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RESEARCH ARTICLE

Impact of different water management and microbe application on yield of rice cultivars under seawater intrusion areas of Indonesia

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ABSTRACT

Primary risk to rice (*Oryza sativa* L.) production is salinity intrusion and water scarcity, leading to a shortage of irrigation water and yield reduction. We examine the impact's effects of alternate wetting and drying (AWD) *vs*. continuous flooding (CF) and microbe application on yields of three rice cultivars (Ciherang, Inpari 34 Salin Agritan, Inpari 35 Salin Agritan) grown under slight and moderate soil salinity in the dry season (DS) 2017 and 2018. Under slight soil salinity, AWD and CF had nonsignificant difference in grain yield. Under a moderate soil salinity level, there was a substantial decrease in grain yield (8.2%), number of productive tillers, seeds panicle^{-1}, and weight of 1000 grains with the plants grown under AWD. Increased soil salinity levels resulted in lower yield reduction with microbial than without microbial treatments. 'Ciherang' showed superiority over 'Inpari 34' and 'Inpari 35' under AWD at slight soil salinity. However, the yield reduction in the moderate salinity level was more remarkable for 'Ciherang' (18.1%) than 'Inpari 34' and 'Inpari 35' (9.7%) as salinity-tolerant varieties. The AWD used almost one-third less irrigation supplement than CF. This greatly assists small farmers in reducing the additional cost of pumping water. On average, AWD improved total water productivity by 32.7% under slight and 20.4% under moderate soil salinity over CF. Here, we lay out the potential for small farmers in slight salinity lowlands areas of the northern coast of Java to apply AWD during the DS. Farmers could manage water efficiently to prevent further yield loss and improve farm profitably.

Key words: Crop yield, plant-growth-promoting bacteria, soil salinity, tolerant rice cultivar, water deficit.

INTRODUCTION

Global changes such as population growth, uncontrolled urbanization, and extreme climatic conditions such as frequent floods and droughts have all contributed to salinity intrusion and water deficit, resulting in a lack of irrigation water and yield decline. The northern coast of Java is one of Indonesia's most important rice-growing areas, and it is critical for food security. The coastal areas of Java are home to over two million people. According to the index of coastline utilization degree, Java's coastal areas are vulnerable to climate change due to ocean surface rise and increased salinity intrusion (Sui et al., 2020). The impact of sea water intrusion entry to the land will be felt during the dry season (DS) affected more than half a million hectares of rice fields (Tivianton et al., 2021). As a result, rice yield during the DS is 11% or around 0.65 t ha^{-1} below the wet season (WS) (CBS, 2021), which is a pivotal issue for Indonesian food security.

While water discharge on the mainland began to decrease, seawater eventually infiltrated through canals, streams, and swamps. This has an impact on paddy fields along the coast because seawater intrusion will contaminate them (Li et al., 2018). Depending on rainfall size, this interface can be jutting into the sea and indented towards the land (Gopalakrishnan et al., 2019). Excessive groundwater uses while limited rainfall causes the interface to rise upwards. Due to decreased inland water discharge during such periods, seawater infiltrates through the canals (Xin et al., 2022). Under this condition, salinity becomes a significant crop yield constraint. This condition will be more critical during the DS when the water supply reduces.

The results of research in overcoming soil salinity have been implemented, such as using tolerant varieties, planting date adjustments, and different water management approaches (Hairmansis et al., 2017). According to Lampayan et al. (2015), alternate wetting and drying (AWD) is one method for reducing total irrigation water use, particularly during DS. The AWD technology has alternately flooded the soil and permitted it to dry. Compared with continuous flooding (CF) conditions, crops established under AWD reported having higher water use efficiency, better root architecture and biology, and higher harvest index (Hussain et al., 2021). The AWD is a viable irrigation technique to help farmers overcome water scarcity (Nhung et al., 2019). Moreover, AWD's greenhouse gas emissions were significantly lower than CF's (Leon et al., 2021). The AWD can increase yield compared to CF under favorable irrigated rice. However, the potency of AWD in unfavorable salt-affected soils in Indonesia has yet to be assessed.

The increased Na concentration in the soil can limit microbe bioavailability, which is essential in nutrient cycling (Kumar et al., 2020). The enzyme 1-aminocyclopropane-1-carboxylate (ACC) deaminase cleaves ACC to α-ketobutyrate and ammonia, which can be expressed by plant growth-promoting bacteria (PGPB) rhizosphere microorganisms, lowering ethylene amounts in plants and promoting plant growth (Singh et al., 2022). Rhizosphere microbial endophytes with ACC deaminase-containing PGPB promote rice growth in salinity-prone soils.

Salinity-tolerant rice cvs. Inpari 34 and Inpari 35, launched in 2014, are more tolerant to salinity stress than the popular rice 'Ciherang' and thus have great potential (Hairmansis et al., 2017; Rumanti et al., 2018). Therefore, we hypothesize that used of salinity tolerant rice cultivars with microbe application under AWD will increase crop yield and water productivity compared to CF. This study aimed to investigate AWD technique in combination with microbe application on yields of three rice cultivars (Ciherang, Inpari 34, Inpari 35) grown during the DS under seawater intrusion areas of the northern coast of Java, Indonesia. In areas where water is already scarce during DS, farmers must be equipped with technologies to grow rice with less water because there is not enough water to grow rice conventionally.

MATERIALS AND METHODS

Description of study area

The study was carried out at Karawang District, North Coast of Java (6°20'7.88" S, 107°, 5'9.37" E; 2.86 m a.s.l.), Karawang District, West Java Province, Indonesia, it has 1143 mm average annual rainfall from 2017-2018, with a dry period between June and October. The average potential evapotranspiration (PET) is 1793 mm in a year (Figure 1). The annual rainfall is lower than the yearly PET. The area needs additional irrigation water from the Jatiluhur dam, which has functions for electricity generation besides providing irrigation water. The research area is tail irrigation far from the source of irrigation water, which often becomes inundated during heavy rains in the wet season (WS) and becomes dry at the end of the WS to the dry season (DS). Hence, rice (*Oryza sativa* L.) cultivation during DS highly depends on rainfall and supplementary irrigation.

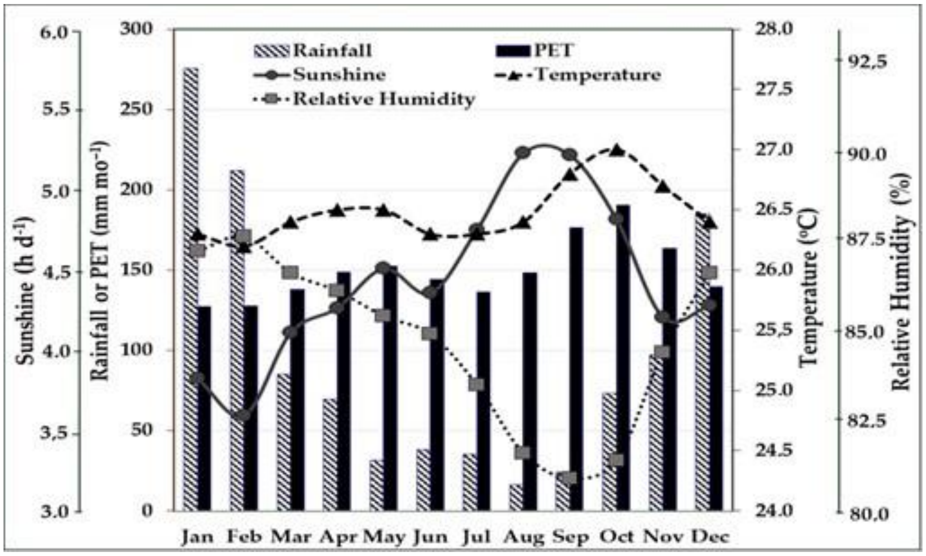

Figure 1. Sunshine, rainfall, and potential evapotranspiration (PET), (left axis), temperature and relative humidity (right axis) during the crop cycle in the study site.

Soil sampling and analysis

We did a visual crop observation to observe the rate of crop damage due to salinity during the generative stage. Samples were collected from two farmers' fields at the beginning of DS to represent low and moderate soil salinity levels. Surface soils (0-20 cm) were sampled using a drill in a zigzag manner and then pooled to form a composite sample.

Conventionally, plant sensitivity to saline conditions has been measured in terms of the electrical conductivity of a saturated soil extract (ECe) than electrical conductivity (EC), and calculated using the formula:

$$ECe = \{14 - (0.13 \times \%\ clay)\} \times EC\ 1{:}5\ (Rengasamy, 2010)$$

The ECe level for salinity soil were 3.13 and 7.09 dS m^{-1} (Table 1), with slight salinity (2-4 dS m^{-1}) affecting the production of sensitive plants and substantially saline (4-8 dS m^{-1}) means yields of susceptible crops are affected, and moderately saline (4-8 dS m^{-1}) means yields of many crops are affected, respectively (Miller and Curtin, 2006).

Field experiments

The field study was set up in separate farm owners' fields, one with slight salinity circumstances and the second with moderately salinity levels (Table 1). A combination of the three factors was arranged under a split-split plot design in each farmer's field during the DS. In each replicate, two irrigation water management methods, alternate wetting and drying (AWD) and continuous flooding (CF) were assigned to the main plots. Two levels of microbial application, addition of microbes and without microbes, were randomized as a subplot treatment in each main plot. Three rice (*Oryza sativa* L.) cvs. Inpari 34 Salin Agritan, Inpari 35 Salin Agritan, and Ciherang, were randomly allocated to three replicates at a sub-sub-plot (Gomez and Gomez, 2004). Each experiment was conducted under slightly and moderate saline conditions during the DS in 2017 and 2018. The same field sites and treatments use each year.

Table 1. Chemical characteristics of experimental soil at two different locations. EC: Electrical conductivity; ECe: electrical conductivity of a saturated soil extract; CEC: cation exchange capacity; ESP: exchangeable sodium percentage.

Property	Site	
	Slightly saline	Moderately saline
Soil texture	Clay	Clay
Organic matter, g kg^{-1}	2.07	1.80
Total-N, %	0.21	0.23
C/N ratio	10.00	8.00
P total, %	0.07	0.04
K total, %	0.41	0.51
EC and pH:		
$EC_{1:5}$ (soil:water ratio 1:5), dS m^{-1}	0.76	1.90
ECe [saturation paste extract), dS m^{-1}	3.13	7.09
pH (Soil suspension 1:5)	5.80	6.10
Exchangeable cations, CEC and ESP		
Ca^{2+}, cmol kg^{-1}	11.03	10.68
Mg^{2+}, cmol kg^{-1}	17.58	19.99
Na^{+}, cmol kg^{-1}	12.35	21.17
K^{+}, cmol kg^{-1}	1.62	2.34
CEC, cmol kg^{-1}	29.54	37.32
ESP, %	41.81	56.73

The first main plot has been intended for interrupted watering (4 cm water depth) to AWD periods at 7 d intervals. Another one, on the other hand, was outfitted with systems for continuous irrigation (to a depth of 4 cm) during the rice-growing cycle. The irrigation water input to each plot was measured using a ultrasonic liquid flow meter (DN25 mm-DN100 mm, TS-2 module, type clamp-on, digital module, Shenzhen Aermanda Technology, Shenzhen, China) inserted in the watering pipelines. For AWD, water irrigates from the nearby canal by pumping if the water level in the plots is 10 cm below the soil surface. In the AWD plots, we installed a water tube measuring device in the form of a PVC tube with a diameter of 15 cm × 25 cm high to a deepness of 15 cm in the field around 2 wk after transplanting. The buried parts of these tubes were holed by 0.5 cm diameter with a distance of 5 cm from each other, allowing water to percolate whenever field water increased or decreased. There are 1 m canals placed between the water treatments for the two main water management plots (with and without standing water). Dikes were constructed between each plot, while dug canals for irrigation and drainage were around the experimental field. The bunds, 30 cm in height and 50 cm in width, were built around each main plot. We irrigated AWD plots along with CF following plant growth up to 14 d after transplanting (DAT). The CF plot was kept in a stagnant condition (4 cm water depth) while the water was held in the AWD plot (beginning the first cycle of AWD). If the water depth in the AWD plots decreased to about 10 cm from the bottom, the AWD plots started to be reirrigated again. The AWD plots went through four cycles of soil drying. At 43 to 45 DAT, when the rice crops initiated flowering, the AWD plots flooded similarly to the CF plots during the flowering stage. At 60 DAT, the AWD plot again passes completed two more cycles. Shortly ahead of physiological maturation, entire fields were drained until harvest.

Rhizospheric plant growth-promoting bacteria (PGPB) were obtained from the Indonesian Soil Research Institute-Bogor for microbe treatments. Bacterial strains from the genera *Pseudomonas* and *Bacillus* were screened from the paddy soil of rice plants growing along the agricultural areas of the north coast of Java. The selected strains produced the enzyme 1-aminocyclopropane-1-carboxylate (ACC) deaminase (E.C.4.1.99.4) as indicated by low ethylene content in rice seedlings grown at high salinity (Husen and Salma, 2012; Husen et al., 2021). Rhizosphere PGPB were inoculated by combining germinated seeds and microbial cultures in peat-based carrier media and air-dried under shade before planting in nursery beds.

This study used rice 'Inpari-34 Salin Agritan', 'Inpari-35 Salin Agritan', and 'Ciherang'. 'Ciherang' is a popular rice used by farmers, while 'Inpari-34 Salin Agritan' and 'Inpari-35 Salin Agritan', according to the description, are saline soil-tolerant cultivars (Hairmansis et al., 2017; Farid et al., 2021). The rice seeds were soaked in a container filled with clean water, and float seeds were discarded. After incubation for 2 d, the pre-germinated seeds of each cultivar were mixed with and without microbial culture and spread evenly in the nursery. Seedlings aged 21 d were planted with a spacing of 20 cm × 20 cm, three seedlings hill^{-1} in a plot size of 5 m × 6 m. The rice plants were fertilized with 125 kg N ha^{-1}, 45 kg P_2O_5 ha^{-1}, and 45 kg K_2O ha^{-1}. Urea and NPK compound fertilizers were used as N, P, and K sources. All NPK and one-third of urea were broadcast 7 DAT. The remaining N doses were applied separately during active tillering and panicle initiation. Plots were kept weed-free by manual weeding.

Parameters observed

Plant biomass was obtained by collecting a 0.4 m^2 sub-sample approximately 1 wk before harvest and drying it at 60 °C into stable weight. The yield components analyzed were the number of panicles hill^{-1}, number of seeds per panicle, filled and empty grains (%), and weight of 1000 grains. The yield of the 9 m^2 sampling area was manually harvested. Grain yield (t ha^{-1}) was calculated at 14% moisture content. Reduction in yield was the difference between grain yield at slight soil salinity and grain yield at moderate soil salinity.

The amount of rainfall and irrigated supplements applied to the plots throughout the growing period was calculated by summing the amounts required to keep adequate water levels in the main plots during each inundation. The percentage of water saving was estimated using the following equation:

$$\text{Water saving (\%)} = \frac{\text{Water used in flooded plot} - \text{Water used in AWD plot}}{\text{Water used in flooded plot}} \times 100$$

Water productivity was calculated as plant yield per unit of water consumed, and total water productivity was computed using the equation (Liang et al., 2016):

$$\text{Total water productivity (TWP)} = \text{Y/TWU}$$

where Y is grain yield (kg ha^{-1}) and TWU is total water used (m^3 ha^{-1}).

Data analysis

The study was conducted over 2 yr. Data for each variable underwent ANOVA and were statistically analyzed using the statistical package of CropStat version 7.2.3 (International Rice Research Institute (IRRI), Los Baños, Laguna, Philippines). Means were separated by the LSD test ($P \leq 0.05$) when the F value was significant. Each experiment was conducted under slight and moderate saline conditions during the DS in 2017 and 2018. We analyzed the sites and the years as four separate environments.

RESULTS

Grain yield

As shown in Table 2, water management, microbial application, and cultivar interactions did not significantly affect grain yield at either year's slight or moderate soil salinity. This study showed that AWD irrigation provides the same mean grain yield in both years compared to CF under a slight level of soil salinity as a single factor. Whereas, in moderate soil salinity, the use of the AWD technique significantly reduced grain yield (5.693 *vs*. 5.225 and 5.586 *vs*. 5.125 t ha^{-1}) or having on average 8.2% less grain yield than the plants grown under CF (Table 3). Increased soil salinity levels from slightly to moderate salinity resulted in almost double percentage yield reduction under AWD compared to CF (9.71% *vs*. 18.08%, Table 3).

Microbial treatment did not significantly influence the mean grain yield under slight and moderate salinity levels in both years. However, increased soil salinity levels from slightly to moderate salinity resulted in lower yield reduction with microbial than without microbial treatments (12.94 *vs*. 9.94%) (Table 3).

Table 2. ANOVA for each parameter observed at slight and moderate salinity levels, Karawang, dry season (DS) 2017 and 2018. *, **, ***Significant at $p \leq 0.05$, 0.01 and 0.001 probability levels, respectively. ^{ns}: Nonsignificant.

	Mean square					
Source of variance	Grain yield	Panicles per hill	Seeds per panicle	Empty grain	Weight of 1000 grains	Above-ground biomass
	t ha^{-1}	Nr hill^{-1}	Nr panicle^{-1}	%	g	g 0.4 m^{-2}
			DS 2017 – Slight level soil salinity			
Water management (A)	2.1855^{ns}	7.2003^{ns}	35.1254^{ns}	22.7211^{ns}	2.2902^{ns}	6.8034^{ns}
Microbe (B)	0.1946^{ns}	7.2953^{ns}	14.9769^{ns}	14.9511^{ns}	2.1122*	10.6124^{ns}
Interaction (A×B)	1.5500^{ns}	0.1736^{ns}	3.2520^{ns}	39.2711^{ns}	0.2880^{ns}	14.2003^{ns}
Cultivar (C)	33.7738***	12.6025*	25.7187***	14.5462***	31.5156***	20.3231***
Interaction (A×C)	3.8655^{ns}	1.7986^{ns}	1.1969^{ns}	5.6144^{ns}	1.7883^{ns}	12.4154^{ns}
Interaction (B×C)	1.3369^{ns}	2.1408^{ns}	23.3626^{ns}	13.8411^{ns}	0.1791^{ns}	32.7719^{ns}
Interaction (A×B×C)	0.2248^{ns}	3.3353^{ns}	50.0078^{ns}	41.3611^{ns}	0.0969^{ns}	68.6579^{ns}
CV, %	20.94	12.47	9.10	24.15	4.11	23.91
			DS 2017 – Moderate level soil salinity			
Water management (A)	13.3590*	1.6044^{ns}	86.0738*	10.4721^{ns}	12.0409*	1.7733^{ns}
Microbe (B)	0.1085^{ns}	0.3211^{ns}	73.0740^{ns}	6.4178^{ns}	0.1419^{ns}	1.8180^{ns}
Interaction (A×B)	0.0182^{ns}	0.0711^{ns}	15.3795^{ns}	1.2844^{ns}	1.5376^{ns}	4.0871^{ns}
Cultivar (C)	10.4786**	22.5969**	41.3935**	67.3156***	39.9872***	11.3747**
Interaction (A×C)	0.3285^{ns}	10.6053*	24.4322^{ns}	15.2053^{ns}	1.4762^{ns}	3.8881^{ns}
Interaction (B×C)	3.7804^{ns}	7.5786^{ns}	6.9327^{ns}	23.5336^{ns}	1.4636^{ns}	15.7364*
Interaction (A×B×C)	0.9992^{ns}	1.2369^{ns}	32.8263^{ns}	22.3886^{ns}	0.4788^{ns}	37.4178^{ns}
CV, %	14.27	8.32	9.32	40.52	6.35	22.95
			DS 2018 – Slight level soil salinity			
Water management (A)	1.7550^{ns}	8.7169*	79.5725*	41.8216^{ns}	2.2902^{ns}	2.0388^{ns}
Microbe (B)	1.8255^{ns}	2.0068^{ns}	21.4577^{ns}	11.8904^{ns}	2.7735*	77.8903^{ns}
Interaction (A×B)	1.3822^{ns}	0.2008^{ns}	2.9927^{ns}	40.8939^{ns}	0.2276^{ns}	16.4169^{ns}
Cultivar (C)	41.0884***	14.0894**	20.5514**	16.8206***	33.6920**	21.1699**
Interaction (A×C)	2.9451^{ns}	1.9978^{ns}	2.4732^{ns}	6.0985^{ns}	2.0054^{ns}	13.4572^{ns}
Interaction (B×C)	1.4852^{ns}	1.9890^{ns}	19.6823^{ns}	12.7845^{ns}	0.1988^{ns}	28.1295^{ns}
Interaction (A×B×C)	0.1877^{ns}	2.8827^{ns}	44.5905^{ns}	33.1284^{ns}	0.1142^{ns}	61.1276^{ns}
CV, %	18.55	14.26	11.89	21.85	8.37	20.04
			DS 2018 – Moderate level soil salinity			
Water management (A)	18.7778**	4.6944*	64.2669^{ns}	19.2284^{ns}	10.8571*	0.0025^{ns}
Microbe (B)	1.0000^{ns}	0.1344^{ns}	39.0063^{ns}	33.6111^{ns}	0.1387*	0.1469^{ns}
Interaction (A×B)	1.7778^{ns}	0.0100^{ns}	64.0247^{ns}	0.5111*	1.4980^{ns}	0.3803^{ns}
Cultivar (C)	4.0000*	6.4933*	20.5577^{ns}	24.0454*	9.0354^{ns}	1.2744**
Interaction (A×C)	2.7778^{ns}	0.1244^{ns}	54.0869^{ns}	13.0681^{ns}	1.2977^{ns}	0.0233^{ns}
Interaction (B×C)	1.3333^{ns}	2.0311^{ns}	17.8115^{ns}	31.1074**	1.3501^{ns}	0.3744^{ns}
Interaction (A×B×C)	0.7778^{ns}	1.1200^{ns}	12.2647^{ns}	21.3941^{ns}	0.4119^{ns}	0.1011^{ns}
CV, %	27.43	21.14	35.19	12.18	10.19	15.38

Table 3. Effect of water management, microbe application, and cultivar in saline soil on means of rice yield, Karawang, West Java, Indonesia, dry season (DS) 2017 and 2018. Within the same column means followed by different letters are significantly different at the 0.05 probability level. CF: Continuous flooding; AWD: alternate wetting and drying; SEM: standard error of the mean.

Treatments	2017, Yield Slightly saline	2017, Yield Moderately saline	Yield reduction		2018, Yield Slightly saline	2018, Yield Moderately saline	Yield reduction	
	$t\ ha^{-1}$	$t\ ha^{-1}$	$t\ ha^{-1}$	%	$t\ ha^{-1}$	$t\ ha^{-1}$	$t\ ha^{-1}$	%
Water management								
CF	6.305[a]	5.693[a]	0.612	9.71	6.014[a]	5.586[a]	0.428	7.12
AWD	6.378[a]	5.225[b]	1.153	18.08	6.082[a]	5.125[b]	0.957	15.73
SEM±	0.562	0.427			0.273	0.136		
Microbe application								
Without	6.332[a]	5.435[a]	0.897	14.17	6.061[a]	5.277[a]	0.784	12.94
With	6.351[a]	5.481[a]	0.870	13.70	6.035[a]	5.435[a]	0.600	9.94
SEM±	0.195	0.109			0.330	0.389		
Cultivar								
Ciherang	6.871[a]	5.534[a]	1.337	19.46	6.588[a]	5.490[a]	1.098	16.67
Inpari 34	5.988[b]	5.242[b]	0.746	12.46	5.698[b]	5.135[b]	0.563	9.88
Inpari 35	6.166[b]	5.598[a]	0.568	9.21	5.862[b]	5.442[a]	0.420	7.16
SEM±	0.165	0.264			0.351	0.164		

Varieties treatments have significantly affected grain yield under slight and moderate salinity levels in both years (Table 3). At slight soil salinity, 'Ciherang' showed superiority over the salinity-tolerant varieties. The average yield of 'Ciherang' was similar to that of 'Inpari 35 Salin Agritan' at moderate soil salinity but still considerably higher than 'Inpari 34 Salin Agritan'. In both years of this study, the average yield reduction at medium salinity compared to slight salinity was more pronounced for 'Ciherang' (16.67%) than average 'Inpari 34 Salin Agritan' and 'Inpari 35 Salin Agritan' (8.52%) as salinity tolerant cultivars.

Yield component and biomass

Water management, microbial application, and cultivar interactions did not significantly affect yield components and above-ground biomass under slightly and moderate levels of salinity in both years. Except the interactions Microbe × Cultivar for moderate salinity were above-ground biomass in 2017 and empty grain in 2018 the interactions were significant (Table 2). In DS 2017, under the slight soil salinity level, all yield components and above-ground biomass were not significantly different between water management treatments (Table 4). However, they tended to be higher under AWD than CF. During DS 2018, under AWD at the slight soil salinity level, the tiller number and seeds per panicle were more significant than CF. Number of tiller and seeds per panicle increased by 9.1% (20.92 *vs*. 19.17) and 6.3% (106.88 *vs*. 100.55), respectively, under AWD. There was nonsignificant change in the percentage of empty kernels and 1000-kernel weight among plants grown on AWD and CF in any year.

We found the opposite results in a moderate soil salinity condition, where the number of seeds per panicle in DS 2017, number of panicles per hill in DS 2018, and 1000 grains weight in any year were significantly lower under AWD than CF (Table 4). Compared to CF, the number of panicles per hill, seeds per panicle, and 1000 grains weight decreased by 12.5%, 9.8%, and 8.7%, respectively, under AWD plots.

Microbial treatments, except for 1000 grains weight, did not significantly affect all yield components and above-ground biomass in both years. Under slight and moderate levels of salinity, the weight of 1000 grains increased significantly with the application of microbial (Table 5). On average, in both years, with rhizospheric PGPB, the weight of 1000 grains increased by 7.4% under slight soil salinity and 8.7% under moderate soil salinity.

Table 4. Effect of water management on yield component and biomass under slight and moderate soil salinity levels, Karawang, West Java, Indonesia, dry season (DS) 2017 and 2018. Within the same column means followed by different letters are significantly different at the 0.05 probability level. CF: Continuous flooding; AWD: alternate wetting and drying; SEM: standard error of the mean.

Water management treatments	Panicles per hill	Seeds per panicle	Empty grain	Weight of 1000 grains	Above-ground biomass
	Nr hill^{-1}	Nr panicle^{-1}	%	g	g 0.4 m^{-2}
		DS 2017 – Slight soil salinity			
CF	20.34^{a}	104.34^{a}	13.95^{a}	21.46^{a}	57.34^{a}
AWD	21.48^{a}	110.58^{a}	14.32^{a}	21.95^{a}	55.78^{a}
SEM±	2.383	7.189	1.419	0.808	4.619
		DS 2017 - Moderate soil salinity			
CF	17.38^{a}	105.28^{a}	15.05^{a}	21.04^{a}	53.27^{a}
AWD	17.22^{a}	94.97^{b}	15.52^{a}	19.18^{b}	52.98^{a}
SEM±	2.644	3.552	3.719	0.395	0.905
		DS 2018 – Slight soil salinity			
CF	19.17^{b}	100.55^{b}	14.18^{a}	21.52^{a}	54.21^{a}
AWD	20.92^{a}	106.88^{a}	14.3^{a}	21.73^{a}	53.56^{a}
SEM±	1.007	2.146	1.125	0.415	2.277
		DS 2018 - Moderate soil salinity			
CF	18.76^{a}	89.45^{a}	17.21^{a}	21.97^{a}	51.48^{a}
AWD	16.42^{b}	87.22^{a}	16.67^{a}	20.09^{b}	50.94^{a}
SEM±	2.478	9.985	2.738	0.472	0.925

Table 5. Effect of microbe application on yield component and biomass under slight and moderate soil salinity levels, Karawang, West Java, dry season (DS) 2017 and 2018. Within the same column means followed by different letters are significantly different at the 0.05 probability level. SEM: Standard error of the mean.

Microbial treatments	Panicles per hill	Seeds per panicle	Empty grain	Weight of 1000 grains	Above-ground biomass
	Nr hill^{-1}	Nr panicle^{-1}	%	g	g 0.4 m^{-2}
		DS 2017 – Slight soil salinity			
Without	20.34^{a}	104.34^{a}	13.95^{a}	22.76^{b}	57.34^{a}
With	21.48^{a}	110.58^{a}	14.32^{a}	24.24^{a}	55.78^{a}
SEM±	1.898	9.027	1.506	0.644	4.735
		DS 2017 - Moderate soil salinity			
Without	17.11^{a}	97.08^{a}	16.15^{a}	21.02^{b}	52.26^{a}
With	17.43^{a}	101.97^{a}	15.44^{a}	22.65^{a}	53.58^{a}
SEM±	0.706	7.553	1.701	1.055	2.021
		DS 2018 – Slight soil salinity			
Without	19.42^{a}	101.44^{a}	13.95^{b}	22.05^{b}	53.87^{a}
With	20.90^{a}	105.21^{a}	14.21^{a}	23.89^{a}	53.88^{a}
SEM±	1.729	9.977	4.951	0.911	1.061
		DS 2018 - Moderate soil salinity			
Without	16.22^{a}	86.10^{a}	17.02^{a}	21.04^{b}	51.62^{a}
With	16.84^{a}	92.29^{a}	16.77^{a}	23.09^{a}	51.90^{a}
SEM±	1.532	11.305	1.851	1.912	0.1594

Under slight and moderate soil salinity, the tested varieties significantly affected almost all yield components and above-ground biomass (Table 6). Under the slight level of soil salinity in both years, the average number of panicles per hill, seeds per panicle, percent of empty grains, and the 1000 grain weight were affected by tested cultivars. The number of tillers was more remarkable for 'Ciherang' compared to

'Inpari 34 Salin Agritan' or 'Inpari 35 Salin Agritan'. There was nonsignificant change in the number of seeds per panicle compared to 'Ciherang' to 'Inpari 35 Salin Agritan'. Still, they were significantly lower for 'Inpari 34 Salin Agritan'. 'Inpari 34 Salin Agritan' also had the highest percentage of empty grains and the highest 1000 grain weight.

Table 6. Effect of rice varieties on yield component and biomass under low and moderate levels of soil salinity, Karawang, West Java, dry season (DS) 2017 and 2018. Within the same column means followed by different letters are significantly different at the 0.05 probability level. *Yield components difference was calculated as the difference in yield components under a slight soil salinity level and yield components under a moderate soil salinity level at the same of year. SEM: Standard error of the mean.

Cultivar	Panicles per hill	Seeds per panicle	Empty grain	Weight of 1000 grains	Above-ground biomass
	Nr $hill^{-1}$	Nr $panicle^{-1}$	%	g	g 0.4 m^{-2}
			DS 2017 – Slight soil salinity		
Ciherang	22.74^a	114.19^a	9.46^c	20.84^b	52.22^b
Inpari 34	19.64^b	90.67^b	19.52^a	24.09^a	58.35^a
Inpari 35	20.35^b	117.53^a	13.44^b	20.20^b	59.12^a
SEM±	2.1445	9.5601	5.1567	2.8937	4.6364
Average	20.91	107.46	14.14	21.71	56.56
			DS 2017 - Moderate soil salinity		
Ciherang	20.12^a	103.78^a	13.55^b	20.19^b	48.98^b
Inpari 34	16.45^b	86.54^b	21.63^a	23.21^a	52.67^a
Inpari 35	17.30^b	101.13^a	15.29^b	20.11^b	53.11^a
SEM±	2.7165	12.098	5.710	1.983	2.6084
Average	17.96	97.15	16.82	21.17	51.59
Diff. (%) (+/-)*	-14.12	-9.60	18.98	-2.49	-8.80
			DS 2018 – Slight soil salinity		
Ciherang	22.11^a	116.24^a	10.37^c	20.79^b	50.66^b
Inpari 34	18.95^b	89.55^c	17.55^a	23.85^a	55.19^a
Inpari 35	19.10^b	105.36^b	14.79^b	20.40^b	55.81^a
SEM±	2.2181	10.1364	2.9284	1.7699	4.2559
Average	20.05	103.72	14.24	21.68	53.89
			DS 2018 - Moderate soil salinity		
Ciherang	18.85^a	89.45^a	15.67^b	20.64^a	48.57^b
Inpari 34	15.70^b	85.30^a	19.82^a	21.88^a	52.30^a
Inpari 35	18.21^a	90.25^a	15.33^b	20.56^a	52.78^a
SEM±	1.4606	6.6627	4.1982	2.0785	2.1638
Average	17.59	88.33	16.94	21.03	51.22
Diff. (%) (+/-)*	-12.30	-14.83	18.99	-3.01	-4.95

To some extent, the results were almost the same between years. Increased soil salinity levels affected all rice yield components and above-ground biomass. On average, under moderate salinity in 2017 and 2018, tiller number, seeds per panicle, weight of 1000 grains decreased by 13.2%, 12.2%, and 2.8%, respectively, while empty grains increased by 19.0%, and above-ground biomass decreased by 6.9% compared to a slight salinity level. Increased soil salinity appeared to impact the rice yield components.

Under moderate soil salinity during DS 2017, water management and rice cultivars' interaction significantly affected the panicles number (Figure 2a; Table 2). Under CF, 'Ciherang' had a substantially higher tiller number than both salt-tolerant varieties. Without continuous standing water in AWD conditions, the tiller number of 'Ciherang' decreased by as much as 12.0%, compared to a 5.9% average tiller number decrease for the salt-tolerant varieties.

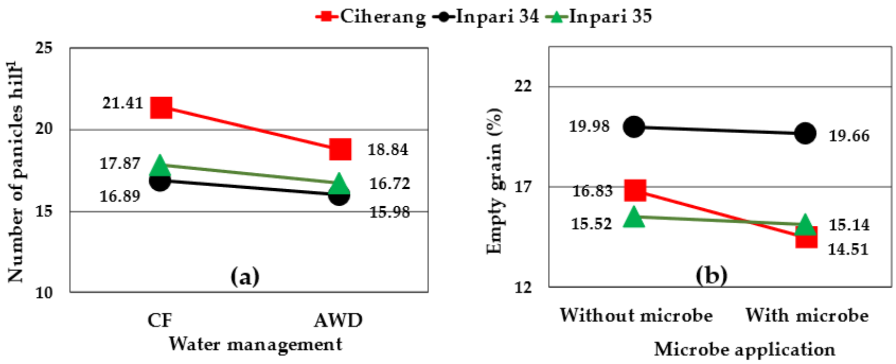

Figure 2. Under moderate salinity level number of panicles was affected by the interaction between water management and cultivar in dry season 2017 (a), and empty grain was affected by microbe application and cultivar in dry season 2018 (b). CF: Continuous flooding; AWD: alternate wetting and drying.

There was nonsignificant interaction between microbe application and cultivar on empty grain under moderate soil salinity during DS 2017. However, the interaction was significant for empty grains during harvest in DS 2018 (Table 2). Microbe application under a moderate soil salinity level resulted in different growth suppression in the salt-tolerant and non-tolerant cultivars. Microbe application did not significantly influence empty grains of salt-tolerant cultivars. However, there was a 13.8% increase in empty grain in the non-salt-tolerant 'Ciherang' when the crop was grown to moderate salt stress compared to the salt-tolerant cultivar, 2.1% (Figure 2b).

Soil bacterial community plays a pivotal role in determining biomass productivity. Above-ground biomass was affected by the interaction of microbe application and cultivar during DS 2017 (Table 2). However, their interaction was nonsignificant in DS 2018. 'Ciherang' responded better to microbe application than salt-tolerant 'Inpari 34 Salin Agritan' and 'Inpari 35 Salin Agritan' (Figure 3). Microbe application did not significantly increase the above-ground biomass of salt-tolerant cultivars. In contrast, it resulted in an 8.5% increase of above-ground biomass in 'Ciherang' when the plants were exposed to moderate salinity levels. As a result, the above-ground biomass of 'Ciherang', when grown with microbe application, was similar to the salt-tolerant cultivars at moderate soil salinity levels. The results indicated that the interaction between water management and cultivar on the number of panicles and the interactions between microbe application and cultivar on empty grain and above-ground biomass are only for moderate soil salinity. The interactions were non-significant for slight soil salinity.

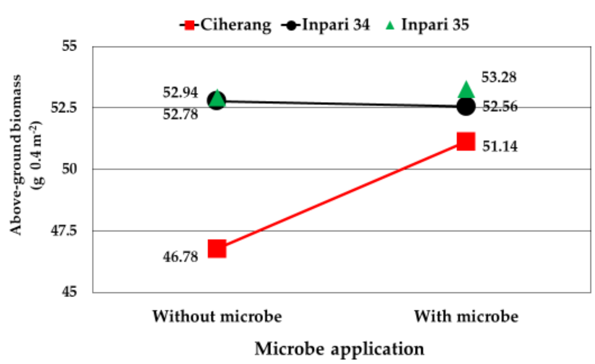

Figure 3. Above-ground biomass as affected by microbe application and cultivar under moderate soil salinity, Karawang, West Java, dry season 2017.

Water saving and productivity

The AWD treatment used 5.567 and 4.852 m^3 ha^{-1} total water compared to CF, 7.509 and 6.186 m^3 ha^{-1}, in DS 2017 and 2018 (Table 7). These mean in both years AWD used less than 25.86% and 21.56% of the total water compared to CF. Irrigation water used by CF treatment during the growing season in 2017 and 2018 was about 5.869 and 5.406 m^3 ha^{-1}, while the AWD treatment was 3.927 and 4.072 m^3 ha^{-1}, respectively. The AWD treatment used irrigation supplements 33.09% and 24.68% less than CF in the DS 2017 and 2018, respectively.

In 2017, AWD improved total water productivity by 36.45% (1.15 *vs*. 0.84 kg m^{-3}) over CF under slight soil salinity. The same year, water productivity improved by 23.80% (0.94 *vs*. 0.76 kg m^{-3}) under moderate soil salinity. In 2018, AWD improved water productivity by 28.94% (1.25 *vs*. 0.97 kg m^{-3}) over CF under slight soil salinity and 16.97% (1.06 *vs*. 0.90 kg m^{-3}) under moderate soil salinity.

Table 7. Grain yield, water used, water productivity, and water-saving in the CF and AWD treatment under slightly and moderately saline in the dry season (DS) 2017 and 2018. CF: Continuous flooding; AWD: alternate wetting and drying.

Water management treatments	Grain yield	Rainfall water used	Irrigation water used	Total water used	Total water productivity
	kg ha^{-1}		m^3 ha^{-1}		kg m^{-3}
			DS 2017 – Slight soil salinity		
CF	6305	1640	5869	7509	0.84
AWD	6378	1649	3927	5567	1.15
AWD water used, %			66.91	74.14	136.45
AWD water saving, %			33.08	25.86	36.45
			DS 2017 - Moderate soil salinity		
CF	5693	1640	5869	7509	0.76
AWD	5225	1649	3927	5567	0.94
AWD water used, %			66.91	74.14	123.80
AWD water saving, %			33.09	25.86	23.80
			DS 2018 – Slight soil salinity		
CF	6014	780	5406	6186	0.97
AWD	6082	780	4072	4852	1.25
AWD water used, %			75.32	78.44	128.94
AWD water saving, %			24.68	21.56	28.94
			DS 2018 - Moderate soil salinity		
CF	5586	780	5406	6186	0.90
AWD	5125	780	4072	4852	1.06
AWD water used, %			75.32	78.44	116.97
AWD water saving, %			24.68	21.56	16.97

DISCUSSION

Crop yield under salinity

This experiment showed no yield penalty of rice yield tested under AWD compared to CF at a slight soil salinity level in both years. However, we found the opposite result under a moderate soil salinity level where the yield of plants grown with AWD were substantially decreased. Increased soil salinity levels from slight to moderate salinity resulted in almost double percentage yield reduction under AWD compared to CF. Several studies under favorable irrigated soil conditions found that the yield under AWD was higher than

CF (Sriphirom et al., 2019; Ishfaq et al., 2020). In contrast, AWD did not alter or had a slightly lower yield than CF (Jiang et al., 2019).

The maintenance of standing water throughout most of the growing season under CF likely reduces the root zone salinity by leaching and diluting the salts (Gelaye et al., 2019). The drier soil under AWD conditions probably increased soil salinity due to groundwater and salts moving upward into the root zone and the soil surface. Even though the grain yield increased not significantly difference, under a slight level of soil salinity, AWD has 7.4% more panicles per hill, 6.1% more seeds per panicle, and 1.6% more weight of 1000 grains compared to CF. Similar findings with improved yield components under AWD compared to CF were reported by Virk et al. (2021). Soil salinity appeared to have a lower effect on the 1000 grain weight and above-ground biomass than the number of productive tillers and number of seeds per panicle, which were lower at moderate salinity levels. This follows the relationships between grain yield and the agronomic traits of rice (Zhao et al., 2020).

The present study showed significant improvement in plant growth supplemented with PGPB regarding the increased weight of 1000 grains and above-ground biomass when the plants were exposed to moderate salinity. Increased soil salinity levels from slight to moderate salinity resulted in lower yield reduction with microbial than without microbial treatments. Managing plant-microbe interaction by inoculating PGPB enhances plant growth and yield and helps confer plant tolerance under stressful environmental conditions. The present study showed significant improvement in plant growth supplemented with PGPB regarding the increased weight of 1000 grains and above-ground biomass when the plants were exposed to moderate salinity. Increased soil salinity levels from slight to moderate salinity resulted in lower yield reduction with microbial than without microbial treatments. Managing plant-microbe interaction by inoculating PGPB enhances plant growth and yield and helps confer plant tolerance under stressful environmental conditions. The activity of the ACC deaminase enzyme to produce ketobutyrate and ammonia can reduce excessive ACC levels in ethylene synthesis under stress conditions and is an efficient mechanism to induce plant tolerance in salt-stress situations (Orozco-Mosqueda et al., 2020). Previous studies have demonstrated that PGPB from the genus *Pseudomonas* and *Bacillus* alleviated salinity's harmful effects on rice growth (Shilev, 2020).

Tested cultivars had significant differences in growth and grain yield production. We assessed salt tolerance by comparing the grain yield production percentage in moderate and slight salinity conditions over the same period. Under slight soil salinity in both years, 'Ciherang' showed superiority over the salinity tolerant 'Inpari 34 Salin Agritan' and 'Inpari 35 Salin Agritan'. 'Ciherang' yields better under AWD-based water-saving irrigation, especially at a slight soil salinity level. However, 'Inpari 35 Salin Agritan' was shown to have a lower yield reduction at moderate soil salinity than other cultivars showing better adaptability under saline conditions. It should thus be promoted in these areas as an alternative cultivar to 'Ciherang'.

Water used and water productivity

Various irrigation techniques can be evaluated to calculate the water needed for optimal rice growth and yield. The AWD treatment used less total water supply than CF treatment to produce the same grain yield. These results agree with the report indicating that the AWD technique could save water usage compared to CF (Monaco et al., 2021; Hussain et al., 2021). Technologies such as AWD irrigation reduce the duration that fields are flooded and are also favored by decreasing the amount of evaporation due to water surfaces having a higher evaporation rate than the soil surface. The AWD also used almost one-third less irrigation supplement than CF. This greatly assists small farmers in reducing the additional cost of pumping water from the canal to meet the water needs of the rice crop. Our data also shows under AWD improved, total water productivity ranging from 24% to 31%, under slight soil salinity and moderate soil salinity over CF. These water productivity values in AWD are lower than that found in favorable paddy fields by around 41% (Hussain et al., 2021).

Numerous studies on manipulating depth and irrigation intervals intended to save water have demonstrated that continuous submergence is optional for obtaining high rice yields (Arai et al., 2022).

Maintaining a significant water depth throughout the season is unnecessary for high rice yields. It can save about 40% of the water used in irrigating the rice crop in the dry season without sacrifice rice yield (Lampayan et al., 2015; Sriphirom et al., 2019). In areas where water is already scarce during DS under seawater intrusion areas on the northern coast of Java, farmers must be equipped with technologies to grow rice with less water because there needs to be more water to grow rice conventionally.

Seawater intrusion, one of the most severe problems in coastal agricultural areas, has the most obstructive impact on crop production (Gopalakrishnan et al., 2019; Nhung et al., 2019). Rice production will significantly require appropriate technology adaptation and mitigation measures (Chen et al., 2021). Since there is no rice yield difference between CF and AWD under the slight level of soil salinity, there is a significant potential for farmers in slight salinity lowlands areas of the northern coast of Java to apply AWD during the dry season. The AWD technology is a method to reduce water consumption and adapt to conditions of limited water availability (Ishfaq et al., 2020). Farmers could make significant water savings from irrigation supplements, which would improve farm profitably due to less water irrigated from the nearby canal by pumping. In this case, AWD practice could help farmers manage water efficiently to prevent further yield loss.

CONCLUSIONS

Our results show that alternate wetting and drying (AWD) gave no yield penalty under a slight soil salinity level for both years. However, under a moderate soil salinity level, the plants are grown under AWD, having significantly less grain yield than those produced under continuous flooding (CF). There is a significant improvement in plant growth supplemented with plant growth-promoting bacteria (PGPB) regarding the increased weight of 1000 grains and above-ground biomass and a lower yield reduction with microbial than without microbial treatments when the plants were exposed to moderate salinity. Under moderate saline conditions, 'Inpari 35 Salin Agritan', as a salt-tolerant cultivar, has a lower yield reduction than 'Ciherang', a non-salt-tolerant cultivar, thus showing better adaptability. The use of salt-tolerant types is likely to increase in the future. The AWD used less water supply than the CF to produce the same grain yield. It improved total water productivity higher under slight soil salinity than under moderate soil salinity over CF. Thus, there is a significant potential for farmers in slight salinity-lowlands areas of the northern coast of Java to apply AWD during the dry season to reduce water consumption. Farmers could manage water efficiently to prevent further yield loss, improving farm profitably and climate change resilience. The results of this assessment can be helpful to policymakers in promoting sustainable rice production and to researchers interested in focusing on specific improvements of salinity-tolerant cultivars.

Author contribution

Conceptualization: H.S., E.E. Methodology: N.A.S., H.S. Writing-original draft preparation: E.E., H.S. Validation: A.J. Water data curation: A.P. Formal analysis: D.N. Investigation: D.N., B.P., E.E., H.S. Review and editing: H.S., E.E. Supervision: P.S., H.S. Project administration: N.A.S. Funding acquisition: H.S. All authors have read and agreed to the published version of the manuscript. All authors reviewed the final version and approved the manuscript before submission.

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