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EFFECTS OF IRRIGATION AND NUTRIENTS MANAGEMENTS WITH PLANT INTENSIFICATION ON RICE UNDER SALINE SOIL

M.H. Ali[1], P. Biswas[1]*, M.A. Islam[1], and A.K. Azad[2]

Abstract

The area of salt affected agricultural soils has grown on a global scale. The toxicity of salt and the unfavorable characteristics of the soil are two major causes of the low crop productivity on salt-affected soil. Thus, effective and economical management techniques are required for crop production which may sustainable. The experiments were conducted to identify appropriate irrigation and other management practices for higher yield of Boro rice at two locations (Horinkhola, Satkhira and Batiaghata, Khulna) of saline area during two successive years (2021 and 2022). Six treatments were used, consisting of continuous ponding of irrigation water along with recommended fertilizer (farmers practice, as control), and a range of combination of irrigation water and gypsum fertilizer and foliar spray of Urea, TSP, MOP and Zinc Sulphate. The results revealed that at both locations, the treatments showed significant difference and the highest yield (7.35 t/ha at Horinkhola and 6.75 t/ha Batiaghata) were obtained in treatment T_5 [Continuous saturation (0-3cm) + 50% recommended fertilizer except MoP + K_2SO_4 equivalent to 50% K+ OM + no ridge, high density (15 cm x 10 cm) + Change of standing water 20 days interval + Foliar application of Urea-40 g, TSP-44 g, MOP-26 g and Zinc Sulphate 3g (4 times : 25, 35, 45, 60 DAT)]. Overall, this treatment produced 19% higher yield compared to farmer’s practice, along with maximum BCR (1.57) and net profit (52,004 Tk/ha). This technique can be adopted for higher yield in saline area.

Keyword: Boro rice, Irrigation management, Organic amendment, Foliar spray, Saline condition

Introduction

Rice (*Oryza sativa* L.) is one of the most crucial staple crops globally (Wanichthanarak *et al.,* 2020), serving as a primary source of sustenance for a significant portion of the world's population. However, the productivity and yield of rice cultivation are often challenged by various environmental stresses, among which soil salinity stands out as a prominent concern (Chen *et al.,* 2021). Salinity stress adversely affects rice growth and development, leading to substantial yield losses and economic burdens on farmers, particularly in regions where irrigation water contains high levels of salts (Irakoze *et al.,* 2022; Marcos *et al.,* 2018). One of the key challenges for the country in future is to increase food production under limited resources (water and land) with huge population growth (Mainuddin *et al.,* 2015; Timsina *et al.,* 2018; Ahmad *et al.,* 2014; Kirby *et al.,* 2015; Bell *et al.,* 2015).

[1]Agricultural Engineering Division, Bangladesh Institute of Nuclear Agriculture, Mymensingh-2202, Bangladesh
[2] Scientific Officer, Soil resource Development Institute, Divisional Laboratory, Khulna, Bangladesh
*Corresponding author’s email: parthi.biswas@gmail.com

Boro rice, predominantly cultivated during the dry season in Bangladesh, faces heightened vulnerability to saline conditions due to reduced freshwater availability and increased soil salinity. Sodium salts cause poor root growth, chlorosis, leaf curling and leaf scorching in this cereal; it also induces stomatal closure, inhibits photosynthesis, alters cell metabolism, causes oxidative stress in the crop, influences spikelet sterility and grain yield, among other effects (Coca *et al.,* 2023). Additionally, salinity causes several nutritional disorders and yield losses by limiting essential nutrient uptake by crop plants (Grattan and Grieve, 1998; Sun *et al.,* 2020). In suchcondition, effective irrigation management strategies coupled with suitable soil amendments emerge as potential avenues to mitigate the detrimental effects of salinity stress on rice cultivation.Mishra *et al.* (2023) pointed out that promising management strategies (soil and plant related) can mitigate hazardous effects of salinity.

Various approaches have been proposed to address salinity management in the crop root zone, such as physical, chemical, hydrological, agronomic and biological methods (Zaman *et al.,* 2018). Crop residue recycling and/or organic amendment can improve soil physical, chemical and biological quality (Singh G., 2018; Goswami *et al.,* 2020). It has been reported that application of organic fertilizer (or compost) and gypsum can reduce the effects of saline water, increase soil microbial activity, enhance mineralization processes, improve soil properties and fertility status, and finally improve crop yields (Wichern *et al.,* 2020; Leogrande *et al.,* 2018; Mitran *et al.,* 2017; Chahal *et al.,* 2017).

Gomes *et al.* (2000) observed that the application of gypsum resulted in the lowest exchangeable sodium percentage (ESP) values, while vinasse application led to reduced soil salinity levels (measured by electrical conductivity- ECs). Organic fertilizers typically contain a range of plant nutrients, notably nitrogen and phosphorus, along with smaller amounts of potassium, which can significantly enhance plant nutrition and other advantages. Incorporating organic amendments like compost has been shown to alleviate the salinity effects according to studies by Delgado-Moreno & Peña (2009) and Orozco *et al.* (2016). These amendments can positively impact soil quality by promoting aggregate formation and providing sustenance to microorganisms, as highlighted by Durán and Henríquez (2010) and Bonanomi *et al.* (2014). Zayed *et al.* (2013) disclosed that employing both organic fertilizer and bio-fertilizers together resulted in improved rice yields in saline conditions. In addition, numerous researchers investigated the effect of foliar application of micro- and macro- plant nutrients on rice yield under saline conditions, and reported positive response (Dorosti *et al.,* 2017; Bhuyan *et al.,* 2015; Pramanik *et al.,* 2015)

Understanding the intricate interactions between irrigation practices, soil amendments, foliar spray of nutrients, and their combined effects on Boro rice is thus imperative for devising sustainable agricultural practice that ensure food security in saline-prone regions.

The objective of this study is to investigate the effects of different irrigation, gypsum fertilizer, plant density and foliar application of plant essential nutrients on Boro rice cultivation under saline condition, to find out a cost-effective management technique for higher yield.

2. Materials and Methods

The experiment was carried out at farmer's field Horikhola, Satkhira and Batiaghata, Khulna. The soil was a loam having pH 7.4 to 7.7, EC 2-2.4 dSm^{-1}, organic matter 1.6 to 1.76%. The seedlings (38 days old) were transplanted on 25 Januarry. The test variety was Binadhan-10.

Treatment combinations:

The treatments were selected based on earlier two recommendations for rice in saline area (BINA, 2011-12; and BINA, 2017-18) [T_1 and T_2, named as Control-1 and Control-2, respectively] along with three new approaches [T_3-T_5] and a traditional farmer's practice [T_6, as control-3].

The hypotheses behind the new approaches were that, high density of plantation will reduce the free evaporation of water during early stage of growth compared to normal culture, resulting in less accumulation of salt in the soil surface. For foliar spray it was presumed that, the water stress due to salinity reduces the uptake of water resulting in less uptake of plant nutrients – which could partially be meet by absorption through leaf. For replace of Muriate of Potash (KCl) fertilizer by K_2SO4, it is presumed that the chloride anion may exacerbate the ionic imbalance and toxicity effect under salinity, in which case the nutrient potassium could be supplemented by K_2SO_4.

The details of the treatments were:

T_1 = Continuous ponding (3-5 cm) + 150 kg/ha Gypsum (basal) + 10 kg/ha Si (basal) + planting in ridge [ridge (30 cm) + Furrow (30 cm, 3 lines)]

T_2= Continuous ponding (3-5 cm) + 45 kg/ha Gypsum (basal) + 23 kg/ha Gypsum (Booting) + no ridge + normal plant spacing (15 cm × 15 cm)

T_3= Continuous saturation (0-3cm) + 100 kg/ha Gypsum (basal) + 10 kg/ha Si (basal) + 50 kg/ha Gypsum (Booting) + additional PK 25% (basal) + additional 25% PK split (at booting) + no ridge + high plant spacing (10 cm × 10 cm) + Change of standing water 20 days interval.

T_4 = Continuous saturation (0-3 cm) + 66 kg/ha Gypsum (basal) + 10 kg/ha Si (basal) +33 kg/ha Gypsum (Booting) + [additional PK 25% + OM (basal)*] + additional 25% PK split (at booting) + no ridge + high plant spacing (10 cm × 10 cm) + Change of standing water 20 days interval.

T_5 = Continuous saturation (0-3 cm) + 50% recommended fertilizer except Muriate of Potash + K_2SO_4 equivalent to 50% Muriate of Potash+OM + no ridge, high plant spacing (15 cm x 10 cm)+Change of standing water 20 days interval+Foliar application of N-P-K-S-Zn (4 times: 25, 35, 45, 60 DAT).

T_6 = Continuous ponding (3-5 cm) + recommended fertilizer** + recommended density (20 m x 15 cm) [*Control, traditional Farmer's Practice*].

Note:

(1) Treatment T_1 and T_2 are considered as Control-1 and Contro-2, respectively. Treatment T_6 is farmer's practice, and T_3, T_4, and T_4 are new.

(2) Washout" of salt by irrigation at 20 days interval (or, when soil salinity exceeds 10 dS/m).

(3) Ratio of mixture of solution for "Foliar application": For one decimal land, Urea-40g, TSP-44g, MOP-26 g and Zinc Sulphate-3g should be mixed sprayed with 20 liter water.

*OM: Locally available organic fertilizer "Tricho-Compost" @ 375 kg/ha
**Recommended dose of fertilizers for Binadhan-10 was Urea, TSP, MoP, Gypsum, and Zinc @ 217, 110, 70, 45, and 4.5 kg/ha (Islam *et al.*, 2013).

Field experiments were conducted at two sites. The experimental design was RCBD, with 3 replications. The yield and yield attributing data were recorded. The statistical evaluation utilized the "STAR" program (version 2.0.1) developed by the International Rice Research Institute (IRRI) in 2014 (IRRI, 2014). The F-test was employed to compute means and conduct analysis of variance (ANOVA) for all factors. Additionally, the least significant difference (LSD) test, as outlined by Gomez and Gomez (1984), was applied to determine the significance of differences between means at a 5% level of probability.

Economic analyses were performed as follows:

In this analysis, total cost of production was included. The cost items were categorized as following heads for analytical advantages:

Operating cost:

Operating cost consists of cost of human labor; power tiller hiring; cost of seed, fertilizer, insecticide, irrigation application; and land use cost.

Human labor requirement consists of sowing, weeding and thinning, insecticide spraying, harvesting, carrying, threshing and cleaning. Land use cost was estimated using seasonal rental value *or* lease value of the land used.

Interest on operating capital:

The operating capital actually represents the average operating costs over the period because all costs are not incurred at the beginning or at any fixed time. The costs were incurred throughout the whole production period. Interest on operation cost was estimated by using the following formula (Ali *et al.* 2023):

Interest on operating capital = (Operating capital/2) × rate of interest × time considered ....(1)

Total cost = Operating cost + Interest on operating cost

Gross return: Per hectare gross return was calculated by multiplying the total amount of product and by-product by their respective market prices.

Net profit (NP) was calculated as: NP = Gross return – total cost

Benefit cost ratio (BCR) was calculated as:

BCR = Total gross return (per hectare) / Total cost (per hectare) ....(2)

3. Results and Discussion

3.1. Horinkhola, Satkhira

The effects of treatments on yield and yield attributing characters of Binadhan-10 at Horinkhola are summarized in the Table 1.1. Treatment wise EC (dS/m) during different growth stages of riceis depicted in Fig. 1.1.

For the year 2020-21, the treatments showed significant difference in plant height, tiller per plant, panicle length, and grain yield (Table 1.1). The highest yield (7.35 t/ha) was obtained in treatment T_5, which is statistically similar to T_2, T_3 and T_4. On the other hand, treatment T_1 and T_2 are similar, T_1 and T_6 are similar, and T6 the lowest.

Earlier researchers (Pal *et al.,* 2019; Zaka *et al.*, 2018; Hafez *et al.*, 2015) noted that application of gypsum and silicon enhanced yield of rice under saline condition. Here, it is also evident that the yield of treatment T_1 – T_5 is higher than T_6. Among the new introduced treatments (T_3 – T_5), all the treatments produced very close results. But the treatment T_5 needs 50% basal dose of fertilizer plus foliar application. The foliar application may have contributed to fertilizer absorption and thus attributed to similar yield. Consequently, the BCR is also higher compared to others (Table 1.1, Table 1.3). Bhuyan *et al.* (2015) and Shygany et al. (2012) also reported better yield applying foliar spray of single *or* multiple elements of N-P-K-B-Zn. In case of foliar application, nutrients are absorbed directly where they are needed, correct the deficiencies immediately and help maximizing yields and quality (Pramanik *et al.,* 2015).

For the year 2021-22, the treatments showed significant difference in panicle length, seed per panicle, and grain yield (Table 1.1). Here also, the highest yield (6.2 t/ha) was obtained in treatment T_5, which is statistically similar to T_1, T_2, T_3 and T_4; and T_6 the lowest.

Table 1.1. Effects of Irrigation Management and amendments on yield and yield attributing characters at Horinkhola, Satkhira

Year	Treatment	Plant height (cm)	Hills/m^2 (No.)	Panicle Length (cm)	Filled grains/ panicle (No.)	Grain yield (t/ha)	% Yield increased	BCR
2021	T1	108 a	25	23 a	113	6.37bc	3.56	1.42
	T2	108 ab	37	22 ab	123	7.07ab	14.84	1.80
	T3	106 ab	74	23 a	115	7.30 a	18.62	1.69
	T4	104 b	73	20 b	101	7.34 a	19.24	1.58
	T5	106 ab	59	20 b	101	7.35 a	19.40	1.77
	T6	107 ab	31	22 ab	110	6.16 c	-	1.57
	F-test at (5%)	S	-	S	NS	S	-	-
2022	T1	111	23	26 b	114ab	5.56ab	10.90	1.24
	T2	111	34	26 b	99 b	5.45ab	8.71	1.39
	T3	111	72	27 a	131 a	5.90ab	17.74	1.36
	T4	110	71	26 b	96 b	5.80ab	15.76	1.24
	T5	110	58	28 a	102 b	6.20 a	23.75	1.49
	T6	111	29	26 b	102 b	5.01 b	-	1.28
	F-test at (5%)	NS	-	S	S	S	-	-

Note: Means with the same letter are not significantly (statistically) different at 5% probability level by Tukeys's Honest Significant Difference (THSD) test.

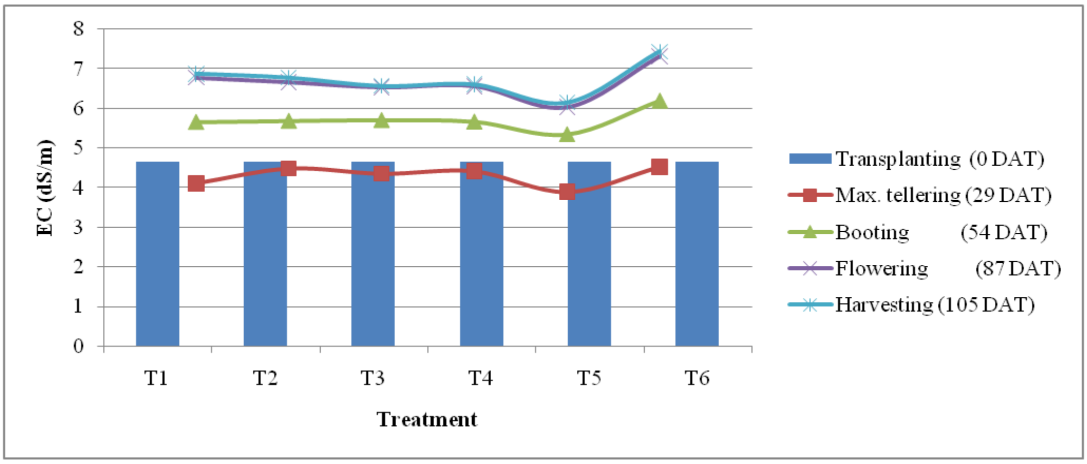

Fig. 1.1. Treatment-wise EC (dS/m) during different growth stages of Binadhan-10 experiment at Horinkhola, Satkhira.

3.2. Batiaghata, Khulna

The effects of treatments on rice yield and yield attributing characters are summarized in Table 1.2. Treatment wise EC (dS/m) during different growth stages of riceis depicted in Fig. 1.2.

For the year 2020-21, the treatments showed significant difference in panicle length only, and the grain yield was not significant (Table 1.2). This may be due to low level of salinity (Fig. 1.2). The highest yield (6.16 t/ha) was obtained in treatment T4. The yield at Batiaghata, Khulna is low in 1st year which may be due to heat stress in the area.

For the year 2021-22, the treatments showed significant difference in plant height, panicle length, seed per panicle, and grain yield (Table 1.2). Here, the highest yield (6.75 t/ha) was obtained in treatment T5, which is statistically similar to T4; and T6 the lowest.

Table 1.2. Mean effects of Irrigation Management and amendments on yield and yield attributing characters of Binadhan-10 under Saline condition at Batiaghata, Khulna.

Year	Treatment	Plant height (cm)	Hills/m^2 (No.)	Panicle Length (cm)	Filled grains/ panicle (No.)	Grain yield (t/ha)	% Yield increased	BCR
2021	T1	106	24	23 a	115	5.76	3.45	1.28
	T2	106	35	22 ab	119	5.61	0.79	1.42
	T3	105	70	23 ab	112	5.70	2.39	1.28
	T4	105	71	20 b	108	6.16	10.53	1.31
	T5	108	57	21 ab	103	5.89	5.77	1.40
	T6	105	30	22 ab	112	5.57	-	1.41
	F-test at (5%)	NS	-	S	NS	NS		
2022	T1	110bc	22	27 c	109ab	5.98bc	6.04	1.33
	T2	115ab	36	28 b	107ab	5.93bc	5.21	1.51
	T3	116 a	74	29 a	128 a	5.88 c	4.24	1.33
	T4	113 abc	73	27 c	127 a	6.45ab	14.29	1.38
	T5	108 c	56	27 c	102 b	6.75 a	19.61	1.62
	T6	112 abc	28	27 c	98 b	5.64 c	-	1.44
	F-test at (5%)	S	-	S	S			

Note: Means with the same letter are not significantly (statistically) different at 5% probability level by Tukeys's Honest Significant Difference (THSD) test. Means with the same letter are not significantly different.

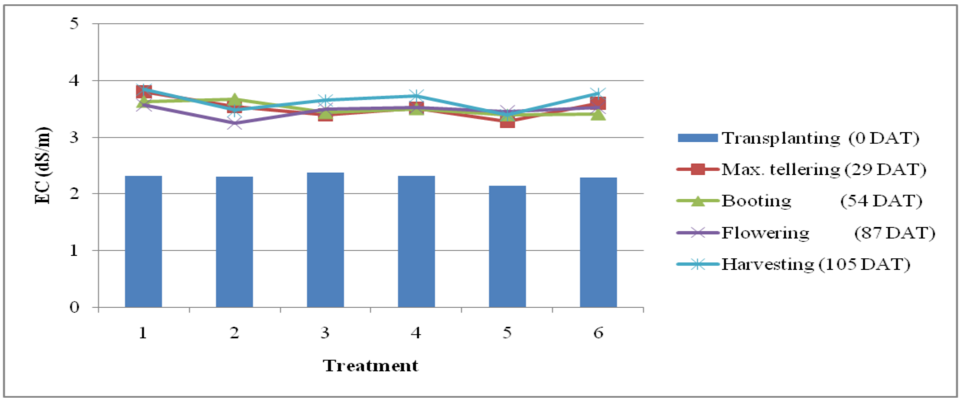

Fig. 1.2. Treatment-wise EC (dS/m) during different growth stages of Binadhan-10 experiment at Batiaghata, Khulna.

3.3. Average yield and BCR over locations and years

The average yield, BCR and net profit over 'locations and years' are summarized in Table 1.3. Overall, the treatment T5 produced highest yield, BCR, and net profit per hectare of land. So, this treatment is recommended for rice cultivation in saline area during Boro season.

Table 1.3. Average yield, BCR and net profit over locations and years

Year	Treatment	Average over locations and years		
		Yield (t/ha)	BCR	Net profit (Tk/ha)
Av. over locations and years	T_1	5.92	1.32	31030
	T_2	6.00	1.53	45526
	T_3	6.19	1.42	39777
	T_4	6.44	1.38	38803
	T_5	6.54	1.57	52004
	T_6	5.59	1.43	36448

Globally, the portion of agricultural soils where crop productivity is impacted by salt has increased. The main factors contributing to the low yield of crops grown on salinized soil are the degraded soil quality, toxicity of salt, and water and nutrient stress. Therefore, efficient and inexpensive management strategies are needed to tackle these negative effects.

This research sought to determine how different agronomic, fertilizer, and water amendments affected the growth and yield of irrigated Boro rice planted in the saline soils of Horikhola (Satkhira) and Batiaghata (Khulna district). Previous research employed foliar spray and organic amendment separately. Here, we made use of both foliar spray and organic amendment, along with plant density and irrigation management. The new approaches were based on the theories that high plantation densities would lessen early-stage free water evaporation in comparison to typical cultures, hence preventing the buildup of salt on the soil's surface. It was assumed that the water stress caused by salt would decrease plant nutrient uptake by foliar spray, with a potential partial solution coming from leaf absorption. It is assumed that the anion chlorine in KClfertilizer may worsen the ionic imbalance and toxicity impact in salinity; in this scenario, K2SO4 might be used to complement the nutrient potassium.

Based on the average grain yield of two locations over a two-year period, treatment T_5 was the most successful treatment. This method will save precious chemical fertilizer, which the country would otherwise have to purchase using foreign exchange, because it uses half of the recommended fertilizer as a basal dose and very little for foliar spray. Thus, this management method may be used for enhanced rice yield combined with higher BCR and net profit in saline soil.

Conclusion

Salinity has a greater effect on crop yields in agricultural soils worldwide. The toxicity of salt and poor soil characteristics are two major causes of the low productivity of crops cultivated on salinized soil. Thus, for sustainable crop production, effective and economical management techniques are required.

In this study, we assessed the impact of various water management practices, agronomic techniques, and fertilizer amendments on the growth and yield of irrigated Boro rice in the saline soils of Horikhola, Satkhira, and Batiaghata, Khulna. Based on the average grain yield over two years at both locations, the study found that the T5 treatment [continuous saturation (0-3 cm) + 50% recommended fertilizer excluding MoP + K2SO4 equivalent to 50% K + organic matter (OM) + no ridge, high planting density (15 cm x 10 cm) + water replacement every 20 days + foliar application of N-P-K-S-Zn (four times: 25, 35, 45, and 60 days after transplanting)] was the most effective. This management approach is recommended for enhancing rice production in saline areas.

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