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OPTIMIZING RICE (*ORYZA SATIVA* L.) GROWTH AND YIELD THROUGH INTEGRATED WATER MANAGEMENT STRATEGIES

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SUMMARY

The presented study sought to evaluate the growth and productivity of various rice (*Oryza sativa* L.) cultivars under different water management systems. The experiment ran from May to September 2024, using a split-plot design with two factors and three replications on irrigated paddy fields in Maradekaya Village, South Sulawesi, Indonesia. The main plots were the water management system (intermittent + discontinuous irrigation and intermittent + AWD [alternate wetting and drying]), and the subplots were six rice cultivars (M70D, Padjajaran, Inpari 13, Inpari 19, Inpari 32, and Cakrabuana). The results showed significant effects on the number of tillers and productive tillers by the interaction of water management and cultivars. Other traits, such as harvest age, grains per panicle, filled grains per panicle, and dry milled grain yield, also showed notable variations across the treatments. In contrast, plant height, flowering age, stomatal density, chlorophyll content, and leaf area did not receive significant changes. The highest productivity came from cultivars M70D and Padjajaran, especially under the intermittent + discontinuous irrigation treatment.

Keywords: Rice (*O. sativa* L.), cultivars, irrigation water management systems, growth and morphological traits, yield-related traits, productivity

Key findings: The highest productivity resulted in the rice (*O. sativa* L.) cultivar M70D, followed by Padjajaran with the intermittent irrigation + discontinuous irrigation water management system.

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INTRODUCTION

Cereal crops, such as rice, wheat, and maize, are primary food sources for humans. Over 90% of people in some regions of Asia, particularly in Southeast Asia, have rice as a staple diet. In light of rice's (*O. sativa* L.) significant position as a staple meal in Indonesia, for food security, ongoing research is necessary to guarantee its sustainable production (Syahputra and Tarigan, 2019). Currently, low rice productivity in Indonesia is due to various factors. The improvement in grain yield arises from a lack of research, innovations, and the underutilization of contemporary agricultural technologies. This includes the underdeveloped efforts to increase productivity from existing farmland through the application of advanced technologies, appropriate fertilization, and the use of biological resources such as hormone-producing fungi (Lestari *et al.,* 2021). Furthermore, water scarcity is one of the primary reasons for low rice productivity, particularly in rainfed regions. Intermittent irrigation and alternate wetting and drying (AWD) irrigation techniques have proven effective for improving and enhancing rice productivity, especially in areas with limited water supply. An intermittent irrigation system keeps the soil moist without submerging, which can fulfill rice plants' water needs with higher efficiency (Sedyowati *et al*., 2024).

Based on data from the Badan Pusat Statistik (BPS, 2020), rice production in Indonesia has shown fluctuations in past years. In 2020, production reached 54.65 million tons of milled dry grain (MDG), followed by 54.42 million tons in 2021 and 54.75 million tons in 2022. However, an estimated decrease to 53.63 million tons in 2023 occurred (Maman *et al*., 2021). This fluctuation indicates rice production is vulnerable and unstable. At the same time, household food expense remains high, accounting for 49.22% of per capita spending, with 11.07% specifically allocated to grains. These facts highlight the urgent need to enhance rice productivity and sustainability, particularly through improved water management practices.

Meeting the increasing demand for rice as a staple meal requires improving agronomic practices in rice farming. Crop yield forecasting is crucial to ensuring sufficient supply and identifying the best planting techniques because the demand for rice rises yearly. In getting the desired yield potential in rice genotypes, information on the amount of land for farming, the number of seeds for sowing, and the type of fertilizer for application is crucial (Herwanto *et al*., 2019). In general, rice cultivation seeks to obtain the optimal production with good quality by optimizing and utilizing available resources efficiently. Intensification methods, such as system of rice intensification (SRI), which emphasizes plant spacing and soil aeration; Hazton—a method involving dense seedling planting using older seedlings—and Jajar Legowo, can be beneficial to increase rice productivity and several other comparative advantages (Makmur *et al*., 2020). The following study aimed to evaluate the growth and productivity of various rice (*O. sativa* L.) varieties under different irrigation water management systems.

MATERIALS AND METHODS

Experimental location and design

This study commenced from May to September 2024 on irrigated rice fields in Maradekaya Village, Bajeng Subdistrict, Gowa Regency, South Sulawesi, Indonesia. A split-plot design with two factors and three replications was the layout used for the presented investigations. The first factor (main plots) was the combination of irrigation water management systems. These are intermittent irrigation systems in the vegetative growth phase + discontinuous irrigation systems in the generative phase (a1) and intermittent irrigation systems in the vegetative growth phase + alternate wetting and drying (AWD) in the generative phase (a2). The second factor (subplots) was the six rice cultivars: v1 = M70D, v2 = Inpari-19, v3 = Cakrabuana, v4 = Inpari-32, v5 = Inpari-13, and v6 = Padjajaran. Creating 36 experimental plots comprised of a total of 12 treatment combinations with three replications.

Research implementation

During the planting process, soil sampling evaluated alterations in the soil's physical, chemical, and biological characteristics. Seed selection, as carried out, chose high-quality seeds from each of the six rice cultivars used in this study. Seed selection considered their physical characteristics, such as size, weight, and integrity, to ensure they had the potential to express their full genotypic performance. The selected seeds underwent soaking in water for 24 h, then drying through aeration for another 24 h, with the soaking and drying process repeated once more.

Before sowing the seeds, carrying out tillage used a tractor with a plow component as the first tillage. After two weeks, conducting tillage continued for the second stage, namely, rotary tilling, then combing and leveling. In the next stage, the paddy field cleaning comprised removing dried straw residues and grasses that remained on the surface after plowing to prepare the soil for further cultivation. Afterward, making 36 experimental plots with a size of 4 m × 3 m proceeded, and the total area was 432 m^2. The last stage was the basic fertilization using 0.6 kg compost/plot. Before sowing, the seeds underwent soaking again to enhance germination. Then, the soaked seeds entailed scattering on the prepared seedbed, allowing seedlings to grow for approximately 17 days until they developed 2-3 leaves, at which point they were ready for transplanting.

Transplantation

The movement of rice seedlings to the area that had been given a path following the designated planting distance proceeded once the seedlings were 17 days old. The seedlings entailed planting with two stems per planting hole and with roots arranged in an L shape. The soil first received wetting and leveling to guarantee even water distribution throughout plots before the implementation of any irrigation treatments. As transplanting happened on the land, it remained damp but not inundated. The Legowo 2:1 was the planting technique used—a method in which every two rows of rice have a space or “row gap” to allow better sunlight penetration and air circulation, as well as facilitate plant maintenance. The planting spacing was 40 cm (between double rows) × 20 cm (between rows within the double row) × 10 cm (between planting holes in a row).

Water management combinations

Three types of irrigation became operational. The first irrigation is the intermittent system, which keeps the soil moist but not flooded, given in the vegetative phase (age 17–45 days after planting [DAP]) at intervals of every three days using a water level of approximately 3 cm. The second irrigation is the discontinuous irrigation system given in the generative phase (46–75 DAP), carried out by shallow inundation at a height of 2–3 cm for two days, interspersed with a dry period of two days. The third irrigation uses the AWD system, where water reapplication occurs if the water level in the PVC observation pipe (3 cm diameter, 30 cm height) falls below 15 cm. The irrigation volume for each application was 2.5 cm, with an estimated pipe capacity of about 1.36 liters. Applying this system also transpired during the generative phase.

Maintenance

Maintenance during the study included irrigation management in accordance with the treatment, replanting, control of plant pest organisms, fertilization, and monitoring soil conditions. Fertilization succeeded three times during the plant growth period. The first fertilization took place at 10 DAP using 100 kg/ha of urea, 100 kg/ha of NPK, and 25 kg/ha of MKP. The second fertilization ensued at 40 DAP with a dose of urea (75 kg/ha) and KNO_3 (50 kg/ha), while the third fertilization occurred at 55 DAP with urea (50 kg/ha) and KNO_3 (50 kg/ha). Before planting, the treatment of 0.6 kg of granular compost per experimental plot served as base fertilizer. Pest control succeeded preventively and curatively by spraying pesticides made from abamectin

18 EC and deltamethrin 25 EC, according to the recommended dose, aimed at overcoming major pests such as stem borers and leafhoppers. Control measures proceeded based on observations of pest attack intensity in the field.

Harvest and post-harvest

Harvesting continued when 2/3 of the panicles with grain indicators had turned yellow and physiologically ripe, and with the age adjusted based on the cultivar description. Completion of harvesting used a sickle; threshing engaged a power thresher. Harvesting proceeded at 24%–25% seed moisture content, which was the harvested dry grain. Meanwhile, post-harvest activities included drying the harvested grain until its moisture content reached 12%–14%, which was the milled dry grain.

Observation parameters

The observations in this experiment included several important parameters. Plant height measurement occurred at 60 DAP, with the number of total and productive tillers per plant counted at harvest time. Flowering age and harvesting age calculations began from the date of transplanting. Attaining panicle length and the number of total and full grains per panicle entailed counting at harvest, including the percentage of full grains. Calculating milled dry grain yield per hectare was at 12%–14% moisture content. In addition, leaf chlorophyll content observation was at the age of 50 DAP using CCM 200 (chlorophyll content meter), with the leaf area measured with the Petiole software (petiole mobile application) and stomatal density calculated using a microscope from samples taken with the cuticle-cellulose acetate method.

Statistical analysis

Performing analysis of variance (ANOVA) analyzed the data for all the studied parameters using the software, whether R or SPSS. The significant mean differences underwent further comparison and separation using the least significant difference ($LSD_{0.05}$) test.

RESULTS AND DISCUSSION

The examined soil samples ascertained the NPK content and the amount of fertilizer dosage on rice cultivars' growth and productivity. The study's dosages (300 NPK kg/ha and 100 urea kg/ha) showed that rice plants could benefit from the synergistic effects of both NPK and urea fertilizers. According to a past study by Barat (2019), the application of 300 kg/ha of NPK fertilizer and 100 kg/ha of urea resulted in more panicles per clump and more full grains compared with the NPK fertilizer application alone. The maximum phosphorus (P_2O_5) content appeared to be 12.51 ppm, as per the soil samples studied. The soil phosphorus is essential for the development and productivity of rice plants. Mansyur *et al*. (2021) also explained that the P_2O_5 level of 12.51 ppm falls into the low to medium range and can have an impact on the rice's growth-related traits.

Improved grain production and the possibility of repeated harvests per year are two agronomic benefits of early-maturing rice cultivars. Farmers can leave and prepare the land early, ready for the following cropping cycle, because of their shorter growth period. However, this flexibility also greatly incurs effects from selected planting techniques and—above all—by irrigation water management, which is essential for maximizing rice plant growth, development, and output. Rismawati *et al*. (2022) also mentioned early-maturing rice cultivars can benefit in many ways, including reducing the risk of environmental factors (pests, diseases, and drought), saving management costs, and enhancing flexibility in managing the next planting strategy. The rice plants' growth and development and production gain significant influences from irrigation water management strategies aside from their types. In paddy fields, intermittent water management is a technique that alternates water application during dry and flooded periods. The strategy seeks to reduce the adverse effects of ongoing flooding and increase water use efficiency. Muhammad (2023) reported that intermittent irrigation in rice plants has numerous advantages, including lowering the amount of water required for irrigation and enabling a greater area for irrigation with the same quantity of water.

Numerous characteristics, such as the total number of tillers and the productive tillers, appeared to interact, as expected (Table 1). The results revealed the rice cultivar M70D in interaction with the intermittent irrigation + discontinuous irrigation water management system showed the most tillers (22.49 stems). Ruminta *et al*. (2017) also mentioned waterlogging, either constant or discontinuous irrigation, during the vegetative phase of rice plants (with 3 to 5 cm plant height), and the early growth phase of rice plants could result in an increase in the tiller number. The intermittent irrigation was notable with the maximum number of tillers, which showed more productive tillers, which also raised the dry grain weight in rice (Wanda *et al*., 2023). A tendency appears for the rice grain's quantity and dry weight to rise parallel to the boost in productive tillers.

The cultivar Padjajaran with the intermittent irrigation + discontinuous irrigation water management system had the most prolific tillers (17.60 stems) (Table 1). Results have demonstrated the cultivar Padjadjaran produces more productive tillers than other genotypes. This cultivar produced more productive tillers, which have a direct relation to a higher rice yield potential. Furthermore, this cultivar performed better for the quantity of complete grains per panicle, which eventually raised the grain yield. According to Hamdani and Haryati (2021), the number of tillers and adaptability of rice cultivars vary depending on the genotype-environment interactions. The productive tillers acquire significant effects from the genetic makeup of genotypes and the intermittent irrigation + discontinuous irrigation water management technique. Idrus (2021) explained that a longer drying period for the rice plants may produce the highest number of tillers with intermittent irrigation treatment. This is because of keeping the rice plants stimulated to produce new tillers each time, as and when the drying period is over.

The research's findings further revealed the rice cultivars gained considerable changes from water management systems, which showed varied values for the traits of harvesting age, grains per panicle, whole grains per panicle, and milled dry grain. On the harvesting age parameter, the cultivar M70D produced the earliest average harvesting age (73.83 days) (Table 2). With several other benefits, cultivar M70D achieved the category of early-maturing rice genotype, reaching maturity within 70 and 90 DAP. Short planting seasons allow farmers to plant and harvest more crops frequently in a single year, which potentially increases their total production. Dhenanta and Kholifah (2022) also reported the rice cultivar M70D attained maturity, resulting in harvest in 70 days. The aforementioned cultivar was both short-lived and robust to environmental variables and pest attacks, exhibiting the best grain yield and yet avoiding collapse.

The cultivar M70D recorded the maximum average number of grains per panicle (124.67 grains) (Table 3). Rice cultivar M70D is typically a superior rice cultivar with a shorter harvest period than other rice cultivars. Several past studies on rice cultivars can give an idea about the potential of the cultivar M70D in this regard. The grains per panicle incurred influences from various factors, including rice cultivars, cultivation techniques, fertilization, and existing environmental conditions. Panicle length also directly affects the number of grains per panicle and has the potential to increase seed size as long as no limiting factors appear during the seed-filling process. Palobo *et al*. (2019) stated rice cultivars with longer panicles typically have more grains per panicle. For instance, the cultivar M70D contains a substantial number of grains per panicle, which can influence the number of grains per panicle and an average panicle length of 22.40 cm.

For the number of full grains per panicle, the cultivar M70D produced the highest average number of full grains per panicle (108.67 grains) (Table 3). The rice cultivar M70D is well-known for its short

Table 1. Rice cultivars with average number and productive tillers per plant under different water management systems.

Irrigation water	Average number of tillers						
	Cultivars						NP LSD (a)
	V1	V2	V3	V4	V5	V6	
a1	22.49	18.22	19.89	19.53	19.4	20.63	
a2	17.87	18.56	14.58	20.13	19.53	17.40	4.05
$LSD_{0.05}$ (v)	3.00						
	Productive tillers per plant						
	V1	V2	V3	V4	V5	V6	
a1	16.60	14.92	15.67	16.93	15.73	17.60	
a2	14.49	16.06	10.99	16.33	16.18	15.27	2.91
$LSD_{0.05}$ (v)	2.27						

Note: numbers followed by the same letter mean that they are not significantly different in the follow-up test at the 95% confidence level.

Table 2. Rice cultivars with average harvesting age and average milled dry grain under different water management systems.

Irrigation water	Average harvesting age					
	Cultivars					
	V1	V2	V3	V4	V5	V6
a1	74.00	84.00	82.33	103.33	90.33	92.67
a2	73.63	83.33	81.67	102.33	89.33	92.00
Means	73.83	83.67	82.00	102.83	89.83	92.33
$LSD_{0.05}$ (v)	1.09					
	Average milled dry grain					
	V1	V2	V3	V4	V5	V6
a1	6.78	7.42	7.11	7.37	7.49	7.48
a2	6.34	7.84	7.54	8.27	7.31	8.30
Means	6.56q	7.63p	7.32p	7.82p	7.40p	7.89p
$LSD_{0.05}$ (v)	0.69					

Note: numbers followed by the same letter mean that they are not significantly different in the follow-up test at the 95% confidence level.

Table 3. Rice cultivars with average grains per panicle and full grains per panicle under different water management systems.

Irrigation water	Grains per panicle					
	Cultivars					
	V1	V2	V3	V4	V5	V6
a1	126.33	109.00	96.00	109.67	118.67	98.00
a2	123.00	124.00	111.00	113.33	111.67	111.33
Means	124.67p	116.50pq	103.50s	111.50pqrs	115.17pqr	104.67qrs
$LSD_{0.05}$ (v)	12.51					
	Full grains per panicle					
	V1	V2	V3	V4	V5	V6
a1	110.67	96.33	87.33	99.67	101.00	87.33
a2	106.67	108.00	97.00	99.00	97.67	93.33
Means	108.67p	102.17pq	92.17qr	99.33pqr	99.33pqr	90.33r
$LSD_{0.05}$ (v)	10.37					

Note: numbers followed by the same letter mean that they are not significantly different in the follow-up test at the 95% confidence level.

Table 4. Rice cultivars with average panicle length under different water management systems.

Irrigation water	Cultivars						Average
	V1	V2	V3	V4	V5	V6	
a1	21.24	22.83	22.24	21.44	21.81	22.06	21.94b
a2	23.22	21.97	24.20	19.90	24.09	22.94	22.72
LSD (a)	0.43						

Note: numbers followed by the same letter mean that they are not significantly different in the follow-up test at the 95% confidence level.

planting period with the highest productivity potential. However, previous studies on this rice cultivar for the number of full grains per panicle showed varied results, depending on planting methods, fertilization, and environmental conditions. Khoizzah and Widodo (2024) also explained this rice cultivar has the potential to produce the most number of full grains per panicle if given the right dose of fertilizer and managed with the proper irrigation water to avoid drought stress. Proper cultivation practices can further increase its productivity with improved grain quality.

For milled dry grain, the water management system remarkably altered the rice genotype and showed varied values. The rice cultivar Padjajaran was evident with an average milled dry grain of 7.89 t/ha (Table 2). This cultivar has the highest yield potential and can reach up to 11 t/ha under ideal field conditions, and it can better provide significant economic benefits to the farming community. In addition, the cultivar Padjajaran is popular for its resistance to several pests, i.e., brown planthopper biotypes 1 and 2. According to Pawan *et al*. (2020), rice cultivar Padjajaran, developed in 2018, gave an average production of 7.8 t/ha and a potential productivity of 11 t/ha. This rice cultivar is the greatest and leading production genotype developed in Indonesia to date.

The analysis revealed the considerable effect on rice by the water management system intermittent irrigation + AWD treatment, which showed varied values for panicle length, with the maximum average panicle length of 22.72 cm (Table 4). The alternate wetting and drying (AWD) water management system affected various aspects of rice plant growth, including panicle length. Although the AWD system is efficient in saving water significantly, its impact on panicle length can vary, depending on specific conditions, such as rice cultivar and its application duration. In line with Yassi *et al*. (2021), the presented study observed no significant differences in panicle length and overall rice growth between the AWD and flooded irrigation systems. The latest study stated the differences in the growth and production of rice plants, including panicle length, providing unnoticeable results between the use of AWD and flooded irrigation.

The rice cultivars and water management systems displayed nonsignificant differences for plant height and the flowering age (Figure 1). However, by observing the data in Figure 1, the intermittent irrigation + AWD water management system with rice cultivar Inpari-32 provided the tallest plant height compared with other treatment combinations. The water management system of intermittent irrigation + discontinuous irrigation using cultivar Inpari-32 gave the best effect on flowering age versus other rice cultivars. According to this study, the cultivars played an important role in supporting IP-300 (cropping intensity of 300%) in rice commodities because plant age and productivity had the cultivar determining them. These results were consistent with the views of Bahri and Radian (2021), who explained that the environmentally adaptable cultivars can result in superior growth, including flowering age, plant height, the number of tillers, and better grain yield.

The interactions of rice cultivars and water management systems showed nonsignificant effects on the chlorophyll a, b, and total chlorophyll contents (Figures 1 and

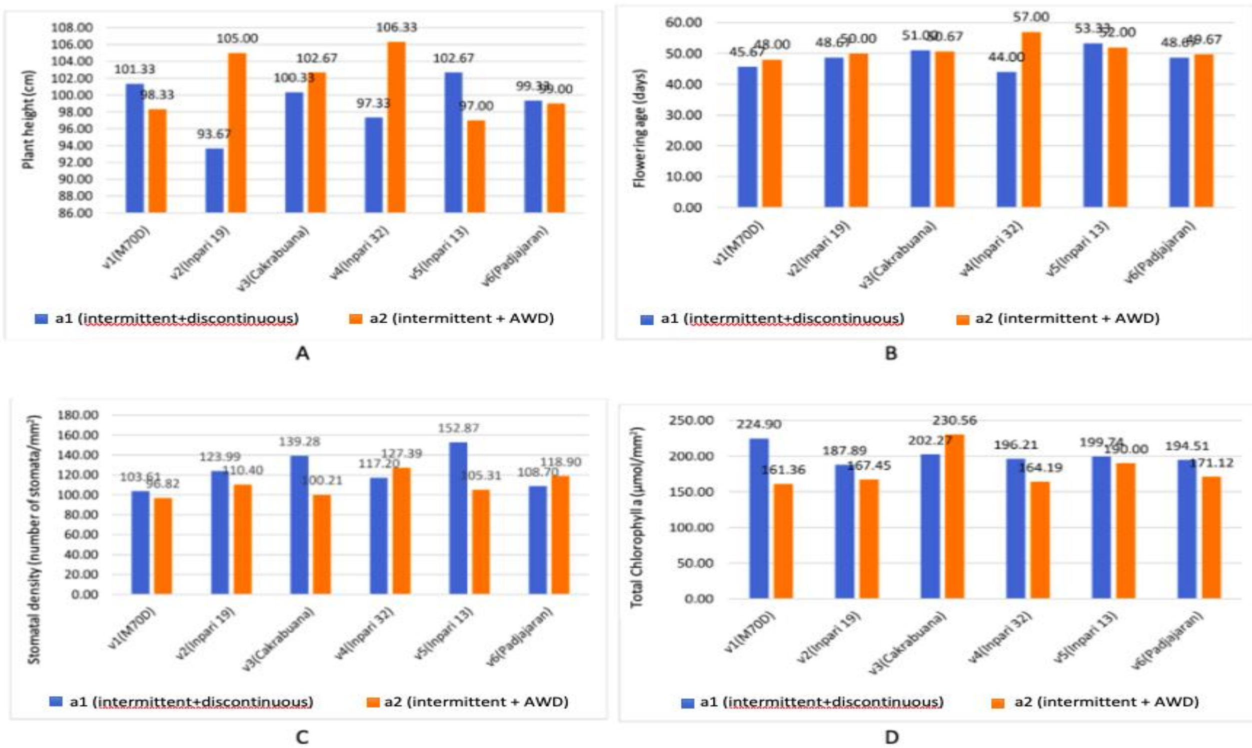

Figure 1. a) Average plant height at the age of 60 DAP, b) Average flowering age, c) Average stomatal density at 50 DAP, and d) Average chlorophyll a index at the age of 50 DAP, in various rice cultivars under different water management systems.

2). However, in the resulting graphs, the cultivar Cakrabuana, using intermittent irrigation + the AWD water management system, provided the best results and influence on the contents of chlorophyll a, b, and total chlorophyll. According to Yassi *et al*. (2021), intermittent irrigation emerged as the recommended irrigation system in rice cultivation. The AWD irrigation system reduced water use and can lead to less water-saturated soil conditions. Rice plants exposed to occasional dry conditions can experience mild stress that has the potential to affect chlorophyll production caused by the possibility of disruption in photosynthesis.

For stomatal density and leaf area, the rice cultivars and water management systems showed nonsignificant effects (Figures 1, 2). However, it can be evident in the resulting graph that the cultivar Inpari-13 with the water management system intermittent irrigation + discontinuous irrigation expressed the best effects on stomatal density compared with other treatments. The same rice cultivar with the intermittent irrigation + the AWD water management system also provided the best outcomes on leaf area as compared with other treatment combinations. Syarifah *et al*. (2021) claimed that hybrid rice has thick cuticles and narrow leaf growth, including the quantity of stomata on the epidermis and the capacity to rapidly close stomata in various physiological processes.

The different rice cultivars and water management systems showed nonsignificant changes in the full grains per panicle (Figure 2). However, the resulting graph revealed the rice cultivar Cakrabuana with the water management system of intermittent irrigation + discontinuous irrigation gave the best outcomes on the percentage of full grains per panicle (91.46%) versus other treatment combinations. Several studies had shown that intermittent irrigation systems can affect the

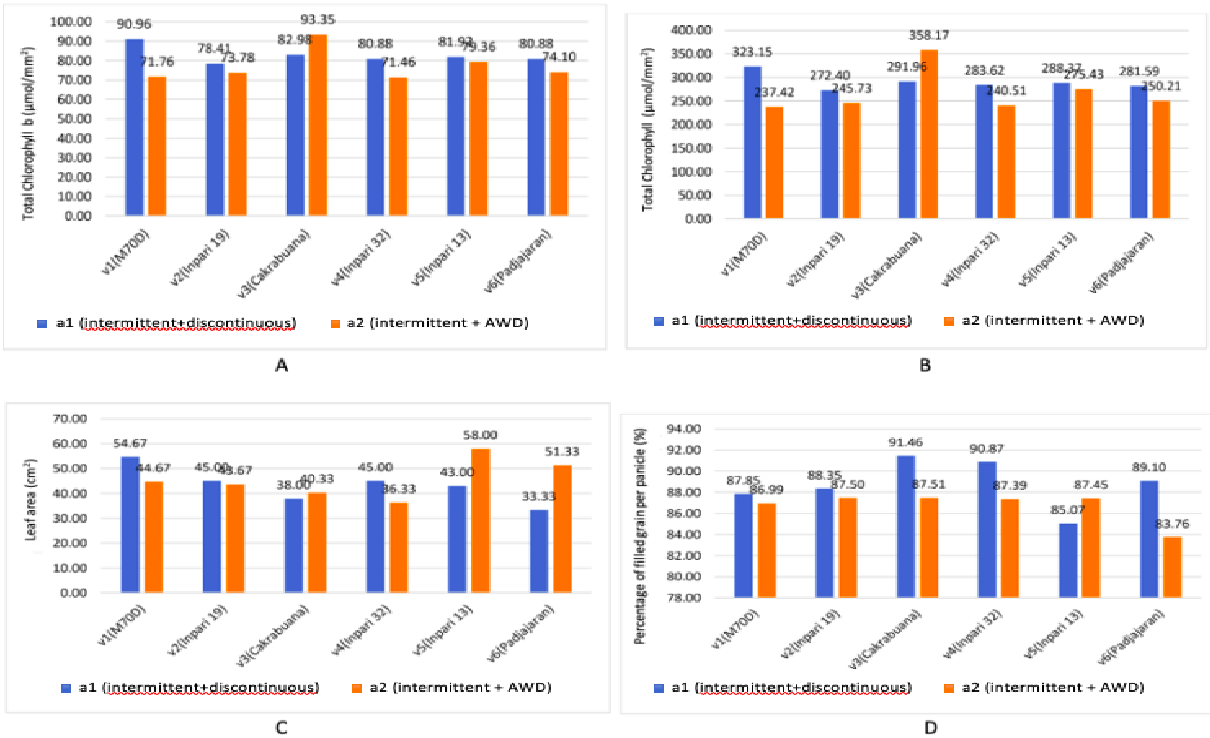

Figure 2. a) Average chlorophyll b index at the age of 50 DAP, b) Average total chlorophyll index at the age of 50 DAP, c) Average leaf area at the age of 60 DAP, and d) Average percentage of filled grain per panicle, in various rice cultivars under different water management systems.

rice plant growth and grain quality. Past studies enunciated the intermittent irrigation system yielded the maximum grains per panicle and the highest percentage of the full grains per panicle in rice (Tamelan *et al.*, 2020). The percentage of hulls per panicle, as influenced by cultivars in addition to water management systems, had among them the cultivar Cakrabuana with the greatest percentage of full grains per panicle. Waluyo and Suparwoto (2023) reported the rice cultivar Cakrabuana exhibited better potential in increasing the number of full grains per panicle and, eventually, the increased grain yield.

CONCLUSIONS

The rice cultivar M70D showed the best performance for the number of tillers, harvest age, and the number of grains per panicle and their quality. The quality traits included a greater proportion of filled grains and a lower percentage of empty grains. The irrigation water management system of intermittent irrigation + discontinuous irrigation also gave superior results for several traits, including the total number of tillers, productive tillers, flowering age, and grain weight. The combination of rice cultivar M70D with the water management systems produced the highest number of tillers, while the cultivar Padjajaran produced the most productive tillers.

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