Enhancing Resiliency and Productivity of Flood Prone Coastal Rice Farming through Integrated Organic-Biofertilizers and Crop Management for Climate Change Adaptation

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Abstract. Coastal rice farming is vulnerable to climate change, including flooding and extreme weather events. To enhance resilience and productivity, innovative approaches are essential. A study investigated the effects of soil amendment and biofertilizers on rice yield. The findings showed that the use of halotolerant rice varieties and the application of soil amendment and biofertilizers can serve as a primary strategy for flooded rice farming. Sustainable farming practices can empower coastal communities to better adapt to climate change and improve the sustainability of rice production.

1 Introductions

Climate change aggravates farming as climate-related extremes occur more frequently and with greater severity. The Indonesian archipelago with 17,480 islands and a coastline area of 91,000 km is highly affected by shifts in rainfall patterns, flooding, droughts, and long-term changes due to sea level rise that also causes salinization and degradation of soils along the coastal areas [1]. The populated country is home to 276 million inhabitants, with an estimated 50-60% of the population lives along the coastal zones and many of the coastal dwellers depend on rice-based farming as a source of livelihood [1, 2].

Sea level rise has become a serious problem for the rice farming system along the southern coastline of Java Island, where tides cause flooding as well as an increased soil salinity of agricultural land [3, 4]. This damages the rice plant throughout their growth cycle. Flooding constrains the nutrient availability and limits the effective use of organic and chemical fertilizers resulting in decreased N use efficiency and N losses through NH_3 volatilization, N_2O emissions, and NO_3 leaching causing environmental pollution [5, 6]. Salinity increases transpiration demands through higher concentration of Na^+ and Cl^- ions and disturbs the

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Table 1. Chemical composition of Azolla biomass[a]

Constituents	Dry Matter (%)
Crude protein	24-30
Crude fat	3.3-3.6
Nitrogen	4-5
Phosphorous	0.5-0.9
Calcium	0.4-1.0
Potassium	2-4.5
Magnesium	0.5-0.65
Manganese	0.11-0.16
Iron	0.06-0.26
Soluble sugars	3.5
Crude fire	9.1
Starch	6.54

[a] Swain et al. (2022)

growth of the rice by damaging its cells, thereby leading to limited development and cellular death [7-9]. Salinity stress also affects soil microbial activity and soil fertility, through reduced N mineralization and enzyme activity [10]. Consequently, rice growth and productivity remains far below its potential, and pro-longed submergence regularly leads to harvest failure up to total crop loss [11].

This research was conducted in a co-creative science-practice partnership to find low-tech and low-cost solutions to address the above mentioned problems. The participatory co-research approach has been developed in the Climate-Resilient Agriculture Investigation and Innovation project (CRAIIP). The programme operates since 2017 in collaboration between the Indonesian Farmers Community Network (JAMTANI), the Centre for Rural Development (SLE) of Humboldt-Universitaet, Germany, and the Agricultural Faculty of Universitas Padjadjaran, Indonesia. It serves as a vehicle for co-creating agroecological knowledge between scientists and farmers in order to increase adaptive capacities in Climate Field Labs (CFL) [12]. This innovative extension approach merges elements of farmer-led research, such as field experiments run by farmers and capacity building in biweekly climate field schools. The latter are an adapted form of farmer field schools that have been introduced in Indonesia in the late 80ies [13]. CFL includes agroecological analysis and learning with a farmer group of 10 to 15 people during one or more growth seasons. Moreover, farmers participate actively in the design, implementation and evaluation of field experiments. This close and direct exchange what is called co-research usually accelerates the process of technology development and scaling of innovations [12,14-15].

In order to adapt rice farming in flood-prone coastal areas a relatively low-cost adaptation strategy is the use of halotolerant varieties. Superior stress-tolerant varieties have been released by the Indonesian Agency for Agricultural Research and Development (IAARD) and are available. The yield potential of two major lowland paddy variety lines, including the Inbrida swamp rice (Inpara) and the Inbrida irrigation rice (Inpari), has been tested in flood-prone rice farming in several regions of Indonesia, mainly in experiments with chemical fertilizer treatments. Studies reveal that the cultivation of a halotolerant variety can increase the growth and yield of rice significantly increases the growth and productivity in saline soils [16-19]. However, there is little literature on halotolerant rice variety performance under organic soil fertility strategies. Generally, organic ameliorants help to improve biological activities and nutrient availability in soils as well as to alleviate salinity stress [20]. A recent study within the framework of CRAIIP using organic soil fertility strategies with goat manure and liquid azolla foliar feeding indicated that flood-tolerant varieties even outperformed the saline-tolerant varieties [11].

Azolla pinnata is a fast-growing water fern living in a symbiotic relationship with cyanobacteria (*Anabaena azollae*), that can fix free nitrogen (N_2) from the air [21, 22]. Furthermore, it acts as green manure and N biofertilizer, and its symbiotic association can provide 100-170 kg ha^{-1} of N per year. The application of 10 tons ha^{-1} Azolla green manure can increase soil nitrogen content yield [15, 23]. Several studies also showed that Azolla increased fertilizer efficiency and reduced the emission of N_2O gases [24-27]. Azolla biomass contains a relatively high amount of essential nutrients, namely 4-5% N, 0.5-0.9% P, and 2.5-4.5% K, as shown in Table 1. This indicates that the liquid azolla can be used as organic foliar feeding in flood-prone rice farming.

In the present study the potential of halotolerant rice varieties planted with innovative formulas of briquetted soil ameliorant (BSA) as basal fertilizer and green liquid azolla biofertilizers (GLB) as foliar feeding is assessed. The paper provides the formulas and its application, the major growth and productivity results of the various treatments, and discusses how this solution could contribute to increase the resilient of flood-prone rice farming for improving the livelihoods of smallholder farmers in coastal areas.

2 Materials and Methods

Field farmer-led research (FFLR) was established in 2019 at Paledah Village, Pangandaran District, West Java, and Cimrutu Village, Cilacap District, West Java, with the main goal to improve the adaptive capacity of farmers and climate resilience of rice farming system in flooded prone areas along the coast, as shown in Figure 1. Furthermore, the chemical and physical properties of the soil in the two FFLR are presented in Table 2. Based on previous findings, the study locations are often flooded with water. The FFLR in Paledah and Cimrutu have non-saline and saline soils, respectively. The halotolerant rice variety was selected by the farmers through participatory approach discussion.

In this study, the extract was enriched with halotolerant plant growth-promoting rhizobacteria (PGPR), which also act as N-fixer and P solubilizer, and it is also known as GLB. PGPR plays an important role as a biofertilizer to facilitate nutrient availability as well as a phytohormone producer (IAA, Gibberellic acid) and bioprotectant [28-30]. The rice species to be tested in field farmers-led research include the Inbrida Swamp Rice (Inpara), Inbrida Irrigation Rice (Inpari), and 2014 released saline-tolerant Inpari 35 and Inpari Unsoed 79/Inpari 79 [16] and swamp rice variety, Inpara 2.

Eco-friendly BSA and GLB were formulated and developed to overcome the obstacles of basal application of organic ameliorants under flooding conditions. Meanwhile, GLB was produced to enable the supply of nutrient supply through foliar feeding to support rice growth and development. BSA consists of 30% compost + 20% biochar + 25% dolomite + 20%

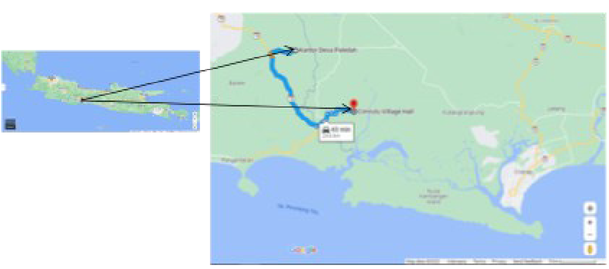

Fig. 1. Research Location

Table 2. Soil chemical and physical properties of FFLR in Paledah and Cimrutu.

Parameters	Unit	Paledah	Cimrutu
pH (H_2O)	-	5.5	5.68
Organic-C	(%)	2.65	2.65
Total-N	(%)	0.21	0.21
P_2O_5 HCl 25%	mg 100 g^{-1}	30.01	31.51
P_2O_5 (Bray)	ppm P	5.63	5.31
K_2O HCl 25%	mg 100 g^{-1}	39.87	49.36
CEE	cmol kg^{-1}	37.57	37.88
Al-saturation	%	8.41	3.55
Salinity	ds m^{-1}	0.0024	6.5
Soil texture (silty clay)			
Sand	%	4.00	2.50
Silt	%	41.50	45.50
Clay	%	54.50	52.00

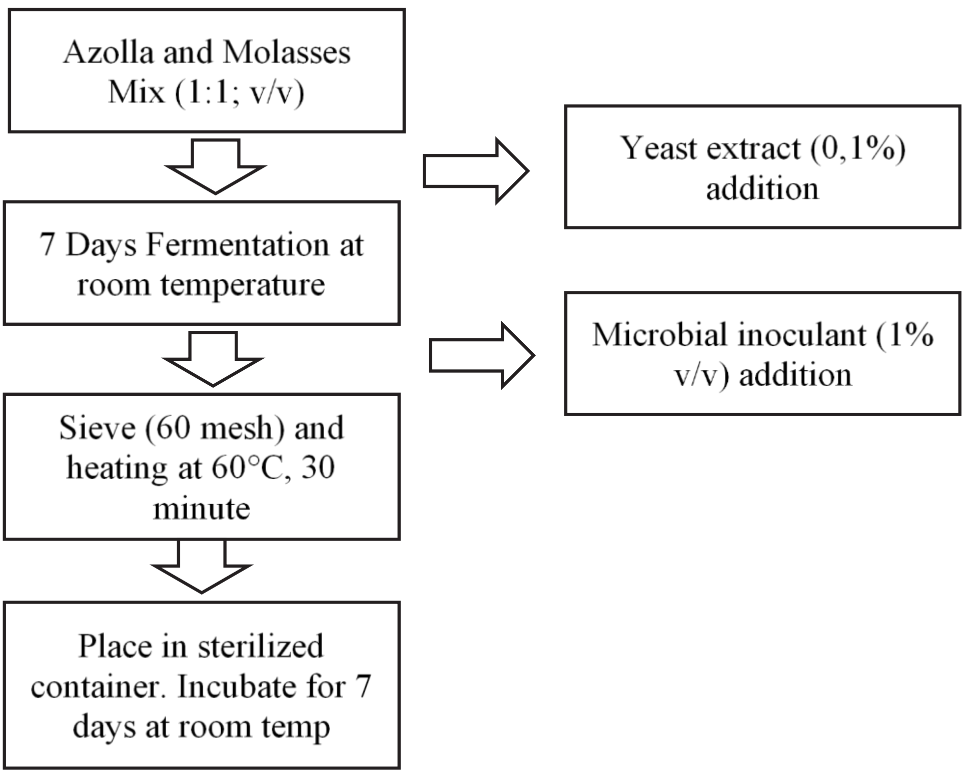

Fig. 2. Production steps of green liquid of biofertilizer (GLB).

guano + 5% tapioca. The BSA is enriched with biochar, dolomite, guano, and humic acid and applied as briquet to the paddy plant clump, followed by foliar application of GLB, Approximately 30% water was added and it was mixed homogenously, followed by pressing with simple tools to form a sample of 20 g briquetted-1 after drying under natural conditions. BSA contains 15.5% organic carbon, 0.98% N, 3.65% P2O5, and 0.85 K2O with a pH of 8.5. Meanwhile, GLB contains Azolla, molasses, as well as the inoculant of N-fixer and

Table 3. Agronomical traits of rice due to BSA combined with GLB

Treatments	Panicle (cm)	Grains Number $Panicle^{-1}$		Weight (g)	Dry Grain Yield	
		Pithy	Empty	100 Grains	g $clumps^{-1}$	Increment (%)
T_0 = Control	21.14 a	76.29 a	68.31 b	2.22 a	42.49 a	-
T_1 = 1 BSA	21.02 a	86.11 b	58.59 a	2.63 c	49.09 bc	15.6
T_2 = 2 BSA	22.02 ab	87.70 b	66.38 b	2.35 b	45.77 ab	7.7
T_3 = 1 BSA + GLB	22.78 b	93.70 c	75.47 c	2.32 ab	52.58 cd	23.7
T_4 = 2 BSA + GLB	21.52 ab	94.63 c	68.31 b	2.40 b	64.34 d	51.4
T_5 = GLB	21.03 a	88.91 b	64.89 b	2.78 d	60.34 d	42.0
CV (%)	6.83	4.79	7.58	4.72	11.15	-

Note: Mean value followed by the same letter within the same column is not different significantly ($p < 0.05$).

Table 4. Effect of combined BSA with GLB on productive tiller of different rice variety at 52 days after planting (DAP).

Rice Variety (V)	Fertilization (F)		
	f_0 = Control	f_1 = LFT	f_2 = BSA + GLB
v_1 = Inpara-2	17.80 a ± 4.76A	19.20 a ± 2.77A	17.40 a ± 7.33A
v_2 = Inpari-35	19.00 a ± 2.45A	17.20 a ± 4.44A	28.20 b ± 5.85B
v_3 = Inpari-79	10.80 a ± 4.49A	16.40 ab ± 6.54A	21.20 b ± 3.11AB
CV (%)	26.46		

Note: Value followed by the different letter is significant ($p < 0.05$). Capital read vertically within the row and small letter read horizontally within the same column.

phosphate solubilizers rhizobacteria. The main content of GLB includes 3.14% organic carbon, 0.14% N, 0.06% P2O5, 0.74% K2O, 107 CFU ml-1 N2-fixer, and 107 CFU ml-1 phosphate solubilizer.

Land preparation and plowing (puddling) was done with a hand tractor. The rice seedlings aged 28 days were planted into a plot of 4 x 5 m with a geometry of 25 x 30 cm. A total of 20 g BSA was then placed into the soils at a depth of 5 cm between four rice clumps. The GLB was sprayed at a concentration of 10 cc L-1 every week for 5 weeks (3, 4, 5, 6, and 7 weeks after planting).

After the design of the study was agreed upon by the scientific team and farmers, members of JAMTANI acted as co-researcher. Simple experiments were carried out in the FFLR of Paledah and Cimrutu. The focus was to determine the effect of organic BSA and GLB on the agronomic traits of Inpari rice. The GLB was prepared as follows Figure 2.

The FFLR experiment in Paledah was carried out using a randomized block design, consisting of 6 treatments, namely T0 = Control, T1 = 1 BSA, T2 = 2 BSA, T3 = 1 BSA + 25 L GLB, T4 = 2 BSA + 25 L GLB, and T5 = 25 L GLB, with 4 replications. The rice seedling aged 28 days was transplanted into the experimental plot of 4 x 5 m with a planting density of 30 x 30 cm. Furthermore, the FFLR in Cimrutu was designed to investigate the growth and yield of the selected halotolerant rice variety treated with BSA and GLB. The experiment was arranged as a factorized randomized block design, consisting of 2 factors, including rice variety (Inpari-35, Inpari-79, and Inpara-2) as well as a combination of BSA + GLB (control, local farmers technology, 1 BSA + 25 L GLB). The 28 days rice seedling were planted into a plot of 4 x 4 m dimension with a planting space of 30 x 30 cm. The simple field study was also arranged in a randomized block design with two factors. The stress-tolerant rice variety (v1 = Inpara-2, v2 = Inpari-25 and v3 = Inpari-79) as well as BSA combined with GLB, which was applied through foliar feeding (f0 = Control, f1 = Local farmers methods (200 kg ha-1 of Urea, 100 kg ha-1 SP36, 75 kg ha-1 KCl) and f2 = 1000 kg BSA + 25 L of GLB ha-1). The selected halotolerant rice variety, namely Inpari-35 and Inpari-79, was planted on a demonstration plot with a dimension of 10 x 100 m.

2.1 Observed Respond

The main observed response includes plant height, number of productive tillers clump-1, panicle length, number of pithy grains panicle-1, the weight of 100 grains (g), grain weight plant-1, and grain yield in ton ha-1.

2.2 Statistical Analysis

The effect of treatment on the observed agronomic traits: plant height, the weight of 1000 grains, dry yield, as well as the number of tillers, panicles, and grains, were statistically analyzed using IBM SPSS Statistics Version 26. Furthermore, the significant effects on the tested variables were assessed using F-test or T-test. When the F-test provided significant results, the process was continued with the Duncan Multiple Range Test at $p < 0.05$ to obtain the mean difference in the treatment response.

3 Results

3.1 Agronomic Traits of Rice in Paledah FFLR

Basal application of BSA and foliar-feeding of GLB significantly increased the yield component, as shown in Table 3. Overall mean the observed variables were higher compared to the control (local farmer's technology) which consisted of inorganic fertilizers. The highest grain yield was obtained with the basal application of 1 and 2 BSA combined with foliar-feeding of GLB which was 5 liter weekly for 5 weeks. The yield was also increased by 23.7-51.4% to 52.58-64.34 g plant^{-1} of dry rice grain or 6.3-7.7 ton grain ha^{-1} compared to the control which was 42.49 g grain yield clump^{-1} or 5.1 ton grain ha^{-1}. Therefore, basal application of BSA combined with foliar feeding can be adopted as a strategy to improve the nutrient supply to support the growth and development of the plant. The number of pithy grains was relatively higher, but it can be reduced through nutrient management improvement.

3.2 Agronomic Traits of Rice in Cimrutu FFLR

Basal application of BSA combined with foliar feeding gave a higher number of tillers compared to the control or local farmers technology (LFT) in all varieties, as shown in Table 4. The highest value of 28.2 was obtained in Inpari-35 variety, followed by Inpari-79 and Inpara 2 variety with 21.20 and 17.40, respectively. This result indicated that basal application of BSA combined with GLB foliar-feeding was the best option for rice growth and development. Similar pattern was observed in plant height, panicle length, 1000 pithy grain weight, and yield, as shown in Table 5. The results showed that the highest dry grain yield of 3.22 kg plot-1 or 5.12 ton ha-1 was obtained in Inpari-35, followed by Inpari-79 and Inpara-2 variety with 3.42 kg plot-1 or 5.47 ton ha-1 and 0.84 kg plot-1 or 1.34 ton ha-1, respectively. Table 5 shows that basal application of BSA combined with GLB sprayed as foliar feeding increased the rice grain yield significantly by 33.6% to 2.38 kg plot-1 compared to the control, while the plot LFT only increased by 10.10%.

The demo plot results revealed that plant height, number of tillers, panicle length, and the yield of Inpari-35 and Inpari-79 variety were not significantly different. But the empty grain and weight of 1000 grains of Inpari-35 variety were higher than Inpari-79 variety, as shown in Table 6. The farmers were also satisfied with the rice yield of 6.92- and 6.60-ton ha-1 obtained under saline conditions. Therefore, due to the result, the two rice varieties were preferred and selected. The results confirmed that the cultivation of halotolerant rice variety as well as the basal fertilizers application of BSA combined with GLB was the best strategy to overcome flooding problems.

4 Discussion

Climate change has been reported to be one of the main reasons for salinity problems, increased sea level, as well as increase the frequency and duration of waterlogging or flood. Previous reports revealed that flood and salinity are the major constraints of rice cultivation in flood-prone areas [1]. Field farmer-led research (FFLR) is a famer-scientist collaboration mainly aimed to empower and increase farmer’s capacity in order to adapt to climate change. Farmers are known to be local experts, that are able to develop a local wisdom on how to deal with climate change adversities. LEISA (low external input sustainable agriculture) was adopted to develop GLB and BSA, which was supported by locally available raw materials. One of the examples is through the application of local Azolla as green manure. Azolla was cultivated with simple methods as the main ingredient of GLB biofertilizers. The farmers were also trained to produce GLB and BSA with appropriate technology.

This study showed through the field farmer-led research, GLB and BSA fertilization can improve the quality of paddy—especially Inpari-35 and Inpari-79 variety—grown in saline and flood prone area. The results also showed that the basal application of BSA improved the nutrient status and soil properties. BSA has a high organic carbon content and enriched

Table 5. Main effect rice variety and fertilization on the agronomic traits (plant height, panicle length, pithy grain weight 100 grains, grain yield).

Rice Variety (V)	Plant Height (cm)	Panicle Length (cm)	Pithy grain ($Panicle^{-1}$)	100 grains (g)	Grain Yield	
					kg $plot^{-1}$	Increment (%)
v_1 = Inpara-2	88.67 (± 6.30)	24.20 a (± 1.28)	92.33 b (± 12.38)	2.50 a (± 0.19)	0.84 a (± 0.38)	-
v_2 = Inpari-35	92.93 (± 12.5)	23.74 a (± 0.82)	77.56 a (± 11.14)	3.33 c (± 0.15)	3.22 b (± 1.04)	-
v_3 = Inpari-79	91.87 (± 5.85)	25.16 b (± 0.99)	85.62 b (± 13.38)	2.86 b (± 0.43)	3.42 b (± 1.03)	-
Fertilization (F)	**Plant Height (cm)**	**Panicle Length (cm)**	**Pithy grain ($Panicle^{-1}$)**	**100 grains (g)**	**Grain Yield**	
					kg $plot^{-1}$	**Increment (%)**
f_0 = Control	94.67 (± 9.49)	24.42 (± 1.14)	90.76 b (± 10.26)	2.85 (± 0.56)	2.16 a (± 0.79)	-
f_1 = LFT	89.33 (± 8.31)	24.42 (± 1.04)	79.07 a (± 17.02)	2.93 (± 0.42)	2.38 a (± 1.43)	10.10
f_2 = BSA and GLB	89.47 (± 7.91)	24.27 (± 1.42)	85.69 ab (± 10.24)	2.92 (± 0.34)	2.94 b (± 1.92)	33.6
CV (%)	8.41	4.23	12.59	9.76	29.95	-

Note: (±) = Standard deviation; Mean value followed by the same letter is not different significantly ($p < 0.05$).

Table 6. The growth, the grain yield, and related traits of Inpari-35 and Inpari-79 variety treated using BSA combined with GLB in demo plot of Cimrutu.

Rice Variety (V)	Plant Height (cm)	Panicle Length (cm)	Pithy grain (Panicle^{-1})	100 grains (g)	Grain Yield	
					kg plot^{-1}	Increment (%)
v_1 = Inpara-2	88.67 (± 6.30)	24.20 a (± 1.28)	92.33 b (± 12.38)	2.50 a (± 0.19)	0.84 a (± 0.38)	-
v_2 = Inpari-35	92.93 (± 12.5)	23.74 a (± 0.82)	77.56 a (± 11.14)	3.33 c (± 0.15)	3.22 b (± 1.04)	-
v_3 = Inpari-79	91.87 (± 5.85)	25.16 b (± 0.99)	85.62 b (± 13.38)	2.86 b (± 0.43)	3.42 b (± 1.03)	-
Fertilization (F)	**Plant Height (cm)**	**Panicle Length (cm)**	**Pithy grain (Panicle^{-1})**	**100 grains (g)**	**Grain Yield**	
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f_2 = BSA and GLB	89.47 (± 7.91)	24.27 (± 1.42)	85.69 ab (± 10.24)	2.92 (± 0.34)	2.94 b (± 1.92)	33.6
CV (%)	8.41	4.23	12.59	9.76	29.95	-

Note: SA = Sampling area (2 x 2 m = 4 m^2), ns = non-significant, * = significant (T-test $p < 0.05$).

with other major nutrients, such as N, P, Ca, and Mg, which act as slow-release fertilizers [20]. Green liquid biofertilizer contains macro or micro essential nutrients, such as N, P, K, Ca, and Mg, as well as beneficial microbes and organic substances [21, 27]. Regular foliar feeding can provide the required nutrients needed for rice growth and development. The nutrients in GLB are easily accessible and can be absorbed by plant through leaves. The extract and biofertilizers also act as a plant growth-promoting rhizobacteria of GLB, which contributes to the production of phytohormone, such as indole acetic acid and gibberellic acid [31].

As this study was carried out by farmers, and the results were expected to provide a solutions to the existing problems of rice cultivation practice in flood-prone areas. Based on observation, Inpari-35 and Inpari-79 gave the desirable yield of rice grown in the saline ecosystem of Cimrutu Village. The limitation of fertilizer administration on flood-prone areas can be solved through the application of BSA and GLB, which contains Azolla and enriched with N2-fixer and phosphate-solubilizing rhizobacteria. The application of 1-2 briquet or 2-4 clumps (1000 kg ha-1) combined with 25 L GLB ha-1 increased rice productivity by 23.6-51.4% in Paledah area. The grain yield of rice (2.94 kg plot-1) in Cimrutu increased by 30.6% and 23.5% compared to the control (2.16 kg plot-1) and local farmer technology (2.38 kg plot-1). The results also showed that Inpari-35 and Inpari-79 can produce 6.92 and 6.60-ton ha-1 of grain, which was higher than the average expectation of 2-4-ton ha-1. Since the farmers were involved in the process, the proposed technology of fertilizers and crop management can be adopted as the main strategy by farms to improve the climate resilience of the rice farming system on flood-prone regions along the coastal area of Java Island.

5 Conclusion

Flooding and salinity are the major constraints along the coastal area of Java Island to the administration of common fertilizers in form of powder or granules because they do not have an immediate effect on the soil. BSA enables basal application by placing it into the soil. Furthermore, enriched GLB facilitates the supply of nutrient and other growth factors through foliar spraying or feeding. The application of 1-2 of BSA (1000 kg ha-1) combined with 25 L GLB ha-1 can increase the agronomic traits of Inpari-35 and -75. The Inpari-35 and Inpari-79 in the FFLR Cimrutu demo plot showed high productivity of 6.92 and 6.60 ton ha-1 of rice grain. The results also showed that the use of selected halotolerant rice variety combined with BSA and GLB can be adopted as one of the strategies to cultivate rice in saline or flood-prone areas. Empowerment and involvement of local farmers through field research to find solutions to locally existing problems can helps to increase the resilience and sustainability of rice farming in changing climate.

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