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Alternate Wetting and Drying as Water Management Techniques for the Growth and Yield of Rice (*Oryza glaberrima*) in Botanical Garden Gombe State University

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ABSTRACT

In Nigeria, the agriculture is encountering a lot of challenges due to climate change, especially the growing scarcity of water for crop production, which threatens irrigated lowland rice production at the botanical garden Gombe State University. Alternate wetting and drying can save a significant amount of irrigation water without affecting its yield, hence; this study evaluated the growth and yield traits of improved and local rice cultivars grown under Alternate Wetting and drying (AWD) and continuous flooding (CF) water management. The experiments were arranged using a randomized complete block design (RCBD) with three replications. The results showed that at 20 weeks after transplanting, Faro44, Nerica, Jamila, and Mai Zabura recorded the highest number of tillers under CF, while B.G Doguwa and B.G Gajera performed better under AWD. For the number of panicles, CF outperformed AWD across all varieties studied. Regarding root length and volume, AWD showed remarkable performance in all varieties except B.G Doguwa, where CF recorded the highest values. No yield was recorded in any variety exposed to the AWD treatment. Therefore, it is necessary to reduce the duration of the AWD treatment and increase plant spacing to at least 15 cm apart. Identifying a promising rice variety with high and stable yields under AWD will help promote the system amongst the farmers and achieve an average of 50% water savings in rice production.

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INTRODUCTION

Rice (*Oryza glaberima*) production is constantly dependent on availability of water, an important food crop in many developing countries and the staple food consumed by more than half of the global population (Bouman and Tuong, 2001). Irrigated lowland rice farming plays a crucial role in global food security, providing 75% of the world's rice supply (Geethalakshmi et al., 2009). However, irrigated rice also requires more water (40% of the global irrigation water) than any other staple crops (Ginigaddara and Ranamukhaarachchi, 2009). In addition to water, nitrogen (N) is another essential input limiting rice production (Grigg et al., 2000). Most cultivable soils contain insufficient amounts of N, and therefore, N accounts for the largest share of fertilizer consumption (Mannan et al., 2009). As competition for water resources increases among agricultural sectors, water scarcity has become a major challenge for poorer farmers, especially in arid areas. Over 2.3 billion people live in water-scarce areas and their number will increase (Mohammed et al., 2002) due to rapid demographic growth. In West Africa, and mainly in semi-arid and arid zones, water scarcity threatens the sustainability of irrigated rice production (NPC, 2006). AWD is an irrigation method in which water is added to the field several days after the ponded water disappeared. This differs from the conventional practice of CF, where the field remains constantly covered with water. In this approach, rice fields are not kept submerged all the time but are allowed to dry out periodically throughout the rice growing period. The number of days where the field is allowed to be ‘‘non-flooded’’ before irrigation is applied can vary from 1 day to more than 10 days (Ramamurthy et al., 2003). The basic idea of this irrigation method is that the rice plant's roots continue to receive enough water for a certain time, even when there is no visible standing water in the field (Kannan, 2014). In the coming decades, the demand on fresh water for rice irrigation will increase due to surge in global population and demand for staple crop like rice, hence the need to adopt water saving irrigation practice like AWD in Gombe state. Therefore, this study was conducted to evaluate the effect of AWD irrigation on reducing water input and to assess the vegetative growth and yield characteristics of both local and improved rice varieties. Additionally, it aims to help local rice farmers understand the growth and yield performance of different local rice cultivars grown under the AWD technique.

MATERIALS AND METHODS

Planting Materials and Growth Condition

Six high-yielding and popular rice varieties of Oryza glaberrima were used in this study. These included four local cultivars (Jamila, B.G Doguwa, B.G Gajera, and Mai Zabura) and two varieties (Nerica and Faro 44). The evaluation was conducted at the Botanical Garden of Gombe State University, geographically located at 10°15′N and 11°10′E in the northern part of Nigeria. The experiments were arranged using a randomized complete block design (RCBD) with three replications. Prior to the experiments, approximately nine soil cores, taken from a depth of 0–20 cm along a diagonal across each field, were combined to create composite samples. These samples were air-dried, sieved, and tested for soil texture (including clay, silt, and sand content) as well as chemical characteristics such as pH (measured with a 1:2.5 soil-to-water ratio), total organic carbon, nitrogen, and available phosphorus (Bray-2), following the analytical procedures outlined by Johnson et al. (2000). The experiment was up of all 6 six varieties in grown in both AWD (Alternate Wetting and Drying) control pots. pots in a randomized design. The rice varieties were planted with two seeds per stand at three locations for each variety along one row, resulting in six rows with three columns for all varieties in both AWD and control pots, totaling eighteen stands per pot. In the control pots, CF was maintained at 3 cm above the soil surface from the seedling stage through physiological maturity to yield. In contrast, the AWD irrigation regime involved 3 cm submergence for one week after planting (seedling stage, week one). The first phase of treatment, water deprivation, lasted for two weeks, during which the water level dropped to 5 cm below the soil surface, as measured through a PVC tube. This treatment was maintained throughout the tillering stage in the AWD pots, with the water level consistently kept at 5 cm below the soil surface. At the panicle stage, the third phase of treatment, the same volume of water (2000 ml per pot daily) was applied, but the water level dropped to the soil surface (0 cm) in the PVC tube before the end of the treatment. The quantity of water applied to CF pots was 2 liters per pot daily throughout the research period, totaling 702 liters over 120 days. AWD pots received 2 liters per pot daily, totaling 351 liters during the re-flooding period when the water level had dropped to 5 cm below the soil surface, as measured through the PVC tube. Urea fertilizer was applied twice, once at the vegetative stage and again at panicle emergence, for both treatments.

Data Collection

Seven morphological traits were collected and measured from the screen house. To obtain the mean values of the variables for each pot, plants were evaluated for growth and yield components, including plant height (PH) at 4 to 20 weeks after transplanting (WAT), tiller number (TN) at 4 to 20 WAT, leaf area index (LAI), number of panicles (NP) following the methods of Tadesse et al. (2013) and Yoshida (11), root length (RL), root volume (RV), shoot dry weight (SDW), root weight (RW), biomass (BM), and yield.

Statistical Analysis

All data on growth, yield, and yield-related traits were analyzed using analysis of variance (ANOVA) with IBM SPSS version 22, and mean comparisons were conducted using the least significant difference (LSD) test at a 5% significance level.

RESULTS AND DISCUSSION

Water and Soil Analysis

The results of the water analysis for the experiment are presented in Table 1. The analysis indicates that the water was slightly alkaline, with a pH of 7.98. The concentrations of various ions were as follows: HCO_3 at 9.78 mg/L, Cl at 6.32 mg/L, Na at 7.12 mg/L, K at 2.00 mg/L, Ca at 6.20 mg/L, and Mg at 10.6 mg/L. The soil used was sandy loam with a high water-holding capacity of 64%, and a soil pH of 6.2. The cation exchange capacity of the soil was 5.76 cmol/kg. The soil nutrient status showed total nitrogen content of 0.16 g/kg, indicating low nitrogen levels. Similarly, the available phosphorus was 0.29 g/kg. (No table is presented for soil analysis.).

Table 1: Quality of Irrigation Water Applied to AWD and CF Pots

Parameters	Values	Limits	Methods
pH	7.98	Alkaline	Digital PH meter
CO2(meq L^{-1})	0.00	No Hazard	Titration with 0.02N H2O4 using Phenolphthalein indicator
HCO3(meq L^{-1})	9.78	--	Titration with 0.02 N H2O4 using Methyl orange indicator
CI (meq L^{-1})	6.32	Safe	Titration with standard AgNO3 using K2rO4 as indicator
Na (meq L^{-1})	7.12	Less sodic	Flame Photometer – CL 361
K (meq L^{-1})	2.00	--	Flame Photometer – CL 361
Ca (meq L^{-1})	6.20	--	Titration with standard EDTA using EBT indicator and ammonium buffer
Mg (meq L^{-1})	10.6	--	Titration with standard EDTA using EBT indicator and ammonium buffer

Growth Characters Yield and Yield Components of Rice

The mean square for plant height at 4, 8, 12, 16 and 20 weeks after germination under screen house condition are presented in Table 2. Highly significant differences ($p \leq 0.001$) were observed among the varieties for plant height. Jamila, under continuous flooding water management, produced the tallest plants at 4 and 8 weeks after germination (WAG), measuring 55.77 cm and 93.35 cm, respectively. In contrast, Nerica (36.82 cm) and B.G Gajera (59.12 cm), managed with alternate wetting and drying (AWD), recorded the shortest plants at 4 and 8 WAT. Mai Zabuwa produced the tallest plants under continuous flooding at 12, 16, and 20 WAT, with heights of 110.77 cm, 117.65 cm, and 124.94 cm, respectively. Conversely, Nerica (76.97 cm) at 12 WAG and Faro 44 at 16 and 20 WAG (78.63 cm and 81.75 cm, respectively), both under AWD management, recorded the shortest plants (Table 2). In this study, the mean number of tillers per plant from 4 to 20 weeks after germination (WAG) is presented in Table 3. Faro 44 produced a remarkable number of tillers under continuous flooding water management at 4, 8, 12, 16, and 20 WAT, with counts of 13.50, 23.00, 26.72, 29.42, and 29.83, respectively. This was followed by Jamila under continuous flooding at the same time points. In contrast, Jamila under alternate wetting and drying recorded the lowest number of tillers at 4, 8, 12, 16, and 20 WAT, with values of 7.11, 7.55, 8.16, 8.88, and 10.66, respectively (Table 3).

Table 2: Effect of Plant Height (cm) on Alternate Wetting and Drying from 4 – 20 Weeks After Transplanting

Variety(s)	Water management (WM)	4 WAG	8 WAG	12 WAG	16 WAG	20 WAG
Faro 44	AWD	39.04 + 16.72	65.0 +10.01	78.22 + 16.77	78.63 +30.38	81.75 + 12.28
	CF	48.00 +5.16	73.6 + 4.94	83.58 +9.38	85.55 +13.73	89.45 +7.38
Nerica	AWD	36.82 + 8.62	67.18 +10.43	76.97 + 15.39	88.20 + 10.43	89.16 + 9.29
	CF	39.54 + 6.67	66.83 +12.94	86.26 +18.2	89.26 + 9.77	100.26 + 12.94
Jamila	AWD	38.59+ 2.63	63.12 + 24.46	80.77 + 13.2	90.46 +23.29	102.83 + 9.15
	CF	55.77 + 6.77	93.35 + 5.71	105.6 + 12.63	111.8+13.43	121.16 + 9.09
B.G. Doguwa	AWD	40.25 +8.65	66.21+12.38	89.51+10.66	81.02 +10.84	109.25 +13.38
	CF	46.03 +7.90	74.97 +11.0	101.53 +15.91	102.16+14.32	105.37 +9.35
B.G Gajera	AWD	43.67 +1.22	59.12 +14.15	81.05 +18.01	97.44 +19.39	110.80 +14.08
	CF	52.28 +1.39	71.07+11.54	106.14 +6.63	115.52 + 7.34	120.89 +8.47
Mai Zabuwa	AWD	44.27 + 9.398	89.58 +11.50	90.72 + 10.72	97.30 + 23.93	115.19 + 12.94
	CF	51.45 +5.97	89.51 +12.35	110.77 + 13.99	117.65+15.09	124.94 + 11.11
L.S (p≤0.05)	Variety	0.001	0.001	0.001	0.001	0.016
	WM	0.061	0.266	0.019	0.007	0.276

Note: WM = Water Management, WAG= Week After Germination

Table 3: Effect of Alternate Wetting and Dry on Tiller Number from 4 – 20 Weeks After Transplanting

Variety	Water management (WM)	4 WAG	8 WAG	12 WAG	16 WAG	20 WAG
Faro 44	AWD	11.38 +1.85	16.16+3.41	15.94+4.46	18.66+16.77	23.94+9.11
	CF	13.50+3.12	23.00+ 5.06	26.72+3.41	29.42+7.38	29.83+10.00
Nerica	AWD	9.66+1.53	8.88 +3.57	8.88+3.97	9.94+3.36	12.56+1.68
	CF	10.61+1.28	15.66 +2.32	17.50+4.27	19.72 +5.91	20.61+4.71
Jamila	AWD	7.11+2.72	7.55+1.75	8.16+13.21	8.88+1.42	10.66+2.9
	CF	12.72+1.92	20.83+6.08	24.77+10.09	25.94+11.67	26.88+13.43
B.G. Doguwa	AWD	9.11+1.23	9.22+2.83	13.05+1.38	13.61+ 5.63	18.44 +10.43
	CF	10.50+1.82	11.66+7.16	16.38 +4.51	19.00+3.89	19.11+4.65
B.G. Gajera	AWD	9.16+1.54	10.11+2.21	9.27+4.11	14.66+4.89	16.83+11.63
	CF	10.77+1.21	13.55+0.70	18.33+3.14	14.61+2.32	13.94+3.63
Mai Zabuwa	AWD	9.44+1.14	11.94+4.49	11.94+5.92	13.77+3.58	15.00+2.83
	CF	11.00+1.81	12.38 +3.91	15.00+2.84	14.83+2.79	14.83+4.37
L.S (p≤0.05)	Variety	0.001	0.001	0.001	0.001	0.001
	WM	0.031	0.000	0.047	0.004	0.128

Note: WM = Water Management, WAG= Week After Germination

Among the varieties studied, the highest leaf area index was recorded in Mai Zabuwa under continuous flooding water management (108.10 cm^3), followed by B.G. Gajera with continuous flooding water management (67.50 cm^3), while Faro 44 with alternate wetting and drying recorded the lowest (41.60 cm^3) (Table 4). For the number of panicles per plant, Jamila with continuous flooding water management produced the highest number (3.33), followed by Faro 44 and B.G Gajera with continuous flooding water management recorded the highest (3.22) number of panicle (Table 4), while the lowest number panicle was recorded in Nerica (2.22) with alternate wetting and drying. Varieties under different water management showed significant effects in root length and volume (Table 4). Faro 44 with alternate wetting and drying recorded the highest root length (38.10 cm) and root volume (28.05 cm^3), while Mai Zabuwa and Nerica had the shortest root length (17.43 cm) and least root volume (11.34 cm^3), respectively.

Table 4: Effect of AWD and CF on Leaf Area Index, Panicle, Root Length, and Root Volume of Rice Varieties

Variety(V)	Water management (WM)	LAI (cm^3)	Panicle	Root length (cm)	Root volume (cm^3)
Faro 44	AWD	41.6+0.31	2.88 + 0.51	38.10+ 5.09	28.05+ 1.06
	CF	59.2+0.21	3.22 + 4.70	20.68+ 5.55	13.37+ 3.73
Nerica	AWD	53.6+0.25	2.22+0.27	24.61 + 1.86	21.76+ 1.57
	CF	54.2+0.41	2.44+ 2.77	17.45+2.66	11.34+ 1.57
Jamila	AWD	44.8+0.23	2.33+0.70	38.05+7.66	24.85+4.01
	CF	65.4+0.26)	3.33+0.50	23.22+2.88	13.82+0.64
B.G. Doguwa	AWD	46.1+0.21	2.44+0.28	30.14 +5.26	19.23+ 2.11
	CF	61.6+0.25	3.11 + 2.21	19.47+ 0.86	12.66+0.86
B.G. Gajera	AWD	43.1+0.22	2.88+0.46	26.02 + 2.89	21.11+ 2.43
	CF	67.5+ 0.28	3.22 + 3.62	18.15+ 2.63	25.86 +6.80
Mai Zabuwa	AWD	64.7+0.27	2.33+0.23	21.07+ 1.84	17.54+ 0.97
	CF	108.1+ 0.31	2.77+2.28	17.43+1.96	12.65 + 1.42
L.S (p≤0.05)	Variety	0.001	0.002	0.001	0.001
	WMC	0.002	0.093	0.001	0.117

Note: WM = Water Management, LAI = Leaf Area Index

For dry shoot weight (Table 5), the weightiest was observed in Jamila under continuous flooding water management (19.05 g), followed by Faro 44 (18.54 g), while B.G. Gajera recorded the least shoot dry weight (14.06 g) under alternate wetting and drying. Water management had a significant effect on root weight among varieties. B.G. Gajera under continuous flooding recorded the highest root weight (12.98 g), followed by Jamila (12.32 g), whereas, Nerica (2.58 g) under alternate wetting and drying recorded the lowest (Table 5). In this study, water management also markedly influenced plant biomass (Table 5). B.G. Gajera (26.91 g) exhibited the highest biomass under continuous flooding, followed by Mai Zabuwa (25.30 g), while B.G. Doguwa (17.18 g) recorded the lowest biomass under alternate wetting and drying. Yield results shows that Faro 44 produced the highest (2.87 g), followed by B.G. Gajera (2.77 g). In contrast, Mai Zabuwa produced the lowest (2.23 g) (Table 5). No yield was recorded under alternate wetting and drying due to water shortage.

Table 5: Effect of AWD and CF on Shoot Dry Weight, Root Weight, Biomass, and Yield of Rice Varieties

Variety (V)	Water management (WM)	SDW(g)	Root weight (g)	Biomass (g)	Yield (g))
Faro 44	AWD	15.16+ 2.72	2.92+0.51	18.08+ 2.04	
	CF	18.54+ 2.81	6.57+4.70	25.11+ 3.08	2.87+0.33
Nerica	AWD	15.40+ 2.08	2.58+0.27	17.98+ 1.07	
	CF	18.90+ 2.74	6.19+2.77	21.48+ 2.01	2.49+ 0.26
Jamila	AWD	15.27+2.31	3.38+0.32	18.57+2.17	
	CF	19.05+2.22	12.32+4.65	33.34+3.01	2.66+0.33
B.G. Doguwa	AWD	15.34+ 3.12	2.43+0.28	17.18+ 2.81	
	CF	18.09+ 2.67	5.61+2.21	23.70+ 2.07	2.57+0.21
B.G. Gajera	AWD	14.06+ 2.87	2.81+0.46	16.87+ 2.07	
	CF	17.79+ 3.71	12.98+3.62	26.91+ 2.22	2.77+0.65
Mai Zabuwa	AWD	15.00+ 2.07	2.58+0.23	17.75+ 2.07	
	CF	18.68+ 2.80	6.62+2.28	25.30+ 2.42	2.23+0.33
L.S ($p \leq 0.05$)	Variety	0.001	0.001	0.001	
	WM	0.001	0.006	0.001	

Note: V = Variety, WM = Water Management, SDW = Shoot Dry Weight

Discussion

Among the agronomic management that can improve the sustainability of rice systems, Alternate Wetting and Drying (AWD) meets the increasing demand for water-saving practices. However, knowledge of the potential effects of soil water status induced by this irrigation regime on the qualitative traits of rice grain remains limited (Orasen et al., 2019). Developing and promoting appropriate water management technologies to increase water use efficiency in rice fields without compromising yields is needed and requires a full approach, including crop genetic makeup, soil, and water management (Bouman et al., 2007). Irrigation efficiency is a serious issue regarding rice water management systems, relating to the rice crop's water requirements in rice fields and serving as a measure of water lost from the system (Huanga et al., 2003). Water use efficiency is the ratio of grain yield produced to the unit of water transpired by plants during the production (Hatfield and Dold, 2019). Physiological trait such as transpiration rate plays a vital role in the water balance of rice fields, alongside with some factors such as irrigation, rainfall, evaporation from standing water or soil surfaces, deep seepage losses, and water percolation into the soil. The water balance of lowland rice fields has been widely studied (Nie et al., 2012; Tabbal et al., 2002).

Likewise, the water stability of irrigation regimes influences the hydrologic relationships of plant shoots, which control crop root water uptake (Parent et al., 2010). At the beginning of AWD treatment, plants exhibited reduced vegetative growth compared to fully irrigated plants. Jamila was observed to better than other varieties in height, suggesting it likely possess drought-resistant traits or water-saving capabilities in its physiological and genetic makeup. Mohammed et al. (2002) reported that rice plant height is controlled by both environmental conditions and genetic factors. This finding aligns with Mannan et al. (2009), Kawure et al. (2018), and Singh (2020), who reported that the vegetative growth of rice is significantly influenced by the variety used. Effective tillering was influenced by the main effects of variety and treatment during the season. Variation in tillering among the varieties was observed. A similar study by Show et al. (2014) reported a decrease in the number of tillers, leaf area index (LAI), and crop growth rate (CGR) of rice under alternate wetting and drying (AWD) irrigation. This decrease resulted in reduced panicle production, grain formation and development, finally causing a lower crop yield under AWD irrigation, compared to continuous flooding where submergence depths were maintained for 3 and 5 days after the ponded water disappeared at harvest.

At 8 weeks of growth, the mean plant height of Mai Zabuwa under AWD was statistically the same with continuous flooding, which could be attributed to the irrigation management method; however, this difference was not significant between varieties. The varieties Mai Zabuwa, B.G. Doguwa, B.G. Gajera, and Faro 44 produced statistically similar tiller numbers, while Jamila had the highest tiller number among all varieties. This finding agreed with the results of Mannan et al. (2009), Kawure et al. (2018), and Singh (2020) and Chukwu et al. (2022), who reported that the vegetative growth of rice is significantly influenced by the variety used. The leaf area index (LAI) of rice across all six varieties under AWD and CF at the booting stage was statistically analyzed. The mean LAI was significantly lower in AWD compared to continuous flooding, likely due to the water management treatment applied in AWD Chukwu et al., 2020 and Akos et al., 2025). The effect of treatment on the number of panicles showed an extreme reduction in panicle development under AWD, attributed to the absence of water. Ramakrishna et al. (2007) reported that continuous flooding resulted in a higher number of panicles, grains per panicle, and longer panicle length compared to a 3-day drainage period and irrigation with 5 cm of water when the water level in the perforated PVC pipe dropped by 10 cm, which produced the second highest yield.

The dry shoot weight (g) in irrigated pots was highest in the Jamila and Mai Zabuwa varieties, which accumulated more dry matter than other varieties under AWD. This may be attributed to the absence of water stress in continuous flooding, where water was maintained above the soil surface, or to the genetic makeup of the plants. These results are consistent with previous studies by El-Refaee et al. (2007) and Singh et al. (2000). Plants under AWD exhibited the low vegetative growth, likely due to reduced soil moisture during treatment periods. Kropff and Spitters (1991) reported that reduced soil moisture limits nutrient movement and absorption by plant roots, thereby reducing growth. Nerica under AWD treatment had the lowest shoot weight since it produced the least tillers, resulting in a smaller canopy, which in turn led to a reduced transpiration rate, as plants with larger canopies transpire more. The dry root weight of all varieties used in this study, the irrigated pots was observed to be higher, with B.G. Gajera exhibiting the greatest weight among all varieties study. The increased root weight under continuous flooding is attributed to a greater number of root hairs, resulting from an increased root surface area due to the availability of water. Rice grown in AWD pots had fewer root hairs because of a reduced root surface area, which was also caused by the lack of a continuous water supply. Martin-Vertedor and Dodd (2011) suggested that rice varieties having a larger portion of their root system located deeper in the soil are likely to show a more consistent phytohormonal response to alternate wetting and drying. The plant biomass of all varieties study under continuous flooding performed better than to those under AWD.

After root lengths were measured in both the continuous flooding and AWD pots, it was observed that most of the root lengths in the AWD treatments were longer than those in the continuous flooding plants. Remarkably, B. G. Doguwa in the AWD treatment exhibited the longest roots. This outcome aligns with previous studies (El-Refaee et al., 2007). AWD has been proposed to increase resilience to lodging, as the crop may develop deeper roots to access soil water (Yang et al., 2009). However, AWD produced the lowest vegetative growth, which may be due to reduced soil moisture. Kropff and Spitters (1991) reported that reduced soil moisture limits the movement and absorption of nutrients by plant roots, thereby reducing rice growth. Additionally, in heavy soils such as clays, drying can lead to particle cementation (Rao and Revanasiddappa, 2006) and soil compaction (Sanchez, 1973), which can also reduce root development and other vegetative growth. The root volume of Faro 44 exhibited the highest mean value among the varieties, while Mai Zabuwa had the lowest in the AWD plants. There was no contrast between continuous flooding and AWD plants regarding seed weight because none of the varieties under AWD conditions produced filled spikelets. This finding aligns with Bouman and Tuong (2001), who reviewed over 31 trials on various forms of AWD and reported a 92% yield loss under the AWD technique. Xu et al. (2015) also reported that differences in the frequency and threshold of drying cycles in water-saving irrigation influenced soil hydrological conditions, which subsequently affected the growth process of rice, leading to changes in yield and yield traits.

CONCLUSION

Improved water management techniques in rice production can greatly lower greenhouse gas emissions from agriculture, reduce the consumption of freshwater, boost the profitability of rice production, and sustain crop yields. AWD irrigation is technically possible, cost-effective, and beneficial for water conservation and productivity in rice production. To optimize AWD, the duration of water management should be wisely controlled to prevent water deficits that could negatively affect the physiological activities of drought-susceptible plants. Maintaining optimal water potential is vital to avoid impairing photosynthesis. Therefore, the AWD treatment duration should be limited to between 7 and 14 days to ensure that plant physiological functions are not adversely affected.

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