Research Article

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Performance of rice paddy varieties under various organic soil fertility strategies

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Abstract: It has been widely known that integrating and adopting sustainable agricultural practices can restore and maintain the health of degraded agricultural land and adapt to climate change. *Azolla pinnata* and *Sesbania rostrata* are local potential plants in paddy fields that can be used as green manures. Two paddy varieties were planted. The experiment was conducted as factorial randomized block design, consisting of green manure types (p1 = goat manure 10 t/ha, p2 = goat manure 10 t/ha + *Azolla* 10 t/ha, p3 = goat manure 10 t/ha + *Sesbania* 2 t/h, and p4 = goat manure 10 t/ha + *Azolla* 5 t/ha + *Sesbania* 1 t/ha) and rice varieties (v1 = Bangir and v2 = Inpari 41). The results indicated that the use of green manure has increased the nitrogen and organic carbon contents in the soil from 0.10% and 0.82% to more than 0.20% and 2.0%, respectively. Inpari 41 variety produced higher grain yield (4.92 t/ha) compared to Bangir variety (3.48 t/ha). These findings indicate that the suitable green manure combined with paddy varieties can improve the resilience of soil health and paddy productivity.

Keywords: *Azolla pinnata*, *Sesbania rostrata*, green manure, paddy variety

1 Introduction

Soil health and fertility decline significantly due to intensive use of inorganic and agrochemical fertilizers

(Souri 2016; Ge et al. 2018). Presently, around 70% of paddy fields in Indonesia contain a low organic content [$<1.5\%$ organic carbon (C)], which can significantly reduce the fertilizer use efficiency (Peng et al. 2017; Simarmata et al. 2018). A large proportion of agricultural lands in Indonesia are at risk of degradation leading to great negative impacts on food production, particularly rice production, with severe consequences for food security sustainability (Cho 2018). Global warming significantly impacts precipitation patterns and plant growth parameters, which in turn exacerbate agricultural productivity. To secure food particularly rice for the growing population, additional pressure on agriculture resources is expected (Yang et al. 2018). National rice production can be reduced by adverse climatic and environmental conditions (Padukkage et al. 2017). Maintaining soil health and restoring degraded agricultural land are the major strategies that need to be adapted. Sustainable agricultural practices are solutions for the preservation of soil, plant, animal, and water resources, by protecting the environment and by following the feasible and economically beneficial as well as socially acceptable procedures. With these traits, sustainable agriculture has a high climate change mitigation and adaptation potential.

The sustainable production of rice can be achieved by adopting the integrated nutrient management strategies. Development of site-specific (agroecological zone-based) nutrient recommendations to achieve target and high profits from rice yield without declining the soil fertility would probably be the best fertilizer management practice in cultivation of rice. Soil organic matter management is the key factor for restoring and maintaining of soil health. Organic matter affects the biological, chemical, and physical properties of the soil and its overall health and productivity (Naiji and Souri 2018). These properties are influenced by organic matters including the structure of the soil, moisture-holding capacity, and the diversity and activity of soil organisms. Plants and other organisms also use organic materials as their source of energy and nutrition (Sullivan 2004).

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Green manure, organic fertilizer, and plant residues can be a medium for delivering organic material. Soil organic C can be increased by more than 2% with the integrated soil organic management.

Azolla pinnata and *Sesbania rostrata* are the organic matter sources in paddy fields that can be used as green fertilizer to increase the soil fertility. They have a relatively high nutrient content including nitrogen (N). *Azolla* is symbiotic with *Anabaena* in binding free N in the air. The symbiosis between *Azolla* and *Anabaena azollae* can be tied to 100–170 kg N/ha yearly (Setiawati et al. 2017) or 30–100 kg N/ha/crop (Yao 2018). *Sesbania* is an ideal green manure because it is fast growing, can be easily decomposed, and has the ability to maintain soil moisture and to induce organic matter and N in the soil. *Sesbania* produces 5.2 t/ha of dry matter, which is equivalent to 135 kg N/ha (Ehsan et al. 2014). The implementation of green manure techniques – *Azolla* and *Sesbania* – has been recommended in the previous studies for reducing the quantity of inorganic N fertilizers in paddy fields (Simarmata et al. 2011).

This study focuses on promoting climate resilient agriculture technologies by appropriately investigating the variety of suitable rice and green manure applications that can enhance the nutrient uptake and rice productivity in a sustainable way. The best performing rice varieties and green manure applications are assessed with the intention to out scale the recommended systems as climate change mitigation and adaptation measures to Indonesian paddy farmers.

2 Materials and methods

The study was conducted in Ciganjeng Village Padaherang, Pangandaran district, West Java (7°34'44" S, 108°42'43" E, altitude: 12 m), where the rice cultivation activities have been accomplished since the last two decades. The period of experimental study was from November 2018 to March 2019, during which, rice was cultivated twice a year by utilizing the chemical fertilizer. During two previous growing seasons, the rice was cultivated using organic fertilizers. The climate belonged to category B with respect to the classification by Schmidt–Ferguson a subhumid agroclimatic zone.

A range of suitable lowland paddy varieties were preselected by the involved researchers based on their variety descriptions. The farmers involved in this research finally chose two suitable varieties to be tested based on their own criteria. The varieties chosen in this

study were a local rice variety Bangir and an introduced variety Inpari 41. Bangir has a good appearance in the growth phase (Prayoga et al. 2018), while Inpari 41 variety has a fairly high yield potential (7.83 t/ha) and is deemed as saline tolerant (Center for Research and Development of Food Crops 2016).

To compare the treatments, a factorial randomized block design was used. The design in this experiment consisted of two factors. The first factor consists of the type of green manure with: p1 = goat manure 10 t/ha, p2 = goat manure 10 t/ha + *Azolla* 10 t/ha, p3 = goat manure 10 t/ha + *Sesbania* 2 t/ha, and p4 = goat manure 10 t/ha + *Azolla* 5 t/ha + *Sesbania* 1 t/ha. The second factor was the variety consisting of: v1 = Bangir (local variety) and v2 = Inpari 41 (recommended variety). The organic manure was added 1 week before planting. Two young single seedlings (8 days) were planted at an interval of 5 cm at each planting point and the distance between planting points was 30 cm × 30 cm. While the size of the experimental farm was set to 1,000 m², the size of a plot per treatment was about 16 m² (8 m × 2 m) with a 0.5 m buffer in between. The soil in field is mainly classified as silty clay. Observations were made in chemical properties of initial soil and after treatments with different types of organic manure. Soil organic was measured by the dichromate digestion method. Total N was measured by Kjeldahl steam distillation method. Soil (0–15 cm) from each replicate was sampled in initial soil and each plot treatment and pooled together, air dried, ground, and through 2 mm sieve for chemical analysis. The plant observations were made on generative and postharvest phases. The observed characters were the plant height and number of tillers carried out at 8 weeks after planting (WAP), the weight of 100 grains, weight grains per plant, and grain yield carried out at 12 WAP.

The differences between green manure and varieties were analyzed via an analysis of variance *post hoc* analysis using the Tukey's honest significance test or Tukey's HSD. The PKBT software package was employed to process the data.

3 Result and discussion

3.1 Chemical soil properties

The goat manure in combination with *Azolla* and *Sesbania* improved organic C, N, and C/N ratio of the

Table 1: Chemical properties of fertilized plot with different types of organic manure

Parameter	Initial soil analysis ^a	Treatments ^a			
		p1	p2	p3	p4
Organic carbon (%)	0.82	2.07	2.37	1.98	2.34
Nitrogen (%)	0.10	0.20	0.25	0.23	0.23
C/N ratio	8.00	11.00	10.00	9.00	10.00

^a Mean of two replicates.

soil compared to the preliminary soil analysis (Table 1). The organic C of soil increased from 0.82% to more than 2% at p1, p2, and p4 treatments, which indicates an increase in soil health. The application of 10 t/ha goat manure + 2 t/ha *Sesbania* had a lower increase in organic C, which did not reach 2%. However, an organic matter content of 2–3% is needed to nurture the long-term soil quality (Simarmata et al. 2018). An application of 2 t/ha *Sesbania* was not sufficient, as the organic C content of *Sesbania* plants is rather low. *Sesbania* are legume plants with a lower potential for increasing the organic C matter in the soil.

Soil N and organic C have also increased when compared to the initial content. Table 1 illustrates that the total N increased from 0.1% to more than 0.2% in all green manure treatments. Nitrogen is one of the most required mineral nutrients for plant growth and productivity, because it not only enhances the yield but also improves the food quality (Ullah et al. 2010; Leghari et al. 2016). Lack of N will cause plants not to grow optimally. In this study, *Azolla* mixed with goat manure produced the highest N content in the paddy soil. *Azolla* is usually very rich in N and therefore particularly well-known for its use as an N fertilizer in rice fields (Hove and Lejeune 2002). It has been estimated that *Azolla* contains 3–6% N of the dry weight of the association. This is 3–6 times higher compared to the N content of goat manure. The symbiotic *A. azollae* is able to reduce atmospheric N through the activity of enzyme nitrogenase present in the heterocysts and fulfill the total N requirement of the association (Pabby et al. 2003). *A. azollae* provides *Azolla* with ammonium, whereas *Azolla* provides the cyanobacterium with a fixed source of C.

Moreover, adding organic content in the form of goat manure and green manure increased the C/N ratio of the soil. The green manure treatment of *Sesbania* showed relatively more N, a lower C/N ratio, and a similar effect

like chemical nitrogenous fertilizers. In wetland rice fields, 40% of the C and 80% of the N of *Sesbania* mineralized in the first 10 days of incorporation. The N release was highest in the fifth week after incorporation (Selvi et al. 2005). *Sesbania* as a legume provides high-quality residues with low C/N, low lignin, and polyphenol contents. In contrast, rice straw can be classified into an intermediate quality category due to its high C/N ratio, but it does not have high lignin and polyphenols (Vityakow et al. 2000).

3.2 Analysis variance of rice varieties and green manure treatments

To see the extent of nutrient uptake by plants, observations were made on several physiological and performance parameters of the rice plants. The results reveal that the coefficient of variation (CV) in each observation parameter ranged from 2.30% to 10.58% (Table 2). The CV indicates the level of accuracy of the treatments that are compared. A CV of less than 25% is considered as good (Prayoga et al. 2016), as the trial error for the observed characters is relatively small. The greater the CV value, the greater the uncertainty of a study.

Table 2: Analysis of variance for each character

Character	Varieties	Type of manure	CV (%)
Plant height	**	ns	2.30
Number of tillers	ns	ns	8.98
Weight of 100 grains	ns	ns	4.46
Weight of grains per plant	*	ns	10.58
Grain yield	**	ns	4.04

Note: * significant in $P < 0.05$; ** significant in $P < 0.01$; ns = nonsignificant.

3.3 Plant height

There were significant differences of plant height between varieties. The Bangir variety was on an average 14 cm higher compared to Inpari 41. The plant height is one of the parameters that indicate the effect of the environment to growth. It is a central part of the ecological strategy of a plant. It is strongly correlated with life span, seed mass, and time to maturity, and is a major determinant of a species ability to compete for

light (Moles et al. 2009). The difference in plant height between Bangir and Inpari 41 varieties was due to genetical difference. Differences in genetic response to the environment affect the growth patterns between varieties (Sitaresmi 2016). The differences in genetic and the physiological response to environmental conditions may explain this result. Understanding patterns of gene expression evoked during changes in physiological state, or in response to environmental change, give insights regarding the molecular basis of phenotype from the cellular on the whole organism level (Table 3).

All treatments with incorporated goat manure and added with Azolla, Sesbania, or both, revealed similar plant height, without significant differences. This can be explained by the observation; that the determinant factor N did not differ much between 0.2% and 0.25% of the four treatments (Table 1). In the vegetative phase, many physiological and metabolism processes are associated with adequate N (Zhong et al. 2017; Souri and Hatamian 2019). All important processes in plants are closely related to protein, of which N is the most important element. Consequently, to obtain good vegetative growth, N application is indispensable and unavoidable. Nitrogen also plays a key role in reproductive growth and increasing rice crop yield. Nitrogen affects the organ construction, physiological characteristics, and substance synthesis as well as their distribution, which in turn affects the rice yield and quality (Maathuis 2009).

Table 3: Plant height (cm) of rice varieties fertilized with different types of organic manure

Varieties	Treatments				Average of varieties
	p1	p2	p3	p4	
Bangir	132.25	126.50	140.75	120.25	129.94 ^a
Inpari 41	109.25	112.50	123.00	119.00	115.94 ^b
Average of treatments	120.75 ^a	119.50 ^a	131.88 ^a	119.63 ^a	

Note: numbers followed by the same superscript letter are nonsignificant ($P < 0.05$).

3.4 Number of tillers

The results for the number of tillers show no significant difference between varieties and between treatments (Table 2). Bangir and Inpari 41 varieties have 22 tillers per plant a similar number (Table 4). According to the

Table 4: Number of tillers of two rice varieties fertilized with different types of organic manure

Varieties	Treatments				Average of varieties
	p1	p2	p3	p4	
Bangir	24.00	24.5	23.50	17.50	22.38 ^a
Inpari 41	18.75	21.75	25.50	20.50	21.63 ^a
Average of treatments	21.38 ^a	23.13 ^a	24.50 ^a	19.00 ^a	

Note: numbers followed by the same superscript letter are nonsignificant ($P < 0.05$).

Rice Standard Evaluation System, the number of tillers are very high (more than 25 tillers/plant), good (20–25 tillers/plant), medium (10–19 tillers/plant), low (5–9 tillers/plant), and very low (less than 5 tillers/plant) (IRRI 2002). The growth rate of rice can be affected by internal effects such as genetic characteristic or agro-nomic traits and external ones, for examples, environmental conditions, biotic factors, chemical, or biological fertilization (Tohidloo et al. 2018; Kim and Lee 2020). The differences in the number of tillers in each variety are suspected due to the abovementioned factors. The differences in plant height and number of tillers are caused by the differences in genetic characteristics that each variety has (Anhar et al. 2016).

A previous study showed that the number of tillers and panicles per hill were significantly higher in a dry season experiment compared to the wet season experiment, for all 15 genotypes that have been tested (Sumarno and Sutisna 2010). In the dry season, each genotype produced normal amount of tillers, ranging from 15 to 21 tillers per hill, and also produced normal number of panicles, ranged from 12 to 16 panicles per hill. For the wet season experiment, the figures were lower, i.e., 9–13 tillers and 7–10 panicles per hill.

In another study, the increasing number of rice tillers was due to the influence of different fertilizers. A higher number of tillers can be the result of more available N, which is responsible for cell division and cell elongation (Mirza Hasanuzzaman et al. 2010; Souri and Hatamian 2019). The N uptake efficiency in rice is generally low due to high denitrification, runoff, and volatilization (Setiawati et al. 2018). In this study, the number of tillers was not influenced by the type of organic fertilizer. This might be due to the fact that the N content did not differ between the treatments (Table 1). The tillering rate can be rated as good and the overall number is higher than the average number of tillers in the dry season experiments.

3.5 Performance parameters: 100-grain weight, weight of grains per plant and yield

With regard to various performance parameters, that is, 100-grain weight, weight of grains per plant and yield, there was no significant difference for different soil fertility treatments (Table 2). However, for two parameters, the weight of grains per plant and the grain yield, the two varieties showed significant differences.

Table 5 shows that the Bangir variety had a similar grain weight like Inpari 41 with a 100-grain weight of 3.55 and 3.61 g, respectively. The grain size is a good indicator for grain weight. As it is mainly influenced by its genetic traits (Lee et al. 2015), and for Bangir and Inpari 41, similar grain sizes can be concluded based on similar 100-grain weights.

Weight of grain per plant which was fertilized with different types of organic manure was not different in the treatments. The type of green manure increased rice yield per plant by only 7–17% compared to goat manure only. Overall, it did not significantly affect the increase of weight per plant (Table 6).

However, Table 6 also shows that there were significant differences between two rice varieties. Inpari 41's grain weight per plant was significantly higher, averaging 78.03 g compared to 64.45 g per plant of Bangir variety. For farmers, the grain yield is of major relevance. Inpari 41 resulted in higher grain yields (4.92 t/ha) compared to Bangir with 3.48 t/ha. The different organic soil fertility treatments did not result in significantly different yields.

The nutrient content in the soil seems to be the most influencing factor of the rice yield. Barison and Uphof (2011) state in their study that under the system of rice intensification (under organic conditions), higher yields were obtained if the supply resources are adequately

Table 6: Comparisons of weight of grain per plant (g) of two rice varieties fertilized with different types of organic manure

Varieties	Treatments				Average of varieties
	p1	p2	p3	p4	
Bangir	59.56	64.64	62.41	71.19	64.45 ^b
Inpari 41	70.68	75.84	83.85	81.75	78.03 ^a
Average of treatments	65.12 ^a	70.24 ^a	73.13 ^a	76.47 ^a	

Note: numbers followed by the same superscript letter are nonsignificant ($P < 0.05$).

enough, which in turn can contribute to higher dry matter accumulation and better partitioning of photosynthate. Moreover, integrated soil fertility management, i.e., the application of manure with N fertilizer, significantly increased the number, length, and weight of panicles, the number of filled grains/panicle, the 1,000-grain weight, and the grain yield in rice (Salem 2006). The increasing grain yield components can be due to the increased availability of water enhances nutrient availability which improved N and other macro- and micro-elements absorption as well as enhanced the production and translocation of the dry matter content from source to sink (Ebaid and El-Refaei 2007). The organic compound of the soil improves the biological, physical, and chemical properties of the soil (Espe et al. 2015). Besides its function as a source of nutrients like N, phosphorus, and sulfur, soil organic matter also increases the ability of the soil to hold nutrients (Liu et al. 2014). In the present study, the p3 and p4 treatments showed the highest performance, even though the differences were not significant (Table 7).

Plant varieties can have different effects on nutrient uptake, causing differences in accumulating nutrients in plant and increasing yield per plant. The rice grain yield is a quantitative character influenced by many genes and strongly by the environment (Assanga et al. 2017). The character of grain yield is used to calculate nutrient uptake efficiency. Consequently, it can be seen that the type of rice variety makes a clear difference in the rice grain yield. Inpari 41 variety has a better ability to absorb nutrients than Bangir under the same environmental conditions. This is one of the reasons that Inpari 41 produces higher yields. In line with Singh et al. (2015), higher grain yield under organic fertilizer treatment appears to be related to both greater and more balanced nutrient uptake.

This study revealed that Inpari 41 variety had a higher ability of nutrient uptake. The higher the nutrient

Table 5: One hundred-grain weight (g) of two rice varieties fertilized with different types of organic manure

Varieties	Treatments				Average of varieties
	p1	p2	p3	p4	
Bangir	3.67	3.61	3.51	3.44	3.55 ^a
Inpari 41	3.54	3.74	3.60	3.54	3.61 ^a
Average of treatments	3.60 ^a	3.67 ^a	3.56 ^a	3.49 ^a	

Note: numbers followed by the same superscript letter are nonsignificant ($P < 0.05$).

Table 7: Comparisons of grain yield (t/ha)

Varieties	Treatments				Average of varieties
	p1	p2	p3	p4	
Bangir	3.36	3.52	3.60	3.44	3.48 ^b
Inpari 41	4.40	4.72	4.72	5.84	4.92 ^a
Average of treatments	3.88 ^a	4.12 ^a	4.16 ^a	4.64 ^a	

Note: numbers followed by the same superscript letter are nonsignificant ($P < 0.05$).

uptake efficiency, the better the variety has the ability to utilize nutrients. The appearance of a plant is the product of interactions between genetics and its environment. Both are interrelated and influence each other. Plants with good genetic makeup do not necessarily show optimal performance if the environment is not supportive and vice versa (Baihaki and Wicaksana 2005). The manure combined with green manure resulted in better environmental conditions for rice plants by providing the nutrients that are required by the rice plants. Moreover, the application of goat manure + Azolla + Sesbania green manure with the improved variety Inpari 41 produced highest grain yields; however, not significantly different from other treatments related to soil health, the application of various types of manure with green manure was able to improve the soil health and nutrient availability to support the rice growth.

4 Conclusion

The applications of different types of organic and green manure were able to improve the soil health and the nutrient availability to support the rice growth. Soil N and C content increased by the application of green manure from 0.10% and 0.82% to more than 0.20% and 2.0%, respectively. The stress-tolerant Inpari 41 variety produced higher grain yield (4.92 t/ha) compared to Bangir variety (3.48 t/ha). It can be concluded that the use of a mixed organic strategy of goat manure combined with green manure and in combination with suitable paddy varieties with good nutrient uptake could enhance the soil health and paddy productivity at the same time.

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