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Floating Rice Cultivation: a Solution to Reduce Crop Failure in Flood-Prone Areas

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***Abstract*— Bojonegoro is a regency in Indonesia located downstream of the Bengawan Solo River, a flood-prone area that caused crop damage and failure. The farmers need appropriate technology as an adaptation to reduce the loss of crop failure. Therefore, this study aims to determine the potential of floating rice cultivation as a solution for reducing crop failure. The experiment was arranged in Randomized Complete Block Design with two factors, namely planting media (soil:organic fertilizer (1:1) (M1); soil:rice husk (1:1) (M2); soil:organic fertilizer:rice husk (1:1:1) (M3)), and plant spacing (15 cm x 15 cm (J1); 20 cm x 20 cm (J2); 25 cm x 25 cm (J3)). Each unit treatment was replicated 3 times. The results showed M2J3 gave the best outcome on plant height of 94.3 cm, the tillers number of 21.7, and produced the highest rice yield of 14.16 tons ha^{-1}. This treatment provides optimal soil conditions, high cation exchange capacity (CEC) of 26.6 cmol (+) kg^{-1}, phosphorus availability (Av-P) 48.5 ppm, and potassium availability 0.9 ppm. The planting media compositions significantly affected soil cation exchange capacity, soil phosphorus availability, plant height, tillers number, and rice yield. The yield on floating rice cultivation was approximately similar when compared to the local farmer's fields. Floating rice cultivation can be used as a solution to reduce crop failure in flood-prone areas in Bojonegoro.**

Keywords: **Adaptation; crop failure; floating rice cultivation; flood-prone area.**

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I. INTRODUCTION

Global climate change causes alterations in the intensity, duration, and distribution of rainfall [1], and Indonesia is one of the countries that will experience increased rainfall due to climatic changes. This change will significantly affect water-related disasters in Indonesia [2], one of which is flooding. In 2019, there were 784 flood disasters, and it increased to 1,080 in 2020 [3]. Bojonegoro is one of the Regency that will experience increased flood frequency due to climate change. It was reported that 2 flood events that occurred in 2015 and 8 in 2016 caused losses of around US$ 3.85 million [4].

Bojonegoro Regency is located downstream of the Bengawan Solo river, and the flood-prone areas reached 65,989.13 ha [5]. The floods that occurred in this Regency were due to the inability of the Solo river to accommodate water discharge during peak run-off [6]. Therefore, the decrease in the carrying capacity of the watershed increases the risk of flooding. Sixteen watersheds in Java, including Bengawan Solo, are categorized as very critical. This condition is exacerbated by the phenomenon of unpredictable climate change.

Fig. 1 Flood area in Karangdayu, Baureno, Bojonegoro in 2017

Floods have adverse impacts on people's livelihoods, health, economy, and education. A sector that is badly affected by annual floods and long-term waterlogging is the agricultural sector [7]. This flooded land cannot be used for agriculture [8]. Severe damage from flooding occurred in lowland rice fields, where the depth and duration were greater and longer [9]. About 14,198 ha of rice fields in Bojonegoro Regency were affected by flooding, resulting in crop failure [5]. Furthermore, the plants often sunk for several days, causing crop failure and decreasing yields and farmers' income [10].

Adaptation is one of the actions that can reduce vulnerability to flooding due to climatic changes [11]. The floating rice cultivation method is one of the solutions implemented as an adaptation effort to reduce crop failure to flooding in Bangladesh [12] and Vietnam [13]. It is a native farming method in the southern floodplains of Bangladesh and a highly innovative farming technique where crops and vegetables are grown on floating platforms (raised beds) [14]. Floating agriculture is one of the climate-smart practices which is used as an adaptation effort to climate change [15]. Therefore, farmers apply this technique to grow crops during floods.

Floating rice cultivation is an excellent method for climate change adaptation, allowing farmers to turn the negative impacts (such as floods and waterlogging) into opportunities for agricultural production [12]. This technique supports farmers in adapting their ecological, social, or economic systems during floods and inundation conditions. This helps them to compensate by continuing agricultural practices during floods and enabling them to turn the devastating effects of climate change into opportunities for crop production [12].

Floating cultivation has been implemented in Riparian Wetlands Indonesia for rice seedlings [16], which is generally done by floating beds. Furthermore, the floating cultivation has been implemented as an adaptation effort in Ciamis, West Java, and Cilacap, Central Java, which are flood-prone areas, with a productivity of 6.4 tons ha^{-1} [17]. The application of floating cultivation is also used for other commodities such as chili pepper (*Capsicum annum* L.) and mustard green in Riparian Wetlands Indonesia [10], [18].

Studies related to floating rice in Bojonegoro Regency have been carried out regarding land potential [5] and socio-economic analysis [11], [8], [19]. However, there has been no study related to the potential application of floating rice to soil fertility and plant growth factors. Therefore, this study aims to determine the potential of floating rice cultivation as a solution for reducing crop failure. It focused on the effect of applying rice floating on soil fertility, growth, and yield. It is believed that this cultivation can be a solution to improve food security in flood-prone areas. Hence, the existence of floating rice cultivation is expected to increase community resilience to flooding.

II. Materials and Method

The experiment was conducted in Karangdayu Village, Baureno District, Bojonegoro Regency, East Java from July to September 2017. This Village was chosen because it is continuously flooded. In addition, soil laboratory analysis was conducted at the Department of Soil Science, Faculty of Agriculture, Universitas Sebelas Maret.

A. Research Design

The experiment was arranged in Randomized Complete Block Design (RCBD) with two factors, namely planting media composition and plant spacing. Each treatment combination was replicated three times. Furthermore, local farmers' rice fields that were using the same varieties were selected as control. The area of paddy fields used for the experiment was 500 m^2; with 27 treatment plots in total. Each treatment plot has a volume of 0.4 m^3 (1.5 m x 1.34 m x 0.2 m). The design of floating rice cultivation is shown in Figure 2, and details of the experimental treatment are shown in Table I.

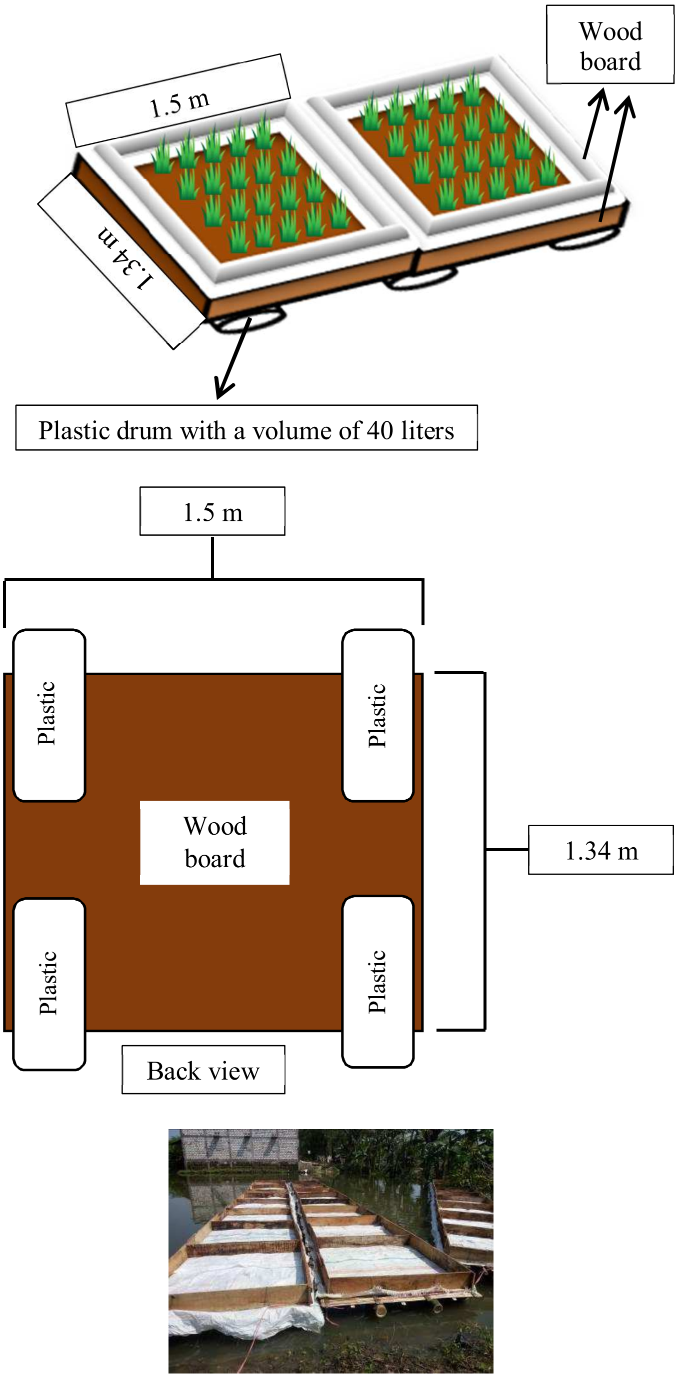


Fig. 2 Design of floating rice cultivation

TABLE I
EXPERIMENTAL TREATMENTS

Treatment	Information
M1J1	soil: organic fertilizer (1:1); 15 cm x 15 cm
M1J2	soil: organic fertilizer (1:1); 20 cm x 20 cm
M1J3	soil: organic fertilizer (1:1); 25 cm x 25 cm
M2J1	soil: husk (1:1); 15 cm x 15 cm
M2J2	soil: husk (1:1); 20 cm x 20 cm
M2J3	soil: husk (1:1); 25 cm x 25 cm
M3J1	soil: husk: organic fertilizer (1:1:1); 15 cm x 15 cm
M3J2	soil: husk: organic fertilizer (1:1:1); 20 cm x 20 cm
M3J3	soil: husk: organic fertilizer (1:1:1); 25 cm x 25 cm

Description: M: planting media composition; J: plant spacing

Floating rice cultivation needs to be based on farmers' knowledge and locally available materials. Also, plastic drums were used for floating material, widely available in the Regency. The drum trial as a floating material was conducted for one month before the experiment to determine the buoyancy with the burden of the planting media. Furthermore, the research team ensured that other plots imbibed no plot by installing plastic on each plot. The rice husks and organic fertilizers used are also widely available materials at the study site.

The rice used was Ciherang, a short-duration variety, and the soil type was Inceptisols. The experimental activities included transplanting, fertilizing with nitrogen fertilizer (UREA) (200 kg ha^{-1}), Phonska (NPK fertilizer) (400 g ha^{-1}), as well as pest and disease control. The fertilization was carried out at 7, 25, and 40 DAP (Days After Planting) with a ratio of UREA 30%, 40%, and 30%, while Phonska 40%, 40%, and 20%. Rice was harvested at 89 DAP.

B. Data Collection

At the maximum vegetative time, the soil samples were obtained from each experimental plot, then air-dried and sieved at 2 mm and 0.5 mm for different laboratory analyses. The observed soil parameters were total organic-C (Walkley and Black), cation exchange capacity (extraction NH_4OAc 1N pH 7), base saturation (extraction NH_4OAc 1N pH 7), available-P (Bray), and available-K (extraction of NH_4OAc 1N pH 7). Furthermore, this analysis was conducted to determine soil fertility. This was determined according to the method from Indonesia Soil Research Center [20].

The observed plant parameters include height, tiller number, and rice yield. The plant height was measured from the base of the stem to the longest end of the leaf. Meanwhile, the tillers number parameter was taken by calculating the number of all tillers (stems). These parameters were observed at 14, 24, 36, 51, and 89 DAP. The yields are represented by grain dry weight per plot, which is then converted to dry grain weight per hectare.

C. Statistical Analysis

All data were analyzed with ANOVA, and when there were significant differences, the Tukey's test for pairwise comparison with 95% confidence level existed employed to ascertain the differences between the treatment means. Pearson's correlation analysis was performed to determine the relationship between soil parameters, rice growth, and yield parameters.

III. RESULTS AND DISCUSSION

High nutrient requirements for rice growth [21] make soil fertility important because it is related to nutrient conditions in the soil. Soil fertility is determined based on the value of organic-C, cation exchange capacity, base saturation, and availability of phosphorus and potassium. High values will be followed by high soil fertility. The average cation exchange capacity (CEC) is 26.0 cmol(+)kg^{-1} including high. The average base saturation (BS) is 49.5%, including moderate, organic-C (org-C) 2.1%, including moderate, phosphorus availability (Av-P) 34.7 ppm, including moderate and 0.8 ppm potassium availability (Av-K) including high (Table II).

Soil fertility in floating rice cultivation is low to high, with a moderate average. The M3J1 treatment had high soil fertility and M2J3 had moderate soil fertility. However, it was low in other treatments. Both treatments resulted in optimal soil conditions, high CEC, Av-P and Av-K compared to others. The increase in CEC may be caused by the negative charge of organic matter and rice husk [22]. Cation exchange capacity is related to the ability of the soil to provide nutrients for plants. Soil with high cation exchange capacity has the potential to provide sufficient nutrients for plants [23]. Meanwhile, the increase in P and K availability was due to the application of rice husks and organic fertilizer. Singh et al. [24] stated that rice husk added to the soil significantly contributed to improving the nutritional status. The soil chemical properties can be improved by applying rice husks, which increase pH, CEC, and nutrient availability [25]. Therefore, adding organic matter such as organic fertilizers increased the cation exchange capacity, available P, and K [26].

TABLE II
SOIL FERTILITY IN FLOATING RICE CULTIVATION

Treat.	**CEC (cmol (+)kg^{-1})**	**BS (%)**	**Org-C (%)**	**Av-P (ppm)**	**Av-K (ppm)**	**Soil Fertility**
M1J1	$21.6_{(2)}$	$46.6_{(2)}$	$2.0_{(1)}$	$27.3_{(2)}$	$0.5_{(2)}$	Low
M1J2	$22.7_{(2)}$	$57.3_{(2)}$	$2.5_{(2)}$	$24.0_{(2)}$	$0.5_{(2)}$	Low
M1J3	$22.0_{(2)}$	$54.5_{(2)}$	$1.5_{(1)}$	$18.9_{(1)}$	$0.9_{(3)}$	Low
M2J1	$23.5_{(2)}$	$43.7_{(2)}$	$1.7_{(1)}$	$43.5_{(3)}$	$0.9_{(3)}$	Low
M2J2	$28.3_{(3)}$	$42.8_{(2)}$	$2.2_{(2)}$	$33.4_{(2)}$	$0.8_{(3)}$	Low
M2J3	$26.6_{(3)}$	$49.0_{(2)}$	$1.6_{(1)}$	$48.5_{(3)}$	$0.9_{(3)}$	Moderate
M3J1	$33.0_{(3)}$	$50.0_{(2)}$	$2.4_{(2)}$	$45.4_{(3)}$	$1.0_{(3)}$	High
M3J2	$25.9_{(3)}$	$51.2_{(2)}$	$2.2_{(2)}$	$38.5_{(2)}$	$1.1_{(3)}$	Low
M3J3	$30.1_{(3)}$	$50.3_{(2)}$	$2.3_{(2)}$	$32.7_{(2)}$	$0.9_{(3)}$	Low
Average	**$26.0_{(3)}$**	**$49.5_{(2)}$**	**$2.1_{(2)}$**	**$34.7_{(2)}$**	**$0.8_{(3)}$**	**Moderate**

Information: number in parentheses indicates the value of the parameter: (1) = Low; (2) = Moderate; (3) = High

The growth was observed from the plant height and tillers number, while the yields were observed from the harvested dry grain in tons ha^{-1}. The data on rice growth and yield are shown in Figure 4. The M2J3 treatment showed the best results on plant growth, which had an average plant height of 94.3 cm and tillers number of 21.7. The M2J3 treatment also gave the highest yield of 14.16 tons ha^{-1}. Meanwhile, the treatment with the lowest yield was M1J3 9.42 tons ha^{-1}. The average yield in this study was 11.58 tons ha^{-1}. It was approximately similar when compared to the local farmer's rice fields of 11.96 tons ha^{-1}. This showed the floating system is one of the potential solutions to reduce crop failure due to flooding, and farmers can still produce rice with similar yields.

7 DAP

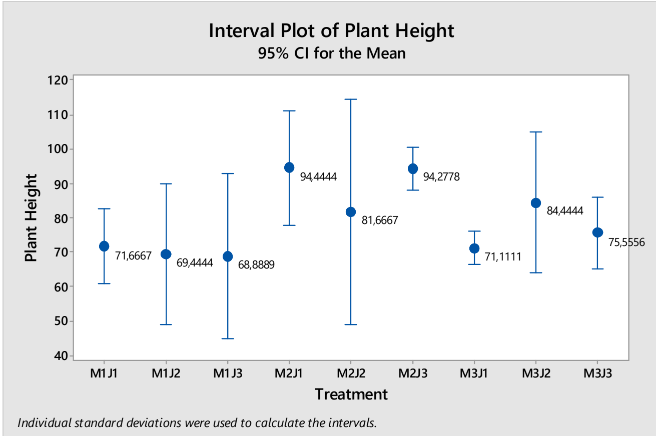
24 DAP

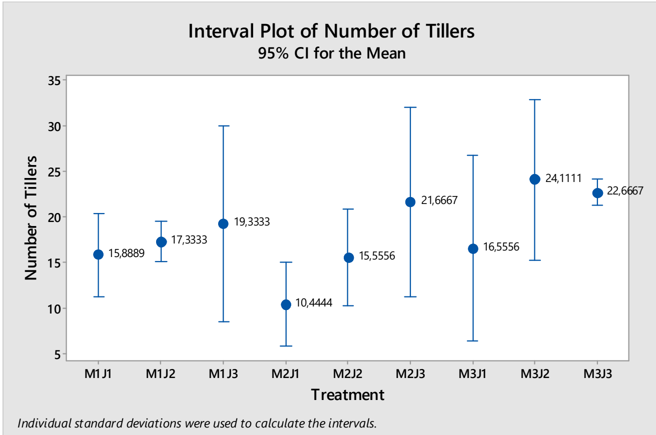
37 DAP

75 DAP

83 DAP

Fig. 3 Plant Growth in the Floating Rice Cultivation





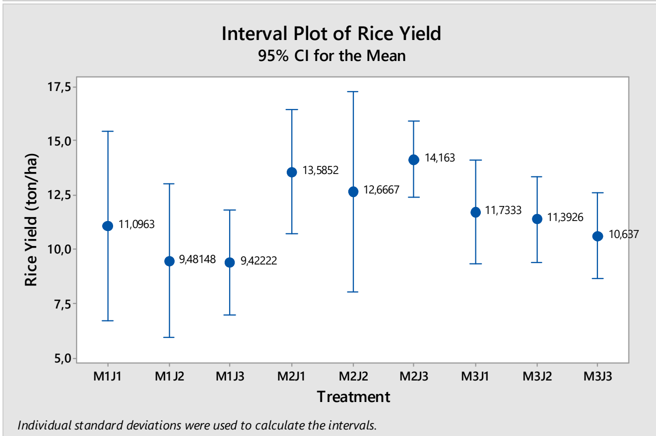


Fig. 4 Plant Growth and Yield in the Floating Rice Cultivation

Plant spacing treatment did not significantly affect their height and yield but significantly influenced the tillers number (Table III). The wider the spacing, the more room for the plants to grow and produce higher tillers number. Thakur et al. [27] and Asghar et al. [28] also mentioned that wider spacing gave better growth. A wider growing space minimizes the competition among plants both above (light) and underground (water and nutrients) [27], [28]. Narrower spacing causes competition between rice plants for nutrients, water, sunlight and air for their biological processes such as photosynthesis and respiration. The competition due to density has a significant negative effect on rice growth [29]. Therefore, proper spacing optimizes light interception which is important for photosynthesis and yields.

TABLE III
ANALYSIS OF VARIANCE

Source of variation	df	SS	MS	Plant Height	
				F-value	P-value
Media	2	1878.41	27.813	12.94	0.000
Spacing	2	5.02	2.509	0.03	0.966
Error	22	1597.18	72.599		
Total	26	3480.61			
Source of variation	**df**	**Adj SS**	**Adj MS**	**Tillers Number**	
				F-value	**P-value**
Media	2	128.50	64.251	6.01	0.008
Spacing	2	225.09	112.547	10.53	0.001
Error	22	235.15	10.689		
Total	26	588.75			
Source of variation	**df**	**SS**	**MS**	**Rice Yield**	
				F-value	**P-value**
Media	2	55.625	27.813	18.34	0.000
Spacing	2	4.511	2.255	1.49	0.248
Error	22	33.357	1.516		
Total	26	93.493			

TABLE IV
TUKEY'S TEST FOR PAIRWISE COMPARISON

Treatment	Soil CEC	Soil Av-P	Plant Height	Tillers Number	Rice yield
M1	22.12 [b]	23.39 [b]	70.00 [b]	18 [ab]	10.00 [b]
M2	26.12 [ab]	41.78 [a]	90.13 [a]	16 [b]	13.47 [a]
M3	29.65 [a]	38.88 [a]	77.04 [b]	21 [a]	11.25 [b]
J1	26.05 [a]	38.71 [a]	79.07 [a]	14 [b]	11.18 [a]
J2	25.63 [a]	33.36 [a]	78.52 [a]	19 [a]	11.41 [a]
J3	26.22 [a]	31.98 [a]	79.56 [a]	21 [a]	12.14 [a]

Planting media composition treatment significantly affected soil CEC, Av-P, plant height, tillers number, and yield (Table IV). The planting media composition of soil: rice husk (1:1) and soil: rice husk: organic fertilizer (1:1:1) increased CEC and Av-P. Also, Masulili et al. [30] stated that the highest CEC, P, and K were observed in soils treated with rice husk. Therefore, the application of organic fertilizers increases the availability of P by increasing the amount of mineralized organic P to inorganic P.

The composition of soil and rice husk (1:1) gave the best growth and yield compared to other treatments. The rice husk application improves the physical and chemical properties of the soil for optimal plant growth. Also, the application provides optimal conditions for the soil by reducing the bulk density, increasing the total porosity [31], [32] and the chemical properties [25], [33]. In this study, the increased availability of phosphorus and cation exchange capacity indicated the increase in soil chemical properties. Meanwhile, the increase in phosphorus availability after the husk application was due to decreased phosphorus retention in the soil [34]. Therefore, the improvement in properties will support plant growth. Previous studies have shown that husk increased rice yield [35], [24]. The increase in growth and yield after the husk application can be attributed to the synergistic effect of increasing soil nutrient availability [24].

Correlation test results show that there is a relationship between soil fertility parameters (Table IV). Soil organic C was significantly positively correlated with cation exchange capacity. These results are in accordance with the research of Herawati et al. [36] which states that an increase in soil organic C will be followed by an increase in CEC. The high soil organic matter increases the absorption of nutrients due to the value of CEC [37]. Soil organic C is also positively correlated with base saturation. The process of decomposition of organic matter, releasing nutrients including base cations [38].

TABLE V
CORRELATION BETWEEN SOIL FERTILITY, RICE GROWTH AND RICE YIELD

	CEC	BS	Org-C	Av-P	Av-K	Plant Height	Tillers Number
BS	**0.390** 0.044						
Org-C	**0.601** 0.001	**0.441** 0.021					
Av-P	0.360 0.065	-0.031 0.879	0.008 0.969				
Av-K	**0.578** 0.002	**0.436** 0.023	0.267 0.178	0.215 0.282			
Plant Height	0.018 0.929	-0.344 0.079	-0.215 0.282	**0.449** 0.019	0.083 0.681		
Tillers Number	0.095 0.638	0.232 0.245	0.065 0.747	0.081 0.689	0.055 0.785	-0.164 0.415	
Rice Yield	0.187 0.350	-0.237 0.234	-0.046 0.818	**0.769** 0.000	0.148 0.462	**0.698** 0.000	-0.079 0.695

Cell content: Pearson's correlation
P-Value

The soil fertility parameter that is significantly correlated with rice yield is phosphorus availability. This is in line with the results of other studies, where phosphorus availability is significantly correlated with grain yield [39], [40]. Furthermore, phosphorus is involved in several metabolic processes of plants and energy production [41]. Plants need the energy for metabolic processes such as photosynthesis, where the results affect plant growth. According to Deng et al. [42], low soil phosphorus content significantly reduced the leaf photosynthesis rate of four rice varieties at the main growth stage.

Phosphorus availability was also significantly correlated with plant height. Plant height is significantly correlated with rice yield. Plants that are tall and have higher stover are indicators that plant photosynthesis is running optimally, resulting in high grain per panicle and grain weight and impacting high grain yields.

The existence of the floating method is expected to increase farmers' ability to continue rice cultivation after a flood on farm households. Floating rice cultivation is a newly introduced practice in Bojonegoro Regency, and much effort would be needed to achieve success in its application. The challenge in floating rice cultivation is not only in terms of the implementation of planting and its maintenance but especially in the process of introducing planting methods, how there must be a change in the mindset and behavior of farmers. Farmers need socialization and training to become more familiar with this technology. Also, support from the local government can increase farmers' aspirations in implementing new technology. In addition, policymaking should be adjusted to farmers' preferences regarding the application of floating rice technology, otherwise, efforts to implement it will be ineffective [43].

IV. CONCLUSION

Floating rice cultivation can be used as a solution to reduce crop failure in flood-prone areas, especially in lowland close to watersheds, such as in Bojonegoro Regency, Indonesia. The average rice productivity from this floating system was 11.58 tons ha^{-1}. The planting media of soil and rice husk with 25 cm x 25 cm plant spacing gave the best result in the growth and yields. This information needs to be circulated to the farmers to provide knowledge regarding the floating cultivation techniques.

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REFERENCES

[1] I. Ridwansyah *et al.*, "The impact of land use and climate change on surface runoff and groundwater in Cimanuk watershed, Indonesia," *Limnology*, vol. 21, no. 3, pp. 487–498, 2020, doi: 10.1007/s10201-020-00629-9.

[2] K. Yamamoto, T. Sayama, and Apip, "Impact of climate change on flood inundation in a tropical river basin in Indonesia," *Prog. Earth Planet. Sci.*, 2021, doi: 10.1186/s40645-020-00386-4.

[3] N. flood management agency Indonesia, "Disaster in Indonesia," 2020. https://www.gfdrr.org/indonesia.

[4] Regional Disaster Management Agency of Bojonegoro Regency, "No Title." http://bpbd.bojonegorokab.go.id.

[5] H. Irianto, Mujiyo, E. W. Riptanti, and A. Qonita, "The land use potential of flood-prone rice fields using floating rice system in Bojonegoro regency in East Java," *IOP Conf. Ser. Earth Environ. Sci.*, vol. 142, no. 1, 2018, doi: 10.1088/1755-1315/142/1/012072.

[6] R. M. S. Prastica, C. Maitri, A. Hermawan, P. C. Nugroho, D. Sutjiningsih, and E. Anggraheni, "Estimating design flood and HEC-RAS modelling approach for flood analysis in Bojonegoro city," *IOP Conf. Ser. Mater. Sci. Eng.*, vol. 316, no. 1, 2018, doi: 10.1088/1757-899X/316/1/012042.

[7] R. Roy, A. K. Gain, M. A. Hurlbert, N. Samat, M. L. Tan, and N. W. Chan, "Designing adaptation pathways for flood-affected households in Bangladesh," *Environ. Dev. Sustain.*, vol. 23, no. 4, pp. 5386–5410, 2021, doi: 10.1007/s10668-020-00821-y.

[8] E. W. Riptanti, Mujiyo, H. Irianto, and A. Qonita, "Efficiency of experimental scale floating rice farming in flood-prone areas," *Ecol. Environ. Conserv.*, 2019.

[9] B. B. Shrestha *et al.*, "Assessing flood disaster impacts in agriculture under climate change in the river basins of Southeast Asia," *Nat. Hazards*, vol. 97, no. 1, pp. 157–192, 2019, doi: 10.1007/s11069-019-03632-1.

[10] E. Siaga *et al.*, "Application of floating culture system in chili pepper (Capsicum annum L.) during prolonged flooding period at riparian wetland in Indonesia," *Aust. J. Crop Sci.*, 2018, doi: 10.21475/ajcs.18.12.05.PNE1007.

[11] H. Irianto, Mujiyo, A. Qonita, and E. W. Riptanti, "Socio-economic characteristics of farmers on the existence of floating-rice cultivation demonstration plots in flood prone area in Bojonegoro, East Java," *IOP Conf. Ser. Earth Environ. Sci.*, vol. 314, no. 1, 2019, doi: 10.1088/1755-1315/314/1/012048.

[12] R. B. Chowdhury and G. A. Moore, "Floating agriculture: a potential cleaner production technique for climate change adaptation and sustainable community development in Bangladesh," *J. Clean. Prod.*, 2017, doi: 10.1016/j.jclepro.2015.10.060.

[13] V. H. Tu, N. D. Can, Y. Takahashi, and M. Yabe, "Water Use Efficiency in Rice Production: Implications for Climate Change Adaptation in the Vietnamese Mekong Delta," *Process Integr. Optim. Sustain.*, 2018, doi: 10.1007/s41660-018-0038-1.

[14] R. Singh and G. S. Singh, "Traditional agriculture: a climate-smart approach for sustainable food production," *Energy, Ecology and Environment*. 2017, doi: 10.1007/s40974-017-0074-7.

[15] M. K. Hasan, S. Desiere, M. D'Haese, and L. Kumar, "Impact of climate-smart agriculture adoption on the food security of coastal farmers in Bangladesh," *Food Secur.*, 2018, doi: 10.1007/s12571-018-0824-1.

[16] B. Lakitan *et al.*, "Recognizing farmers' practices and constraints for intensifying rice production at Riparian Wetlands in Indonesia," *NJAS - Wageningen J. Life Sci.*, 2018, doi: 10.1016/j.njas.2018.05.004.

[17] S. Purnamawati, "Potensi Pengembangan Teknologi Budidaya Padi Apung untuk Mengatasi Risiko Banjir," Institut Pertanian Bogor, 2013.

[18] E. Siaga and B. Lakitan, "Budi daya Terapung Tanaman Sawi Hijau dengan Perbedaan Dosis Pupuk NPK, Ukuran Polibag, dan Waktu Pemupukan," *J. Ilmu Pertan. Indones.*, 2021, doi: 10.18343/jipi.26.1.136.

[19] H. Irianto, Mujiyo, E. W. Riptanti, and A. Qonita, "Farmers ' intention to adopt agriculture technology in the flood-prone areas," *Eurasian J. Biosci.*, vol. 7658, no. 2, pp. 7651–7658, 2020.

[20] Soil Research Center, "Soil Fertility Evaluation Technical Instructions," Bogor, 1995.

[21] M. Mujiyo, Y. Y. Setyawan, A. Herawati, and H. Widijanto, "The effect of land use on soil quality in Giriwoyo Sub-district, Wonogiri Regency," *J. Degrad. Min. Lands Manag.*, 2021, doi: 10.15243/jdmlm.2021.082.2559.

[22] K. Mehmood, M. A. Al Baquy, and R. kou Xu, "Influence of nitrogen fertilizer forms and crop straw biochars on soil exchange properties and maize growth on an acidic Ultisol," *Arch. Agron. Soil Sci.*, 2018, doi: 10.1080/03650340.2017.1385062.

[23] M. Mujiyo, S. Suntoro, R. P. Tyas, A. Herawati, and H. Widijanto, "Mapping soil quality in various land uses as a basis for soil management in Wonogiri, Indonesia," *J. Settlements Spat. Plan.*, vol. 11, no. 2, pp. 127–135, 2020, doi: 10.24193/JSSP.2020.2.06.

[24] C. Singh, S. Tiwari, V. K. Gupta, and J. S. Singh, "The effect of rice husk biochar on soil nutrient status, microbial biomass and paddy productivity of nutrient poor agriculture soils," *Catena*, 2018, doi: 10.1016/j.catena.2018.07.042.

[25] Z. Li *et al.*, "Effects of phytolithic rice-straw biochar, soil buffering capacity and pH on silicon bioavailability," *Plant soil*, 2019, doi: 10.1007/s11104-019-04013-0.

[26] S. Suntoro *et al.*, "Effect of cow manure and dolomite on nutrient uptake and growth of corn (Zea mays l.)," *Bulg. J. Agric. Sci.*, vol. 24, no. 6, pp. 1020–1026, 2018.

[27] A. K. Thakur, K. G. Mandal, and S. Raychaudhuri, "Impact of crop and nutrient management on crop growth and yield, nutrient uptake and content in rice," *Paddy Water Environ.*, 2020, doi: 10.1007/s10333-019-00770-x.

[28] M. Asghar, T. ul Hassan, M. Arshad, A. Aziz, M. T. Latif, and A. M. Sabir, "Effect of plant spacing on incidence of rice planthoppers in transplanted rice crop," *Int. J. Trop. Insect Sci.*, 2021, doi: 10.1007/s42690-020-00242-4.

[29] W. Hou *et al.*, “Nitrogen rate and plant density interaction enhances radiation interception, yield and nitrogen use efficiency of mechanically transplanted rice,” *Agric. Ecosyst. Environ.*, 2019, doi: 10.1016/j.agee.2018.10.001.

[30] M. S. Masulili, A., Utomo, W. H., and Syechfani, “Rice Husk Biochar for Rice Based Cropping System in Acid Soil 1. The Characteristics of Rice Husk Biochar and Its Influence on the Properties of Acid Sulfate Soils and Rice Growth in West Kalimantan, Indonesia,” *J. Agric. Sci.*, vol. 2, pp. 39–47, 2010.

[31] E. P. A. Pratiwi and Y. Shinogi, “Rice husk biochar application to paddy soil and its effects on soil physical properties, plant growth, and methane emission,” *Paddy Water Environ.*, vol. 14, no. 4, pp. 521–532, 2016, doi: 10.1007/s10333-015-0521-z.

[32] M. Ghorbani, H. Asadi, and S. Abrishamkesh, “Effects of rice husk biochar on selected soil properties and nitrate leaching in loamy sand and clay soil,” *Int. Soil Water Conserv. Res.*, 2019, doi: 10.1016/j.iswcr.2019.05.005.

[33] B. A. Goodman, “Utilization of waste straw and husks from rice production: A review,” *Journal of Bioresources and Bioproducts*. 2020, doi: 10.1016/j.jobab.2020.07.001.

[34] J. O. Eduah, E. K. Nartey, M. K. Abekoe, H. Breuning-Madsen, and M. N. Andersen, “Phosphorus retention and availability in three contrasting soils amended with rice husk and corn cob biochar at varying pyrolysis temperatures,” *Geoderma*, 2019, doi: 10.1016/j.geoderma.2019.01.016.

[35] K. Kartika *et al.*, “Effects of particle size and application rate of rice-husk biochar on chemical properties of tropical wetland soil, rice growth and yield,” *Aust. J. Crop Sci.*, 2018, doi: 10.21475/ajcs.18.12.05.PNE1043.

[36] A. Herawati, J. Syamsiyah, Mujiyo, M. Rochmadtulloh, A. A. Susila, and M. R. Romadhon, “Mycorrhizae and a soil ameliorant on improving the characteristics of sandy soil,” *Sains Tanah*, vol. 12, no. 2, 2021, doi: 10.20961/STJSSA.V18I1.43697.

[37] N. J. Sithole and L. S. Magwaza, “Long-term changes of soil chemical characteristics and maize yield in no-till conservation agriculture in a semi-arid environment of South Africa,” *Soil Tillage Res.*, vol. 194, 2019, doi: 10.1016/j.still.2019.104317.

[38] A. Cai *et al.*, “Manure acts as a better fertilizer for increasing crop yields than synthetic fertilizer does by improving soil fertility,” *Soil Tillage Res.*, vol. 189, 2019, doi: 10.1016/j.still.2018.12.022.

[39] W. Ahmed *et al.*, “Tillage practices improve rice yield and soil phosphorus fractions in two typical paddy soils,” *J. Soils Sediments*, 2020, doi: 10.1007/s11368-019-02468-3.

[40] Y. Zhang, W. Zhang, M. Wu, G. Liu, Z. Zhang, and J. Yang, “Effects of irrigation schedules and phosphorus fertilizer rates on grain yield and quality of upland rice and paddy rice,” *Environ. Exp. Bot.*, 2021, doi: 10.1016/j.envexpbot.2021.104465.

[41] A. S. Saputra, S. Suprihati, and E. Pudjihartati, “The Effect of Phosphorus and Potassium on the Growth and Quality of Viola (Viola cornuta L.) Seed Production,” *Caraka Tani J. Sustain. Agric.*, 2019, doi: 10.20961/carakatani.v35i1.33618.

[42] Y. Deng *et al.*, “Tolerance to low phosphorus in rice varieties is conferred by regulation of root growth,” *Crop J.*, 2020, doi: 10.1016/j.cj.2020.01.002.

[43] S. Aravindakshan *et al.*, “Quantifying farmers’ preferences for cropping systems intensification: A choice experiment approach applied in coastal Bangladesh’s risk prone farming systems,” *Agric. Syst.*, 2021, doi: 10.1016/j.agsy.2021.103069.