilized. Maize (*Zea mays*) is a fast-growing, high-yielding cereal crop that has the potential to alleviate global cereal crop shortages. It is the third most significant grain crop in the world pertaining to the grass family Poaceae (Djaman *et al*, 2018). Maize is produced for human and animal sustenance all over the world. This crop is consumed as a main diet by many people in Mexico, Central and South America and parts of Africa whereas in Europe and the rest of North America it is popular for animal feed. Because of its C4 pathway, it has a high rate of photosynthetic activity, resulting in higher grain yield and biomass potential. Maize grain is a rich source of starch, protein, oil, fiber and minerals (Reddy and Reddy, 2003). Some researchers considered maize as more nutritious than rice in terms of protein, phosphorus and carotene content. Various food items *viz*. soup, corn flakes, khichuri, bhutta polao etc. can be prepared from maize. Maize flour alone or in combination with flour from other cereals and pulses is also used to make bread, mixed parota, pulse puri and other foods. In fact, it can be utilized in the same way as rice and wheat. So, Maize production in the country can be a significant source of food and nutrition for the country's growing population.

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Irrigation and fertilizers are two of the most important inputs for higher crop productivity. Irrigation and fertilization have contributed to the advancements of soil fertility, crop productivity and food security as it affects the farm environment by altering soil water and nutrient content (Godfray *et al*. 2010). As a high-yielding crop, maize requires adequate soil moisture in the root zone for proper growth and development. Maize is typically planted during the dry season. The moisture level of the soil declines gradually over the dry season. Lack of water induces water deficit condition in soil and plant system. Moisture stress causes maize plant to delay tasseling and silking, as well as limits vegetative development and production of yield (Abrecht and Carberry, 1993; Singh *et al.*, 2007). Additional irrigation is necessary during dry season for proper crop performance. Inappropriate irrigation scheduling can lead to both water wastage and decrease in crop production which ultimately results in energy loss and low returns to the farmers. So, proper irrigation planning is required for the most effective use of available water in improving maize yield.

Nitrogen (N) is a vital nutrient and plays important role in the improvement of crop production. It is an integral component of many plant structures and processes, both internal and external (Szulc *et al*., 2016). Maize is a nitro-positive crop which necessitates a greater amount of nitrogen for its economic production (Adhikary *et al*., 2020). But nitrogenous fertilizers can be raised to a certain point before losing it via leaching, runoff, volatilization and other means that plants cannot use. Thus the non-judicial use of nitrogenous fertilizers causes environmental pollution and increases farmers cost of production. To reduce nitrogen losses while also increasing crop output and farm income, an appropriate level of nitrogen fertilizer is compulsory.

World's demand for maize is growing day by day because of its excellent nutritive values and ability to minimize reliance on rice and wheat. The high productivity of maize can be achieved under the most favourable irrigation practices with applying the needed nutrients in right amounts and at the right times. Until recent, Very limited researches are available relating to coupling effect of irrigation and nitrogen application on maize yield. Therefore, an attempt has been made to evaluate the effect of irrigation and nitrogen on the performance of maize with the goal of establishing an irrigation schedule and nitrogen dose that will result in the highest possible maize yield.

MATERIALS AND METHODS

The experiment was conducted at the research field under department of Soil Science of Bangabandhu Sheikh Mujibur Rahman Agricultural University, Gazipur, Bangladesh, during November 2018 to April 2019. The country receives about 2500 mm of rainfall on average each year which occurs mostly during the monsoon (June to October). There is little or no rain during dry season but it is uncertain and unpredictable. The examined area belongs to AEZ 28 known as Madhupur tract and corresponds to the order Inceptisols under Salna series, characterized by Shallow Red Brown Terrace soil having bulk density (1.41 g cm^{-3}), porosity (47.4%), field capacity (30.1%), pH value about 5.8, organic carbon (0.62%), total nitrogen (0.072%), available phosphorus (10.22 mg kg^{-1}), available sulphur (12.01 mg kg) and exchangeable potassium [0.15 cmol (+) kg^{-1}].

The effect of two factors was evaluated in the study. Factor A consisted of four irrigation schedules (irrigation at 20%, 40%, 60% and 80% available water) and factor B consisted of three nitrogen doses [75%, 100% and 125% of recommended dose (RD) as per fertilizer recommendation guide (FRG). The treatments were settled down in a randomized complete block design (RCBD) with three replications.

A high yielding maize variety BARI Hybrid Maize-9 was used as test crop in the experiment. A plot size of 3 m × 2 m was constructed after preparing the land. The amounts of N, P, K and S were applied in various doses as urea, triple super phosphate (TSP), muriate of potash (MoP) and Gypsum depending on the treatment requirements. One third of the N and full amount of all other nutrients were applied at final land preparation before sowing. The remaining two third of N was top-dressed at knee height and tassel emergence. Two seeds at each hill were sown at a spacing of 75 × 25 cm on 5 December 2018. Intercultural activities were performed as per needed. The soil was moistened by ten light irrigations up to 40 days following emergence to encourage improved germination and establishment of seedlings. After that irrigation water was applied according to the treatment plan to bring the soil moisture up to field Capacity and rooting depth of the crop.

Soil available water for plant was calculated using following formula:

$$\text{Available water} = \text{Field capacity} - \text{Wilting point}$$

Irrigation requirement was calculated as follows:

$$IR = \{(MFC - MBI) \div 100\} \times \rho b \times D$$

Where,

IR= Irrigation requirement (cm).

MFC= Soil moisture (%) at field capacity.

MBI= Soil moisture (%) before irrigation.

ρb= Soil bulk density (g cm^{-3}).

D= Rooting depth (cm).

The crops were harvested when around 50-60% of the cobs turned into straw color. Four plants were randomly marked for data collection. Number of cobs per plant, cob length and cob diameter were recorded at the time of each harvest and the average value of four plants was treated as one replication. Dry matter yield was estimated after drying the plants as whole plot basis. Cob yield and grain yield per plot was converted to ton per hectare.

Water use efficiency of maize was calculated from total dry matter and grain yield by using following formula:

Water use efficiency based on total dry matter=

$$\frac{\text{Total dry matter (kg ha}^{-1}\text{)}}{\text{Evapotranspiration (mm)}}$$

Water use efficiency based on total dry matter=

$$\frac{\text{Grain yield (kg ha}^{-1}\text{)}}{\text{Evapotranspiration (mm)}}$$

The data on different parameters were statistically analyzed using Statistix 10 software. The difference between the treatment means were adjudged by Duncan's multiple range test (DMRT) according to Gomez and Gomez (1984).

RESULTS AND DISCUSSION

Effect of irrigation on yield and yield components of maize

The varying degrees of irrigation had offered significant impact on maize yield attributes like cobs per plant, cob length, cob diameter, cob yield, grain yield and dry matter yield (Table 1). Treatment I_3 resulted the maximum cobs per plant (1.11) followed by I_4 and I_2 treatment (1.08 and 1.00

respectively). The highest cob length (21.29 cm) and cob diameter (4.72 cm) was also found with I_4 treatment and the lowest (20.38 and 4.52 cm respectively) was with I_1 treatment. Different levels of moisture contributed significantly to cob yield (t ha^{-1}), grain yield (t ha^{-1}) and dry matter yield (t ha^{-1}) of maize. I_4 treatment produced significantly increased cob yield (13.93 t ha^{-1}), grain yield (7.86 t ha^{-1}) and dry matter yield (8.01 t ha^{-1}) whereas the decreased results (11.11 t ha^{-1}, 6.48 t ha^{-1} and 4.60 t ha^{-1} respectively) were found with I_1 treatment. The study signified that enhancement in irrigation levels provided positive impact on plant growth and development. Increased soil moisture level led to conducive environment for plant growth through boosting plant nutrient availability, photosynthetic activity and metabolic rates which in turn improves plant yield. Our research results are in accordance with the findings of Kidist (2013) and Akbar (2003).

Effect of nitrogen on yield and yield components of maize

The effect of different levels of nitrogen application on yield and yield components of maize was found significant except number of cobs per plant (Table 2). However, number of cobs per plant was increased with increased level of nitrogen application. The size of maize cobs was also varied significantly while N_2 treatment produced largest cob length (21.15 cm) and cob diameter (4.70 cm) which was statistically identical with N_3 treatment (20.95 and 4.69 cm respectively). The highest cob yield (13.22 t ha^{-1}), grain yield (7.44 t ha^{-1}) and dry matter yield (7.37 t ha^{-1}) was also obtained with N_2 treatment followed by N_3 treatment (12.27, 7.36 and 7.30 t ha^{-1} respectively) simply with no statistical variation between two treatments compared to N_1 treatment. The results reveal that the nitrogen requirement of maize to get optimum yield under Salna soil series can be satisfied by applying nitrogen according to 100% RD. Application of lower amount of N produced unacceptable yield of maize. The optimal rate of N promotes photosynthetic processes as well as net assimilation rate, resulting in increased yield of maize. On the other hand, higher dose of N could not give higher yield because N is particularly reactive and volatile in soils, it is vulnerable to losses through volatilization, denitrification, leaching and surface runoff. These findings were similar with other studies depicted by Hou *et al.* (2012) and Halvorson *et al.* (2006).

Interaction effect of irrigation and nitrogen on yield and yield components of maize

Significant interactive response had been exhibited by yield and different yield attributes of maize to varying degrees of irrigation and nitrogen excluding number of cobs per plant shown in Table 3. However, the interaction effect was found significant on cob length (cm) and cob diameter (cm). I_4N_2 treatment showed highest cob length (22.01 cm) and cob diameter (4.83 cm) which was statistically similar to treatments I_3N_3 and I_4N_3 for cob length and I_4N_3, I_3N_3, I_3N_2, I_2N_3 and I_2N_2 for cob diameter. The maximum cob yield (16.89 t ha^{-1}), grain yield (9.19 t ha^{-1}) and dry matter yield (10.15 t ha^{-1}) was found with I_4N_2 treatment which was statistically identical to I_3N_3. On the other hand, the minimum cob yield (10.67 t ha^{-1}), grain yield (6.07 t ha^{-1}) and dry matter yield (3.86 t ha^{-1}) was observed with I_1N_1 treatment. It can be ascertained from the study that proper water application with nitrogen dose is indispensable to ensure proper yield of maize as optimum moisture level and nitrogen supply favours the growth and development of the crop. Similar results were pointed out by Paolo and Rinaldi, (2008).

Table 1: Effect of irrigation level on yield and yield attributes of maize.

Irrigation level	Cobs per plant	Cob length (cm)	Cob diameter (cm)	Cob yield (t ha^{-1})	Grain yield (t ha^{-1})	Dry matter yield (t ha^{-1})
I_1	1.06ab	20.38b	4.52b	11.11c	6.48b	4.60d
I_2	1.00b	20.78b	4.68a	12.00bc	6.95b	6.05c
I_3	1.11a	20.75b	4.66a	12.29b	7.08ab	6.93b
I_4	1.08ab	21.29a	4.72a	13.93a	7.86a	8.01a
CV (%)	9.38	2.53	2.25	7.99	11.26	3.66
LSD (0.05)	0.09	0.51	0.10	0.96	0.78	0.23

Legends, I_1, I_2, I_3 and I_4: Irrigation at 20%, 40%, 60% and 80% available water.

Table 2: Effect of nitrogen application on yield and yield attributes of maize.

Nitrogen level	Cobs per plant	Cob length (cm)	Cob diameter (cm)	Cob yield (t ha^{-1})	Grain yield (t ha^{-1})	Dry matter yield (t ha^{-1})
N_1	1.04a	20.30b	4.53b	11.11b	6.48b	4.53b
N_2	1.06a	21.15a	4.70a	13.22a	7.44a	7.37a
N_3	1.08a	20.95a	4.69a	12.67a	7.36a	7.30a
CV (%)	3.38	2.53	2.25	7.99	11.26	3.66
LSD (0.05)	0.08	0.45	0.09	0.83	0.68	0.20

Legends, N_1, N_2 and N_3: Application of N at 75%, 100% and 125% of recommended dose (RD) as per fertilizer recommendation guide, 2012 (FRG).

Interaction effect of irrigation and nitrogen on the primary nutrient contents of maize

Maize grains were analysed to evaluate the interaction effect of irrigation and nitrogen treatments on primary nutrient contents exposed in Fig 1. The primary nutrient contents of maize grain showed remarkable variation with the variation of applied irrigation and nitrogen. The highest grain N (0.87%) was attained from I_4N_2 which did not differ statistically from I_3N_1, I_3N_2, I_3N_3 treatment. Treatment I_4N_2 also resulted in the highest level of P (0.20%) which was in the same statistical category as I_3N_3 treatment (0.19%). Similar trends also recorded for K content of grain where K content was highest with treatment I_4N_2 (0.26%). As compared to other treatments, I_1N_1 treatment produced lowest values for N (0.29%), P (0.06%) and K (0.16%) content of maize grain. As a result of the current research, it can be revealed that nutrient mineralization, availability to the root zone and assimilation by plants are aided by adequate supply of water and nitrogenous fertilizer which eventually improve maize grain quality. These findings agree with that of Li *et al.* 2020 findings.

Interaction effect of irrigation and nitrogen on water use efficiency of maize

The data conveyed on the interaction effect of irrigation and nitrogen on water use efficiency of maize was presented in Fig 2. Water use efficiency of maize was estimated based on total dry matter and grain yield. The maximum water use efficiency for total dry matter (24.67 kg ha^{-1} mm^{-1}) was

Table 3: Interaction effect of irrigation and nitrogen on yield and yield attributes of maize.

Treatment (I × N)	Cobs per plant	Cob length (cm)	Cob diameter (cm)	Cob yield (t ha^{-1})	Grain yield (t ha^{-1})	Dry matter yield (t ha^{-1})
I_1N_1	1.08	20.05f	4.42e	10.67d	6.07d	3.86i
I_1N_2	1.00	21.00bcde	4.58cde	11.11d	6.72bcd	5.43f
I_1N_3	1.08	20.08f	4.55cde	11.56cd	6.66cd	4.50h
I_2N_1	1.00	20.23def	4.64bcd	11.11d	6.68cd	5.04fg
I_2N_2	1.00	21.02bcde	4.70abc	12.89bc	7.11bcd	7.20c
I_2N_3	1.00	21.08bcd	4.69abc	12.00cd	7.04bcd	5.91e
I_3N_1	1.08	20.17ef	4.50de	10.67d	6.44cd	4.22hi
I_3N_2	1.08	20.58cdef	4.69abc	12.00cd	6.75bcd	6.69d
I_3N_3	1.17	21.50ab	4.79ab	14.22b	8.06ab	9.87a
I_4N_1	1.00	20.75bcdef	4.57cde	12.00cd	6.72bcd	5.00g
I_4N_2	1.17	22.01a	4.83a	16.89a	9.19a	10.15a
I_4N_3	1.08	21.13abc	4.77ab	12.89bc	7.66bc	8.89b
CV (%)	9.38	2.53	2.25	7.99	11.26	3.66
LSD (0.05)	0.17	0.89	0.18	1.67	1.35	0.40

Legends, I_1N_1: Irrigation at 20% available water+N at 75% of recommended dose (RD), I_1N_2: Irrigation at 20% available water+N at 100% of RD, I_1N_3: Irrigation at 20% available water+N at 125% of RD, I_2N_1: Irrigation at 40% available water +N at 75% of RD, I_2N_2: Irrigation at 40% available water+N at 100% of RD, I_2N_3: Irrigation at 40% available water+N at 125% of RD, I_3N_1: Irrigation at 60% available water +N at 75% of RD, I_3N_2: Irrigation at 60% available water+N at 100% of RD, I_3N_3: Irrigation at 60% available water + N at 125% of RD, I_4N_1: Irrigation at 80% available water +N at 75% of RD, I_4N_2: Irrigation at 80% available water+ N at 100% of RD, I_4N_3: Irrigation at 80% available water+ N at 125% of RD.

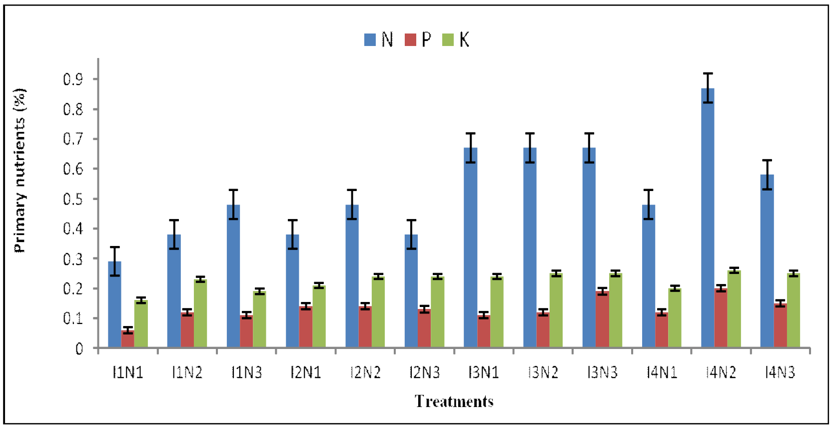

Fig 1: Primary nutrient contents of maize as affected by combined application of irrigation and nitrogen.

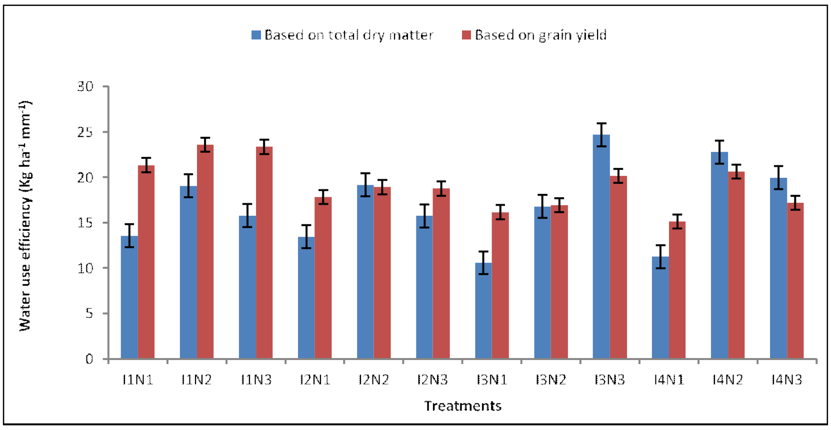

Fig 2: Water use efficiency (kg ha^{-1} mm^{-1}) as affected by combined application of irrigation and nitrogen.

Legends, I_1N_1: Irrigation at 20% available water + N at 75% of recommended dose (RD), I_1N_2: Irrigation at 20% available water + N at 100% of RD, I_1N_3: Irrigation at 20% available water + N at 125% of RD, I_2N_1: Irrigation at 40% available water+ N at 75% of RD, I_2N_2: Irrigation at 40% available water+ N at 100% of RD, I_2N_3: Irrigation at 40% available water+ N at 125% of RD, I_3N_1: Irrigation at 60% available water + N at 75% of RD, I_3N_2: Irrigation at 60% available water+ N at 100% of RD, I_3N_3: Irrigation at 60% available water+ N at 125% of RD, I_4N_1: Irrigation at 80% available water + N at 75% of RD, I_4N_2: Irrigation at 80% available water+ N at 100% of RD, I_4N_3: Irrigation at 80% available water+ N at 125% of RD.

generated from treatment I_3N_3 and the minimum (15.13 kg ha^{-1} mm^{-1}) was from treatment I_3N_1. Treatment I_1N_2 produced highest water use efficiency (23.59 kg ha^{-1} mm^{-1}) for grain yield and the lowest was recorded from I_4N_1 (15.13 kg ha^{-1} mm^{-1}). According to the study, crops' water use efficiency was increased under moderate irrigation and high nitrogen application. However, excessive irrigation and insufficient nitrogen application caused reduction in water use efficiency of crops due to water loss and low yield.

CONCLUSION

Maintaining soil moisture condition by giving irrigation at 80% available water along with application of nitrogen at 100% of recommended dose as per Fertilizer Recommendation Guide and irrigation at 60% available water using 125%, recommended dose facilitate superior growth and development of maize that results the maximum yield and improved grain primary nutrient contents of this crop. The crop's water use efficiency was also increased with above mentioned irrigation and nitrogen levels. Both low water application and low nitrogen dose contributed reduced yield of maize. The study's findings may lead to the conclusion that providing irrigation at 80% available water with applying 100% of recommended dose of nitrogen may be the best option for the farmers to improve maize yield while avoiding the negative effects of excessive nitrogenous fertilizer use on soil and environment at the same time reducing farmer's cost of production.

Conflict of interest: None.

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