Transplanting date adjustment in Boro rice cultivation as a strategy to reduce groundwater withdrawal in Bangladesh

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Abstract:

Due to intensive irrigated rice cultivation during dry season, declining trend of groundwater level is observed in many parts of Bangladesh. Field experiments were conducted in 2015 and 2016 at four experimental stations of Bangladesh Institute of Nuclear Agriculture, Bangladesh to evaluate the performance of some Boro rice cultivars in different planting dates with respect to yield and irrigation water requirement, and to optimize between yield and irrigation water requirement, with a view to reduce groundwater withdrawal and hence reducing mining of groundwater. The transplanting dates were 21st January (T1), 15th February (T2), 7th March and 30th March. Four rice cultivars were used. The results showed that the rice growth period was shortened with the later dates of transplanting. Generally, the yield of all cultivars at first and second transplanting (i.e. in T1 & T2) are good, and decrease at the later transplanting dates (T3, T4) and hence could not be recommended among farmers. When we consider the irrigation savings in T2 compare to T1, the irrigation savings varies with location and year, but the general tendency is that the second transplanting can save irrigation water. By considering economic (intrusion of additional rabi crop between two rice crops) and ecological factor (irrigation reduction, and hence reducing groundwater withdrawal), we recommend that the most suitable transplanting time for Boro rice should be 15th February. As such, we can effectively achieve good yield, reduce irrigation requirement, and creating opportunity for possible intrusion of addition Rabi crop between two rice crops. Overall, the findings of the present study can provide effective transplanting time and cultivar to reduce groundwater withdrawal in the present agro-ecosystem of northwestern Bangladesh and other similar areas.

Keywords: Boro rice, irrigation requirement, transplanting date, groundwater withdrawal, ecosystem

1.0. Introduction:

In the rain-fed farming systems of arid and semi-arid regions, water stress is the main limiting factor for crop production. Water resources are becoming scarce worldwide [1,2]. Bangladesh is no exception [3-5]. Bangladesh contains world's one of the largest delta and is, therefore, heavily depends on rivers originating in other countries and rainfall for its water supply. Climate change (rise in temperature and changing rainfall patterns), deforestation and construction of dams in common rivers have led to a reduced amount of water entering into Bangladesh [6]. As surface water supply is decreasing day by day, irrigation pressure is going towards groundwater resource. But this resource is not unlimited. In intensive tube well areas, water level is declining gradually in dry season [7-9]. Climate change has worsen the situation [10,11]. So, the judicious use of water resources in intensive irrigated area is a crucial need for maintaining sustainable crop production.

Rice is one of the major consumers of water in agricultural sector. However, the sources of fresh surface water are limited and casing dependent on groundwater. It has been estimated that about 3000 -5000 litres of water is required to produce one kilogram of rice [12,13]. Intensive rice cultivation during dry, Boro season to feed the increasing population of the country have contributed to excessive groundwater withdrawal in many parts of Bangladesh [14]. This situation of groundwater may cause a great threat for future groundwater availability for irrigation, and ultimately for sustainable Boro production which contributes major share of total rice production. In a situation of higher demand of rice (due to increasing population), there is no alternate choice but to produce more rice. In terms of solar radiation, the period from November to April is more suited for crop production [15,16]. For Boro-rice, irrigation is indispensable, as the entire growing season falls within the dry period [17,18]. There is a great need to increase the productivity of water in rice irrigation systems in a sustainable way [19]. If the water demand is partially meet by rainfall, the irrigation cost is reduced and also the pressure on dwindling groundwater resource is lessened. In this context, a suitable transplanting date of rice should be determined which can maintain potential or acceptable yield with reduced irrigation water.

A group researchers investigated the efficacy of different planting dates (PDs) on rainfed maize yield and water-use efficiency in semi-arid region of China [20]. They found that, within a certain time range, dry matter production per plant did not obviously change across PDs. However, the dry matter accumulation in the ear after flowering, the yield, and the WUE in the treatments under appropriate PDs were higher than those in the early or delayed PDs. Other group of researchers observed the yield, water productivity and economic returns of malt barley following different sowing dates and supplemental irrigation [21]. They found that in terms of water use, sowing by mid-November is advantageous since more rainfall is generally available. Some researchers conducted field study under the semi-arid environment of Faisalabad, Pakistan [22]. They observed significant differences among different transplanting dates of wet-season rice, as well as among cultivars. They explored that late transplanting caused yield reduction which could not be recommended among farmers.

For rice, information on different transplanting date and its effects on irrigation requirement and water use efficiency is scarce in Bangladesh. The frequency and total amount of irrigation for the growing season depends on the soil type, cultivar (maturity period, drought resistance capacity), ET demand, and rainfall availability [3, 23, 24]. Thus, it is not appropriate to make definite recommendation regarding the number and amount of irrigation to be applied for all cultivars under diverse planting dates. Utilization of rainwater without sacrificing yield can reduce valuable groundwater withdrawal, which is desirable for sustainability of the resource in the region [14].

Therefore, the present experiment was designed to evaluate the performance of some Boro rice cultivars in different planting dates with respect to yield and irrigation water requirement, and to optimize between yield and irrigation water requirement, with a view to reduce groundwater withdrawal and hence reducing mining of groundwater.

2.0. Materials and methods

2.1. Description of the experimental site

The experiment was conducted at four experimental stations of Bangladesh Institute of Nuclear Agriculture (BINA), Bangladesh, covering different agro-ecological and hydrological regions (Figure 1). The latitude and longitude of the areas and main features are provided in Table 1.

Figure 1: Location map of the study area (• black marked)

Table 1: Latitude, longitude and main characteristics of the study sites

Sl	Location/ Station	Latitude (degree)	Longitude (degree)	Altitude (Above Mean Sea Level) (m)	Main characteristics of the area
1	Mymensingh	24°43'	90°26'	6	Medium land, alluvial deposit, loamy soil
2	Ishwardi	24°08'	89°03'	15	Relatively highland, calcareous soil, dry region
3	Cumilla	23°28'	91°10'	9	Medium land, loamy soil
4	Rangpur	25°45'	89°15'	34	Relatively cool weather, sandy loam soil

2.2. Experimental design and field management

The experiment was conducted during Boro season (Jan.-June) of 2015 and 2016. The design was Randomized Complete Block (RCB) with split-plot arrangement. The main plot treatments (time of transplanting for saving irrigation) were: T1= Transplanting on 21st January and irrigation at 3 days after disappearance of ponded water (DADPW); T2= Transplanting on 15th February and irrigation at 3 DADPW, T3= Transplanting on 7th March and irrigation at 3 DADPW, T4= Transplanting on 30th March and irrigation at 3 DADPW. The Sub-plot treatments (cultivars) were: V1 = Binadhan-14, V2 = BRRIdhan 29, V3 = BRRIdhan 28. The cultivar V4 = Binadhan-10, was added in second year. In Bangladesh, in general, the temperature and hence the heat unit and ET₀ increase from the first transplanting (21st January) to onward (Figure 2).

Figure 2: Long-term ET₀ pattern during crop-season in Mymensingh, Bangladesh

2.3. Climate and rainfall distribution

The climate of the regions falls within humid sub-tropic with summer dominant rainfall. The annual rainfall at the study sites varies from 1500 mm to 3300 mm; approximately 70% of this rainfall occurs during the months of May to August, which is noted as monsoon season.

2.4. Fertilization, Irrigation and management

The seedlings of rice were transplanted according to the scheduled treatments. Each plot was fertilized uniformly with basal dose of Triple super phosphate, Muriate of Potash, Gypsum, and Zinc by 80, 110, 70, 45, 4.5 kg ha⁻¹, respectively. Urea was applied in three equal splits by 70 N ha⁻¹ at 10, 30 and 45 days after transplanting. Measured amount of water was applied in each plot through water-meter, attached at the outlet point of rubber hose pipe. All cultural practices were followed as and when necessary. The grain and straw yields were adjusted to 12% moisture content following the equation [25]:

$$Y_{adj} = Y_i * \frac{(100 + M_t)}{(100 + M_i)} \quad \dots\dots\dots (1)$$

where M_i the initial moisture content, Y_i the initial yield (at M_i moisture content), M_t the targeted moisture content (say, 12 %), and Y_{adj} the adjusted yield (at M_t % moisture content).

2.5. Data analysis

The analysis of variance technique (ANOVA) was carried out on the data. The software "STAR", developed by International Rice Research Institute (IRRI), was used to analyze the data. The significance among the means of the treatments was determined using least significant difference (LSD) technique at 5% probability level.

3.0. Results and Discussion

3.1 Year 2015

Table 2.1: Effect of treatments (transplanting time) on grain yield at each level of cultivars (2015)

	Treatment	Cultivars		
		V1 (Binadhan-14)	V2 (BRRIdhan 29)	V3 (BRRIdhan 28)
Mymensingh	T1(Jan.21)	5.77 a	6.00 a	6.62 a
	T2 (Feb.15)	5.79 a	4.49 b	6.26 a
	T3 (Mar.7)	3.29 b	3.68 c	2.48 c
	T4 (Mar.30)	3.85 b	2.04 d	3.35 b
	LSD (5%)			
Rangpur	T1	6.29 b	7.36 a	7.26 ab
	T2	8.05 a	7.20 a	8.71 a
	T3	4.84 bc	3.21 b	5.82 b
	T4	4.51 c	0.49 c	3.37 c
	LSD (5%)			
Ishwardi	T1	5.71 a	7.04 a	5.66 a
	T2	5.24 a	7.59 a	4.32 b
	T3	4.98 a	5.34 b	5.94 a
	T4	5.54 a	6.99 a	5.03 ab
	LSD (5%)			
Cumilla	T1	4.39 ab	6.47 a	3.83 b
	T2	5.08 a	4.61 b	5.27 a
	T3	4.00 b	0.00 c	3.01 c
	T4	2.31 c	0.00 c	2.28 c
	LSD (5%)			

Means with same letter are not statistically different at 5% probability level by LSD.

The transplanting date showed significant difference in yield for each cultivars in different locations (Table 2). For the cultivar V1, in general, the yield of second transplanting (T2) is slightly higher than that of first transplanting (T1), and gradually declines thereafter, except at Ishwardi location. For the cultivar V2, in general, the highest yield was obtained in first transplanting (T1), and then gradually declined, with the exception of Ishwardi location, where the second transplanting produced the highest and the last harvesting produced good yield. The yield of cultivar V3 is not consistent, first transplanting produced the highest at one location (Mymensingh), the second transplanting at two locations (Rangpur and Cumilla) and the third transplanting produced the highest yield at one location (Ishwardi).

Figure 3: Rainfall distribution during rice growing period in 2015

The mean yields over locations and average crop duration are summarized in Table 2.2. In general, crop duration decreases with late transplanting dates, mainly due to higher heat units (Figure 2). The irrigation needed under different treatments (transplanting time) and cultivars is given in Table 2.3. The irrigation amount varied among locations, mainly due to variation of rainfall (Figure 3). The highest irrigation amount was needed at Rangpur location. Here, the first and second transplanting date (T1 and T2) needed almost similar irrigation, but the 3rd and 4th transplanting saved about 14% and 35% irrigation water compared to 1st and 2nd transplanting, coupled with declined yield (Table 2).

Table 2.2: Mean grain yield of cultivars at different locations under different transplanting dates (treatments) (2015)

		Yield (t/ha)				Mean yield (t/ha)	Average crop duration (days), SS*
		Mymensingh	Ishwardi	Rangpur	Cumilla		
T ₁ D/T: Jan.21	V1	5.77	5.71	6.29	4.39	5.54	137
	V2	6.00	7.04	7.37	6.47	6.72	158
	V3	6.62	5.67	7.27	3.84	5.85	138
T ₂ D/T: Feb.15	V1	5.80	5.24	8.06	5.08	6.05	131
	V2	4.94	7.60	7.20	4.61	6.09	152
	V3	6.26	4.32	8.71	5.27	6.14	131
T ₃ D/T: Mar.7	V1	3.29	4.98	4.85	4.01	4.28	113
	V2	3.68	5.34	3.21	0	3.06	129
	V3	2.48	5.94	5.83	3.02	4.32	114
T ₄ D/T: Mar.30	V1	3.85	5.55	4.52	2.32	4.06	120
	V2	2.04	7.00	0.49	0	2.38	140
	V3	3.35	5.03	3.37	2.28	3.51	121

*SS means "Seed to seed"

3.2. Year 2016

The mean grain yields under different treatments (transplanting time) are summarized in Table 3.1. The interaction effects of treatments and varieties showed significant effects at two locations, Rangpur and Cumilla. For the cultivar V1, in general, the yields of 1st and 2nd transplanting (T1 and T2) are statistically similar, and gradually declines thereafter, except at Ishwardi location. For the cultivar V2, for all locations, the highest yield was obtained in first transplanting (T1), and then gradually declined.

For the cultivar V3, similar trend of V2, that is, the highest yield at 1st transplanting and then gradually declined. For the cultivar V4, the yields of 1st and 2nd transplanting are statistically similar at three locations (Mymensingh, Rangpur and Ishwardi) and differed at one location. The irrigation needed under different treatments (transplanting time) and cultivars are given in Table 3. The irrigation amount varied among locations, mainly due to variation of rainfall (Figure 4). Average irrigation savings by T₂V₁ compared to T₁V₄ is 37%, while the grain yield decreased by about 14% (Table 3).

Figure 4: Rainfall distribution during rice growing period in 2016

3.3. Considering the average yield and possible intrusion of addition Rabi crop between two rice crops

Table 2.3: Irrigation amount needed at different locations (2015)

		Irrigation amount (cm)			
		Rangpur	Mymen-singh	Ishwardi	Cumilla
T ₁ (30 DOS) D/T: 21-1-15	V1	65	63	33	36
	V2	80	63	33	36
	V3	65	63	33	36
T ₂ (26 DOS) D/T: 15-2-15	V1	66	29	24	36
	V2	71	29	24	36
	V3	66	29	24	36
T ₃ (25 DOS) D/T: 7-3-15	V1	56	50	24	39
	V2	56	50	24	39
	V3	56	50	24	39
T ₄ (25 DOS) D/T: 30-3-15	V1	42	39	23	39
	V2	42	39	23	39
	V3	42	39	23	39

The mean yields over locations and years are summarized in Table 4. Generally, the yield of all cultivars at first and second transplanting (i.e. in T₁ & T₂) are good and decrease at the later transplanting dates (T₃, T₄). So, optimization should be made between these two dates and the cultivars considering yield, irrigation water savings, and possible intrusion of addition Rabi crop between two rice crops.

Table 3.1: Effect of treatments (transplanting time) on grain yield at each level of cultivars (2016)

	Treatment	Cultivars			
		V1 (Binadhan-14)	V2 (BRRIadhan 29)	V3 (BRRIadhan 28)	V4 (Binadhan-10)
Mymensingh	T1 (Jan.21)	5.12	6.13	5.28	5.57
	T2 (Feb.15)	5.18	5.76	5.22	4.42
	T3 (Mar.7)	4.13	4.82	3.67	3.95
	T4 (Mar.30)	4.94	4.99	4.17	4.45
	LSD (5%)	NS	NS	NS	NS
	T1	5.74 a	7.04 a	6.60 a	7.12 a

Rangpur	T2	5.62 a	5.04 b	5.79 a	6.94 a
	T3	5.78 a	1.69 c	6.76 a	4.77
	T4	2.15 b	0.65 c	1.53 b	0.97 c
	LSD (5%)				
Ishwardi	T1	6.02	5.53	5.32	6.99
	T2	6.19	5.35	4.70	7.08
	T3	6.26	5.14	5.04	7.02
	T4	6.87	5.04	4.91	6.96
	LSD (5%)	NS	NS	NS	NS
Cumilla	T1	4.98 a	6.05 a	4.84 a	6.39 a
	T2	4.74 a	5.46 a	3.99 a	4.03 b
	T3	3.09 b	2.10 b	1.93 b	2.22 c
	T4	2.58 b	0.00 c	1.58 b	2.62 c
	LSD (5%)				

Note: Means with the same letter are not significantly different by LSD at 5% level.

Table 3.2: Irrigation water requirement (cm) under different transplanting time at each level of cultivars (2016)

Treatment	Cultivar	Water requirement (cm)				
		Cumilla	Mym	Ishwardi	Rangpur	Average
T1	V1	34	36	47	78	49
	V2	34	36	47	83	50
	V3	34	36	47	78	49
	V4	34	40	50	93	54
T2	V1	23	36	39	60	40
	V2	23	36	39	75	43
	V3	23	36	39	60	40
	V4	23	36	52	110	55
T3	V1	19	27	40	82	42
	V2	19	27	40	92	45
	V3	19	27	40	82	42
	V4	19	27	52	92	48
T4	V1	0	32	40	59	33
	V2	0	32	40	69	35
	V3	0	32	40	59	33
	V4	0	32	46	69	37

Table 4.1: Mean yield over locations and years under different transplanting time at each level of cultivars

Treatment	Cultivar	Mean yield (t/ha)
T1	V1	5.50
	V2	6.45
	V3	5.68
	V4	6.52
T2	V1	5.74
	V2	5.75
	V3	5.53
	V4	5.62
T3	V1	4.55
	V2	3.25
	V3	4.33
	V4	4.49
T4	V1	4.10
	V2	2.53
	V3	3.28
	V4	3.75

Table 4.2: Water savings (cm) in T2 compared to T1

Year	Cultivar	Water savings, cm			
		Cumilla	Mymensingh	Ishwardi	Rangpur
2015	V1	0	34	9	-1

	V2	0	34	9	9
	V3	0	34	9	-1
2016	V1	11	0	8	18
	V2	11	4	-2	-17
	V3	11	0	8	18
	V4	11	0	8	8

In many areas of Bangladesh, two crops are grown in a year, and thus the land becomes free at first transplanting time. But the major land-type of Bangladesh is medium land, and in such areas, one Rabi crop (pulses, oil-seeds, potato or wheat) can be grown between two rice crops in a yearly cycle, and hence possibilities of increasing cropping intensity of the country. In such case, the land will be free at second transplanting time. In this case, the high performing cultivars at first transplanting (V1 and V4, Table 4) have to be sacrificed to gain additional Rabi crop, and irrigation savings in second transplanting (T2) compare to first one (T1). In second transplanting, the cultivar V1 and V2 produced almost similar yield. So, any of this cultivars can be grown. When we consider the irrigation savings in T2 compared to T1 (Table 4), the irrigation savings varies with location and year, mainly due to variation of rainfall amount and distribution. The crop duration of the cultivar also plays a role. The general tendency is that, the second transplanting can save irrigation water. When we consider the crop duration of cultivar V1 and V2 (Table 2), the V1 is shorter duration, and hence should be used (as the yield is similar).

By considering economic factor (intrusion of additional rabi crop between two rice crops) and ecological factor (irrigation reduction, and hence reducing groundwater withdrawal), we recommend that the most suitable transplanting time for Boro rice should be 15th February. As such, we can effectively achieve good yield, reduce irrigation requirement, and creating opportunity for possible intrusion of addition Rabi crop between two rice crops. Overall, the findings of the present study can provide effective transplanting time and cultivar to reduce groundwater withdrawal in the present agro-ecosystem of northwestern Bangladesh and other similar areas.

4.0. Conclusion

As surface water supply is decreasing day by day, irrigation pressure is going towards groundwater resource. Judicious withdrawal of groundwater in intensive irrigated area is a crucial need for maintaining sustainability of the resource. Field experiments were conducted of Boro rice cultivars in different planting dates with respect to yield and irrigation water requirement, and to optimize between yield and irrigation water requirement, with a view to reduce groundwater withdrawal and hence reducing mining of groundwater. The results showed that in general, the yield of all cultivars at first and second transplanting are good and decreased at the later transplanting dates, which could not be recommended among farmers. When we consider the irrigation savings in second transplanting compared to first one, the irrigation savings varies with location and year, but the general tendency is that the second transplanting can save irrigation water. The cultivar Binadhan-14 (V1) can be selected for its good yield at second transplanting and short duration. By considering economic actor (intrusion of additional rabi crop between two rice crops) and ecological factor (irrigation reduction, and hence lower groundwater withdrawal), we recommend that the most suitable transplanting time for Boro rice should be 15th February. In this case, we can achieve good yield, reduce irrigation requirement, and create opportunity for possible intrusion of addition Rabi crop between two rice crops. The findings of the present study can help in selecting transplanting time and cultivar to reduce groundwater withdrawal in the present agro-ecosystem of northwestern Bangladesh and other similar areas.

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