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Effect of potassium fertilizer and alternate wetting and drying (AWD) irrigation system for *Boro* rice cultivation in Faridpur region

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ABSTRACT

Globally, climate change, population growth, urban and rural expansion are all lowering the amount of freshwater available for irrigation. Therefore, the research was carried out to investigate the combined effects of irrigation systems and split application of potassium fertilizer on BRRI dhan89. The study was laid out in a split-plot based on a randomized complete block design with 7 treatments and 3 replications. Irrigation systems (CF, AWD-1, AWD-2, and AWD-3) were the main factors while split application of potassium (K-1, K-2, and K-3) was the subfactor. The findings showed that the potassium treatment was significant for yield contributing traits but not for grain yield, straw yield, biological yield, and harvest index. The findings also revealed that the irrigation treatments had a significant effect on yield components and grain yield of BRRI dhan89. In most cases, CF (continuous flooding)gave the maximum plant height (114.33 cm), tillersm^{-2} (269.00), paniclesm^{-2} (258.22), grainspanicle^{-1} (138.89), thousand grain weight (23.78 g), grain yield (8.33 tha^{-1}), straw yield (9.20 tha^{-1}) and biological yield (17.53 tha^{-1}), but in all of those cases AWD-1, gave nearly similar results. However, the highest grain yield (9.00 tha^{-1}) was recorded from treatment interaction CF + K-3 followed by AWD-1 + K-3 (8.95 tha^{-1}) and AWD-1 + K-2 (8.36 tha^{-1}).It was evident that both the CF + K-3 and AWD-1 + K-3 treatment combinations generated nearly equal grain yields. As, AWD irrigation system saves a huge amount of fresh water compared to CF, the treatment combination AWD-1 + K-3 could be an alternative option for rice cultivation.

INTRODUCTION

Agriculture confronts two major difficulties in the 21st century such as rapid population growth and water scarcity (Yang and Zhang, 2010). The dynamics of the world population growth rate are very alarming (UNDESA, 2019). To ensure the food security for the growing population agricultural production must be doubled and water supply must be assured for crop production (Bouman, 2007). About half of the world's population lives in Asia, which consumes nearly all of the rice produced globally (Dass and Chandra, 2013; Chauhan et al., 2017).The food security system of Bangladesh is mainly dependent on rice cultivation (BRRI, 2019). In Bangladesh, rice cultivation accounts for approximately half of all rural employment, two-thirds of the overall calorie supply, and half of the country's total protein intake (BRRI, 2020).

Rice plant tissue usually contains 2.0-5.0% potassium (K), which is essential for its growth and development (Dai et al., 2008). Potassium helps to accelerate the metabolic activity and stress tolerance of rice (Yemelyanov et al., 2020). Moreover, potassium fertilizer has a significant impact on rice yield as well as nitrogen uptake and utilization by rice (Hu and Wang, 2004; Bahmaniar and Rainbar, 2007).In Bangladesh, farmers are very much familiar with the application of potassium to rice fields right before transplanting or during final land preparation. As a result, potassium deficiency appeared in rice plants

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during the active tillering to panicle initiation stage due to leaching, percolation, fixation to the clay minerals etc. (Majumdar et al., 2017; Sharma and Singh, 2021). By limiting leaching losses, the split application assures a sufficient supply of available potassium during important crop growth stages (Correa et al., 2018). Potassium deficiency is also caused by the continued use of imbalanced fertilizers, high-yielding cultivars, and intense agricultural production (Sharma et al., 2012).

For rice production, potassium application time is very critical (Mahfuza et al., 2010). To achieve maximum yield, a continuous supply of potassium from the reproduction stage to the heading stage is essential (Singh et al., 2004). Doberman et al. (1995) found that adding potassium to rice increased yield by 12%. Many researchers have found much-improved rice yields due to split potassium application rather than a single application (Vijayakumar et al., 2022; Atapattu et al., 2018). It was investigated that the two equal split applications of potassium @ 60 kgha^{-1} during final land preparation and panicle initiation stage of rice accelerated yield up to 14.47% when compared to the only basal application of potassium during final land preparation (Pal et al., 2000). Verma et al. (1979) and Nand et al. (2020) also found that around 8% and 9% higher grain yield was obtained by the split applications (50% planting + 25% at maximum tillering + 25% at panicle initiation) of potassium @ 105 kgha^{-1} when compared to the only basal application of potassium during transplanting.

Rice, more than any other crop, consumes the maximum amount of irrigated fresh water (Bouman and Tuong, 2001; Deng et al, 2021). On the other hand, the availability of fresh water is limited due to climate change, environmental pollution, uncontrolled population growth, and resource depletion by urban and industrial development (Belder et al., 2005). Recently, several irrigation systems have been developed to enable farmers to effectively minimize irrigation costs, as well as to conserve water for other uses (Bouman, 2007).Alternate wetting and drying (AWD), such new water-saving technology has the ability to enhance soil aeration (Fang et al., 2018), increase root functions (Chu et al., 2015),reduce greenhouse gas emissions (Li et al., 2018), decrease hazardous chemical surplus (Cucu et al., 2014) as well as reduces pollutants in the environment (Subedi and Poudel, 2021). The AWD method is more important for rice cultivation because it can save up to 38% of irrigated water without affecting rice yield than the continuous flooding irrigation system (Price et al., 2013).Tan et al. (2013) also found that under AWD conditions, there was no significant yield loss and saves 17% fresh water when compared to continuous flooding irrigation. As a result, the study was carried out to determine the suitable potassium fertilizer management for *Boro* rice (BRRI dhan89) cultivation under several AWD environments.

MATERIALS AND METHODS

Experimental site

The experiment was carried out at the Spices Research sub-center, BARI, Faridpur during the period from December 2019 to May 2020. The trial place is positioned at 23.603078 N latitude, and 89.779281 E longitude, with an elevation of 11.89 m above sea level.

Climatic condition and edaphic factors

The experimental site belongs to tropical wet and dry weather under the active ganges river floodplain (AEZ-10) (Mostafizur et al., 2018). Figure 1 showed the average monthly climatic condition of the study area during 2020. The soil of the study plot was very fertile having pH value of 7.89. Other edaphic factors were presented in Table 1.

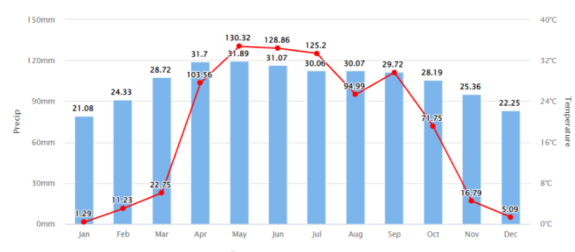

Figure 1: Average monthly temperature and precipitation of the experimental site during the study period (2020)

Table 1: Physical and chemical properties of the experimental soil sample

Soil Properties	Value
Sand (%)	10.25
Silt (%)	55.42
Clay (%)	34.33
pH	7.89
Organic matter (%)	1.35
Total nitrogen (%)	0.08
Available phosphorus (µg/g soil)	6.74
Exchangeable potassium (meq/100 g soil)	0.21
Available sulfur (µg/g soil)	12.6
Available zinc (µg/g soil)	1.70
Textural class	Silt loam

Experimental material

In this study, BRRI released a high-yielding *Boro* rice variety named BRRI dhan89 (parentage: BRRI dhan29/ *Oryza rufipogon* (IRGC103404) was used as study material. The average plant height and thousand kernel weights are 106 cm and 24.4 g. The growth duration of BRRI dhan89 is 3-5 days earlier compared to BRRI dhan29. The grain was medium slander and contain 28.5% amylose (BRRI, 2020).

Experimental design and treatments

BRRI dhan89 was evaluated in a split-plot design with three replications, where irrigation methods (CF: Continuous flooding, AWD-1: Irrigation was applied when water in the plastic tube remained at field level, AWD-2: Irrigation applied was when water in the plastic tube remained below 5 cm from the field level, and AWD-3: Irrigation was applied when water in the plastic tube remained below 10 cm from the field level) were in the main plot and potassium split (K-1: Potassium was applied during final land preparation, K-2:Potassium was applied in two splits during final land preparation and panicle initiation stage, and K-3:Potassium was applied in three splits during final land preparation, tillering stage/with 2nd urea split and panicle initiation stage) in the subplots (Table 2). The unit plot size was 20 m^2. A 20 cm × 20 cm spacing and 2-3 seedlings per hill were maintained. The distance between unit plots and between replications was 50 cm and 100 cm.

Seed sowing, transplanting, and fertilization

Healthy and disease-free seeds were selected and soaked in freshwater for 24 hours. After that, the seeds were taken out of the water and placed tightly into gunny bags. After 72 hours the sprouted seed was sown at the rate of 80-100 gm^{-2} in the seedbed on 5 December 2019. To save the seedlings from cold injury proper fertilization and water management were maintained in the seedbed followed by BRRI (2020).Forty days old seedlings were transplanted into the main field on 13 January 2020. All the fertilizers were applied during the final land preparation (DAP: MoP: Gypsum: Zinc sulfate @ 105:150:105: 11 kg ha^{-1}). However, three equal splits of urea (262 kg ha^{-1}) were applied as a top dress after 15, 30, and 45 days after transplanting.

Cultural operations

Cultural management like weeding, irrigation and drainage, insecticide and pesticide application were done when necessary.

Alternate wetting and drying (AWD) method

A 25 cm long plastic PVC pipe with an 8 cm diameter was used in this experiment. The holes were bored in the lower portion (15 cm from the bottom) of the PVC pipe each around 0.5 cm in diameter and spaced 5 cm apart (Figure 2). Just prior to transplanting, the PVC pipes were installed near the edge of the paddy field in such a way that the perforated portion remained below the field level and the plain portion remained above the field level. After irrigation, the experiment plot was flooded, and the water seeped into the PVC pipe through the holes. The water level within the tube remained the same as it is outside. The receding depth of the field's water level was monitored and measured in each AWD-based treatment using a centimeter scale. During the seedling establishment and just before heading to the milk stage all plots were flooded with irrigation water and maintained up to 5-7 cm water depth. After completion of the milk stage, AWD methods were followed in each treatment. Irrigation was stopped before 2 weeks of harvest. When heavy rainfall occurred, excess water was drained out from the experiment plot.

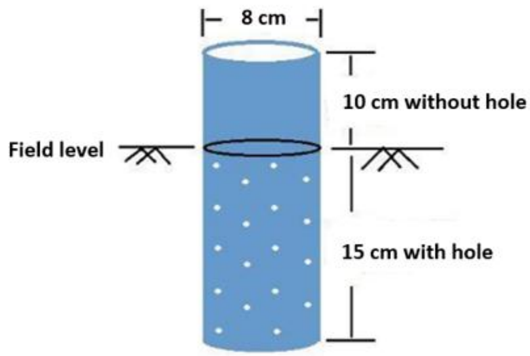

Figure 2: PVC pipe (upper 10 cm without hole and lower 15 cm with hole)

Data collection

Data were collected on plant height and no. of tillers per hill at 30 DAT, 60 DAT, 90 DAT, and 120 DAT (days after transplanting). At maturity, data were also recorded on plant height (cm), tillersm^{-2}, paniclem^{-2}, panicle length (cm), grainspanicle^{-1}, sterility (%), 1000 grain weight (g), growth duration (days), grain yield (tha^{-1}), straw yield (tha^{-1}), biological yield (tha^{-1}) and harvest index (%).Harvesting was done when 85% grain per panicle was matured. Grain yield (kg) was measured on a 10 m^2 sample area without borderline from each replication. Moisture percent was also recorded in each plot. The grain yield (tha^{-1}) of each plot was calculated at 14% moisture content using the following formula:

Grain yield (tha^{-1})

$$=\frac{(100-\text{obtained moisture per plot})}{(100-14)} \times \text{grain yield } \left(\frac{\text{kg}}{10\text{m}2}\right)$$

Biological yield (tha^{-1})= Grain yield (tha^{-1}) + Straw yield (tha^{-1})

$$\text{Harvest index (\%)} = \frac{\text{Grain yield}}{\text{Biological yield}} \times 100$$

Data analysis

The collected data were then gathered and statistically analyzed using the Excel 2010 and STAR 2.0.1 software (https://sourceforge.net/projects/linnix/).

Table 2: Treatment combination and fertilizer rate (kg ha^{-1})

Irrigation method	Potassium application (K)	Potassium application time	N-P-K-S-Zn (kg ha^{-1})
CF	K-1 (Single split)	During final land preparation	262-105-150-105-11
	K-2 (Two split)	50 % during final land preparation + 50% at panicle initiation (PI) stage	262-105-150-105-11
	K-3 (Three split)	50% during land preparation + 25% at tillering stage (with 2nd urea split) + 25% at panicle initiation (PI) stage	262-105-150-105-11
AWD-1 (Field level)	K-1 (Single split)	During final land preparation	262-105-150-105-11
	K-2 (Two split)	50 % during final land preparation + 50% at panicle initiation (PI) stage	262-105-150-105-11
	K-3 (Three split)	50% during final land preparation + 25% at tillering stage (with 2nd urea split) + 25% at panicle initiation (PI) stage	262-105-150-105-11
AWD-2 (< 5 cm)	K-1 (Single split)	During final land preparation	262-105-150-105-11
	K-2 (Two split)	50 % during land preparation + 50% at panicle initiation (PI) stage	262-105-150-105-11
	K-3 (Three split)	50% during final land preparation + 25% at tillering stage (with 2nd urea split) + 25% at panicle initiation (PI) stage	262-105-150-105-11
AWD-3 (< 10 cm)	K-1 (Single split)	During final land preparation	262-105-150-105-11
	K-2 (Two split)	50 % during final land preparation + 50% at panicle initiation (PI) stage	262-105-150-105-11
	K-3 (Three split)	50% during final land preparation + 25% at tillering stage (with 2nd urea split) + 25% at panicle initiation (PI) stage	262-105-150-105-11

Here, CF: Continuous flooding, AWD: Alternate wetting and drying, AWD-1 (Field level): Irrigation was done when water in the PVC tube remain at ground level, AWD-2 (< 5 cm): Irrigation was done when water in the tube remain 5 cm below from the field level, and AWD-2 (<10 cm): Irrigation was done when water in the tube remain 10 cm below from the field level.

RESULTS AND DISCUSSION

Plant height and height growth rate

The combined effect of irrigation methods and potassium (K) showed significant differences in plant height at 30, 60, 90, and 120 DAT (Table 3) but not at harvest (Table 5). At 30, 60, 90, 120 DAT and harvest, maximum plant height (39.39, 72.62, 90.40, 99.19 and 115.67 cm) was recorded in treatment combination of CF + K-3 and minimum (27.72, 63.26, 81.12, 90.65 and 106.00 cm) in treatment combination of AWD-3 + K-1 (Table 3). The differences were significant at 60 DAT and 90 DAT but not significant at 120 DAT. Hight growth rates were higher in between 60 and 90 DAT compared to 30 - 60 DAT and 90- 120 DAT. For HGR_{30-60}, the highest height growth rate was observed in K-1 under AWD-2 and AWD-3 conditions and the lowest growth rate in K-2 under CF treatment conditions. The maximum height growth rate for HGR_{60-90} was recorded in K-3 under both AWD-1 and AWD-2 conditions and the minimum in K-1 and K-3 under CF environments. The highest height growth rate for HGR_{90-120} was found in K-2 in CF environment and the lowest in K-3 in AWD-2 environment (Table 3).Plant height is a genetic trait that is affected to a certain degree by environmental factors and agronomic practices. The present findings reported that variation in plant height depends mostly on irrigation and potassium availability. It was obvious that continuous flooding (CF) boosted plant height considerably more than AWD water (Khairi et al., 2016). It was also evident that Potassium (K) enhanced plant height (Bhiah et al., 2009), but a lack of K caused lodging (Mahbub et al., 2006). On the other hand, split application of K generates a gradual effect on plant height particularly when irrigation is limited (Santoes et al., 1999). Many researchers have also observed differences in plant height as a result of irrigation systems and fertilizer application rates (Farzana et al., 2021; Subedi et al., 2021).

Table 3: Mean interaction of irrigation method and potassium application for plant height (cm) and height growth rate (cm day^{-1}) of BRRI dhan89

Irrigation method	Potassium split	Plant height (cm)				Height growth rate (cm day^{-1})		
		30 DAT	60 DAT	90 DAT	120 DAT	HGR_{30-60}	HGR_{60-90}	HGR_{90-120}
CF	K-1	35.53 c	69.55 b	87.37	96.61	1.13	0.59	0.31
	K-2	37.26 b	70.32 b	88.15	98.35	1.10	0.60	0.34
	K-3	39.39 a	72.62 a	90.40	99.19	1.11	0.59	0.30
AWD-1	K-1	33.23 b	67.83 a	86.86	95.38	1.15	0.64	0.28
	K-2	33.95 ab	68.16 a	87.70	96.11	1.14	0.65	0.28
	K-3	34.71 a	68.62 a	88.54	97.71	1.13	0.66	0.31
AWD-2	K-1	29.51 c	65.29 b	84.47	93.20	1.19	0.64	0.29
	K-2	31.33 b	66.70 a	85.68	94.41	1.18	0.63	0.29
	K-3	32.52 a	66.47 a	86.34	94.24	1.13	0.66	0.26
AWD-3	K-1	27.72 a	63.26 b	81.12	90.34	1.19	0.59	0.30
	K-2	27.95 a	63.28 b	81.42	90.48	1.18	0.60	0.30
	K-3	28.48 a	64.16 a	82.47	91.32	1.18	0.61	0.30
Mean		32.5	67.37	87.17	94.99	1.16	0.63	0.29
CV (%)		2.02	0.88	0.86	0.78	2.74	3.39	11.56
LSD (<0.05)		1.13	1.02	0.64	0.41	0.05	0.03	NS

CF: Continuous flooding; AWD: Alternate wetting and drying; HGR_{30-60}, HGR_{60-90}, and HGR_{90-120} indicate height growth rate (cm day^{-1}) between 30 and 60 DAT, 60 and 90 DAT, and 90 and 120 DAT; DAT: Days after transplanting

No. of tillers per hill and tillersm^{-2}

Table 4 showed the effect of potassium fertilizer and irrigation methods on the no. of tillers per hill at 30, 60, 90, and 120 DAT. A significant difference was observed at 60, 90, and 120 DAT. During 30, 60, 90, and 120 DAT, the maximum no of tillers per hill (8.00, 12.33, 16.00, and 17.00) was found in CF + K-3 treatment combination. For 30 DAT, the minimum of 4.37 tillers per hill was observed in K-1 under AWD-2 treatment condition and for 60, 90, and 120 DAT the lowest no. of tillers per hill were recorded in K-1 under AWD-3 treatment condition.

Table 4: Mean interaction of irrigation method and potassium application for no. of tillers per hill of BRRI dhan89

Irrigation method	Potassium split	30 DAT	60 DAT	90 DAT	120 DAT
CF	K-1	7.00	12.00	13.00	14.33
	K-2	7.00	12.00	14.00	16.00
	K-3	8.00	12.33	16.00	16.00
AWD-1	K-1	5.67	10.00	12.00	13.33
	K-2	6.43	10.17	12.67	14.18
	K-3	6.00	11.33	13.00	15.67
AWD-2	K-1	4.37	8.33	11.00	12.33
	K-2	6.60	10.33	12.00	13.00
	K-3	5.33	11.00	12.33	14.00
AWD-3	K-1	5.33	8.00	9.33	11.33
	K-2	5.00	9.00	10.67	12.00
	K-3	4.83	9.33	11.33	12.00
Mean		5.96	10.32	12.18	13.68
CV (%)		13.03	10.18	6.33	5.97
LSD (<0.05)		NS	0.91	0.67	0.75

CF: Continuous flooding; AWD: Alternate wetting and drying; DAT: Days after transplanting

Table 5 displayed that data recorded on tillersm^{-2} was significant for both irrigation methods and potassium (K) application but not for their interaction. The highest no of tillersm^{-2} for irrigation method was found in CF (269.00) whereas the lowest was in AWD-3 (239.11). Similarly, for potassium (K) treatment, the highest no of tillersm^{-2} was recorded in K-3 (263.50) while the lowest was observed in K-1 (253.25). In the case of treatment interaction, the maximum tillersm^{-2} were found in CF + K-3 (274.00) and the minimum (235.00) in AWD-3 + k-1 treatment environment. Norton et al. (2017) reported that AWD stimulates rice plants to generate thicker roots, which allows the root system to get more water and oxygen during the crop vegetative stage, leading to tiller production. In another study (Oliver et al., 2010), the highest no of effective tillersm^{-2} was found under CF conditions than AWD which supports the present study. Moreover, Surendran (2005) investigated that the application of 50% potassium at tillering and panicle initiation stage resulted in more effective tillers hill^{-1}.

Paniclesm^{-2}

No. of paniclesm^{-2} is an important yield contributing trait for rice. In the present study, irrigation methods showed a significant effect on no of paniclesm^{-2} where the maximum no of paniclesm^{-2} was recorded in CF (258.22) and minimum (226.33) in AWD-3 treatment condition. The potassium treatment also showed a significant effect for paniclesm^{-2} where the highest no of paniclesm^{-2} was found in K-3 (251.83) and the lowest (240.92) in K-1 treatment. But their interaction was non-significant for paniclesm^{-2}. However, the highest no of paniclesm^{-2} (264.00) was recorded numerically in CF + K-3 treatment interaction whereas the lowest no of paniclesm^{-2} (222.00) was found in AWD-3 + K-1 (Table 5). Li et al. (2014) emphasizes that no of paniclesm^{-2} is the foundation for boosting source and sink and ensuring higher yields. Gravois and Helms (1992) reported that without maximum panicle density at uniform maturity, the best rice production could not be achieved.

Panicle length

In the present investigation, panicle length was significant for irrigation treatment. The highest panicle length (24.22 cm) was obtained from AWD-1 treatment and the lowest panicle length (23.44 cm) was obtained from AWD-3 treatment. The panicle length also exhibited a significant effect for potassium (K) split application. The treatment K-3 generated the longest panicle length (24.37 cm), while K-1 treatment gave the shortest

Table 5: Effects of irrigation method, potassium application and its interaction on grain yield and yield contributing traits of BRRI dhan89

Irrigation method	PH (cm)	Tillersm^{-2} (no.)	Paniclesm^{-2} (no.)	PL (cm)	GP (no.)	S (%)	TGW (g)	GD (days)	GY (tha^{-1})	SY (tha^{-1})	BY (tha^{-1})	HI (%)
CF	114.33 a	269.00 a	258.22 a	24.18 ab	138.89	19.61 c	23.78 a	161.44 a	8.33 a	9.20 a	17.53 a	47.50 c
AWD-1	113.00 b	266.22 a	254.44 b	24.22 a	138.44	21.23 c	23.76 a	158.00 b	8.32 a	9.01 a	17.33 a	48.01 b
AWD-2	108.89 c	256.89 b	245.22 c	23.82 b	136.78	27.34 b	22.48 b	156.78 b	7.39 b	7.86 b	15.25 b	48.46 a
AWD-3	107 d	239.11 c	226.33 d	23.44 c	136.22	30.22 a	21.66 c	155.44 c	6.46 c	6.84 c	13.30 c	48.59 a
Lsd (<0.05)	0.74	3.19	3.16	0.37	NS	1.71	0.5	1.28	0.42	0.41	0.82	0.37
Potassium application												
K-1	109.75 b	253.25 c	240.92 c	23.38 b	135.92 b	27.01 a	22.57 b	157.83	7.2	7.8	15.00	48.03
K-2	111.00 a	256.67 b	245.42 b	24.00 a	137.08 b	24.41 b	22.98 a	157.67	7.63	8.28	15.92	47.98
K-3	111.67 a	263.50 a	251.83 a	24.37 a	139.75 a	22.38 c	23.21 a	158.25	8.05	8.6	16.65	48.41
Lsd (<0.05)	0.95	1.84	2.05	0.52	2.21	1.83	0.26	NS	NS	NS	NS	NS
Treatment interaction												
CF + K-1	112.67	264.33	252.33	23.71	137.00 b	21.23	23.40	161.00	7.76 c	8.64 c	16.40 c	47.32 b
CF + K-2	114.67	268.67	258.33	23.97	136.67 b	20.09	23.76	161.00	8.23 b	9.17 b	17.39 b	47.31 b
CF + K-3	115.67	274.00	264.00	24.86	143.00 a	17.51	24.16	162.33	9.00 a	9.80 a	18.80 a	47.88 a
AWD-1 + K-1	112.00	262.33	248.67	23.74	134.33 b	24.06	23.40	158.00	7.66 c	8.35 c	16.01 c	47.82 b
AWD-1 + K-2	113.33	263.67	253.33	23.98	139.00 a	19.99	23.83	157.67	8.36 b	9.12 b	17.48 b	47.84 b
AWD-1 + K-3	113.67	272.67	261.33	24.94	142.00 a	19.63	24.07	158.33	8.95 a	9.56 a	18.51 a	48.36 a
AWD-2 + K-1	108.33	251.33	240.67	23.52	136.67 a	29.58	22.14	156.67	7.18 c	7.62 b	14.81 c	48.52 ab
AWD-2 + K-2	109.00	256.67	245.00	24.06	135.33 a	27.18	22.58	157.00	7.40 b	7.81 b	15.21 b	48.68 a
AWD-2 + K-3	109.33	262.67	250.00	23.90	138.33 a	25.26	22.73	156.67	7.59 a	8.16 a	15.74 a	48.19 b
AWD-3 + K-1	106.00	235.00	222.00	22.56	135.67 a	33.16	21.34	155.67	6.21 b	6.59 b	12.80 b	48.49 b
AWD-3 + K-2	107.00	237.67	225.00	23.98	137.33 a	30.39	21.74	155.00	6.53 a	7.05 a	13.58 a	48.09 c
AWD-3 + K-3	108.00	244.67	232.00	23.77	135.67 a	27.11	21.90	155.67	6.65 a	6.87 a	13.52 a	49.20 a
CV (%)	0.98	0.83	0.96	2.51	1.43	8.58	1.30	0.52	1.31	1.57	1.37	0.48
Lsd (<0.05)	NS	NS	NS	NS	3.4	NS	NS	NS	0.17	0.22	0.38	0.39

CF: Continuous flooding, AWD: Alternate wetting and drying, K: Potassium, NS: Not significant, PH: Plant height (cm), PL: Panicle length (cm). GP: Grains panicle^{-1} (no.), S (%): Sterility (%), TGW: Thousand grain weight (g), GD: Growth duration (days), GY: Grain yield (tha^{-1}), SY: Straw yield (tha^{-1}), BY: Biological yield (tha^{-1}), HI: Harvest index (%).

panicle length (23.38 cm). However, there was no significant variation in panicle length due to the interaction effect of potassium and irrigation treatment. The highest panicle length (24.94 cm) was recorded from AWD-1 + K-3 and the lowest (22.56) from AWD-3 + K-1 treatment interaction. Islam et al. (2015) reported that split application of potassium (K) significantly increased the panicle length and the lowest water treatment, reducing the average panicle length and weight of rice (Pascual and Wang, 2017) which is similar to the present findings.

Grains panicle^{-1}

In the current study, the no. of grains panicle^{-1} was significantly influenced by the potassium treatment. The maximum no. of grains panicle^{-1} (139.75) was collected from K-3 treatment and the minimum no. of grains panicle^{-1}(135.92) from K-1 treatment. Alternatively, the water management had no significant effect on the no. of grains panicle^{-1} (Table-5). In CF condition we found the maximum no. of grains panicle^{-1} (138.89) while the minimum number (136.22) in AWD-3 treatment condition. The treatment interaction of both potassium and irrigation methods had a significant influence on no. of grains panicle^{-1}. Numerically, the highest no. of grains panicle^{-1} (143.00) was noticed from CF + K-3 and the lowest no. of grains panicle^{-1} (134.33) was noticed from AWD-1 + K-1 treatment interaction. Nwe et al. (2015) confirmed that potassium fertilizer management significantly affected the no. of grains panicle^{-1} which had a significant and positive correlation with grain yield (Liu et al., 2019). However, CF condition generates more no. of grains panicle^{-1} compared to AWD (Ara et al., 2021). On contrary, Hussain et al. (2021) recorded the maximum no. of grains panicle^{-1} under AWD condition.

Sterility (%)

Both irrigation methods and potassium treatment had a significant effect on sterility percent in the current study, but their interaction had no effect. Table 5 showed that the AWD-2 treatment condition had the highest (27.34%) sterility percent, whereas the CF treatment condition had the lowest (19.61%) sterility percent. Similarly, the maximum (22.38%) sterility percent was identified in the K-1, while the lowest (22.38%) was found in the K-3 treatment condition. In the case of a treatment interaction, AWD-3 + K-2 gave the highest (30.39%) sterility percent while CF + K-3 gave the lowest (17.51%).From previous studies (Akram, 2013; Ofori and Anning, 2019), the sterility percent was affected significantly by the irrigation treatments and it rose when a water shortage occurred during the grain filling stage. This contradicts the findings of Momo et al. (2013), who found that limiting water after full heading had no influence on unfilled grains number, grain yield, and straw yield. In another study, Banerjee et al. (2018) investigated that rice growth was accelerated by increasing the potassium rate, which decreased the number of ineffective tillers and unfilled spikelet per panicle, lowering the sterility percentage.

Thousand grain weight

Both irrigation and potassium treatment had a significant effect on thousand grain weight. For irrigation treatment, the maximum (23.78 g) thousand grain weight was recorded from CF and the minimum (21.66 g) from AWD-3. Likewise, the highest (23.21 g) thousand grain weight was counted from K-3 and the lowest (22.57 g) from K-1 treatment. There was no significant effect was observed on thousand grain weight for treatment interaction. The highest (24.16 g) thousand grain weight was found in CF + K-3 and the lowest (21.34 g) in AWD-3 + K-1 treatment interaction (Table 5).According to Yoshida (1981), thousand grain weight is a hereditary feature, and so the environment has little influence on it. This result backs with Anning et al. (2018) findings that water stress has no influence on grain weight.

Growth duration

In this study, it was observed that water treatment had a significant influence on the growth duration of BRRI dhan89. The maximum (161.44 days) growth duration was recorded for CF and the minimum (155.44 days) for AWD-3 treatment condition. Alternatively, the potassium treatment and their interaction had an insignificant influence on growth duration. In the case of potassium treatment, the longest (162.33) growth duration was found in CF + K-3 condition whereas the shortest (155.00) was found in AWD-3 + K-2 (Table 5). According to Parveen et al. (2019), water stress from flowering to physiological maturity could be employed to speed up ripening and shorten crop growth period.

Grain yield

Mainly, panicles m^{-2}, grains $panicle^{-1}$ and thousand grain weight (g) are the maximum contributors to increase grain yield. In this study, a significant variation in grain yield was observed for irrigation methods and treatment interaction but not for potassium treatment. The highest grain yield was observed in CF (8.33 tha^{-1}) followed by AWD-1 (8.32 tha^{-1}) and the lowest in AWD-3 (6.46 tha^{-1}) treatment condition. For potassium treatment, the highest (8.05 tha^{-1}) grain yield was found from K-3 and the lowest (7.20 tha^{-1}) from K-1. For treatment interaction, the maximum (9.00 tha^{-1}) grain yield was recorded from CF + K-3 and the minimum (6.21 tha^{-1}) from AWD-3 + K-1 treatment combination. There were no significant differences observed for CF + K-3 (9.00 tha^{-1}) and AWD-1 + K-3 (8.95 tha^{-1}) treatment interaction (Table 5). Atapattu et al. (2018) showed that the application of potassium (37.5 $kgha^{-1}$) at the time of heading, is perfect to obtain the highest grain yield which is consistent with the investigation. Our findings corroborate with the findings of Ara et al. (2021) who observed that the grain yield increases as the water depth from the field water level decreases. On the contrary, when compared to flooded irrigation, Zheng et al. (2020) discovered that AWD methods increased grain yields by more than 13%.

Straw yield

Table 5 showed that the potassium treatment had no discernible influence on straw yield. The highest (8.60 tha^{-1}) straw yield was received from K-3 while the lowest (7.80 tha^{-1}) was received from K-1 treatment. As a result of the irrigation treatment, the straw yield changed significantly. The maximum (9.20 tha^{-1}) straw yield was obtained from CF and the minimum (6.84 tha^{-1}) from AWD-3 treatment condition. The interaction of irrigation methods and potassium application had a significant effect on straw yield. The highest straw yield was recorded from CF + K-3 and the lowest from AWD-3 + K-2 treatment interaction (Table 5). Brohi et al. (2000) showed that as a result of potassium fertilization rice plants absorb more micronutrients and generate more dry matter. Zheng et al. (2020) discovered that AWD could maximize straw yield by up to 5.3 percent as compared to CF. However, Raihan et al. (2015) investigated that the highest straw yield was noticed from CF compared to other irrigation treatments which are similar to the study.

Biological yield

Due to various irrigation treatments, a considerable variation was observed in biological yield (Table 5). The maximum biological yield (17.53 tha^{-1}) was received from CF and the minimum (13.30 tha^{-1}) from the AWD-3 treatment condition. For the potassium treatment, the obtained result had a significant impact on biological yield. The biological yield varied from 15 tha^{-1} (K-1) to 16.65 tha^{-1} (K-3). Potassium and irrigation had a strong interaction effect on biological yield. The maximum (18.80 tha^{-1}) biological yield was obtained from CF + K-3 (12.80 tha^{-1}) while the minimum was from AWD-3 + K-1 treatment condition. Mahfuza et al. (2010) found the maximum biological yield (9.99tha^{-1}) due to the interaction effect of variety and split application of potassium (three splits of K). In comparison to the CF condition, BRRI hybrid dhan2 produced a maximum biological yield of 13.33 tha^{-1} (irrigation when water level below 15 cm soil surface) and 12.39 tha^{-1} (irrigation when water level below 20 cm soil surface) (Rahman and Bulbul, 2014).

Harvest index (%)

For irrigation treatment, the harvest index was significant. The highest (48.59%) harvest index was found from AWD-3 and the lowest (47.50%) from CF (Table 5). On the other hand, the potassium level had no effect on the harvest index. The maximum (48.41%) harvest index was obtained from K-3 and the minimum (47.98%) from the k-2 treatment. However, the interaction between potassium and irrigation had a significant influence on the harvest index. The highest (49.20%) harvest index was recorded from AWD-3 + K-3 whereas the lowest (47.31%) was from CF

+ K-2. The use of potassium enhanced the crop harvest index as well as the grain quality indicator (Umar et al., 1999). Amanullah et al. (2015) obtained the maximum harvest index (39.2%) utilizing 90 $kgha^{-1}$ K in the research plot, which is a little lower than the current finding results. AWD improves harvest index, resulting in a dual purpose of increased grain yield and saving water (Yang and Zhang, 2010). A crop with a water management system that can accelerate grain development rate or improve assimilate remobilization from vegetative tissues to grains during the grain-filling period tends to have a higher HI (Zhang et al., 2008; Bueno and Lafarge, 2009; Ju et al., 2009).

CONCLUSION

According to the findings, the effect of CF + K-3 and AWD-1 + K-3 treatment interaction on grain yield was almost similar. Despite the fact that AWD-1 irrigation treatment could not enhance grain yields as compared to CF, it could save a significant amount of irrigation water, and reduce the production cost. Therefore, the AWD-1 + K-3 treatment combination might be considered as an alternative technique in the context of *Boro* rice (BRRI dhan89) production in the study area.

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