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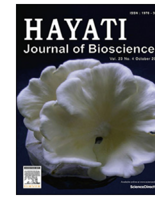

Original research article

Application of Bioameliorant and Biofertilizers to Increase the Soil Health and Rice Productivity

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ABSTRACT

The major rice intensity of diseases in Indonesia was increased significantly and has caused a yield loss of up to 20–30%. The experiments had been conducted to investigate the effect of bioameliorant or composted straw (CS) combined with consortia of biofertilizers (CB) and biocontrol agent to restore the soil health and promote the induced systemic resistance (ISR) for increasing the rice productivity. The experiment arranged as randomized block design consisted of 12 treatments (0, 2.5, 5.0 and 7.5 ton of CS per ha combined with 400 g of CB and 200 g inoculant of CB + 200 g inoculant of *Trichoderma* sp and was provided with three replications. The experimental results revealed that application of 2.5–7.5 ton per ha of bioameliorant combined with 400 g per ha of CB and 400 g *Trichoderma* sp has increased the ISR and enhanced the rice productivity significantly. The brown spot, sheath rice blight and bacterial leaf blight diseases were reduced from 16.7% to 3.3–8.0%, 20% to 4–10%, 24% to 2.7–4.7% and 20.7% to 8–14.0%, respectively at 7 weeks after transplanting. In addition, the rice grain yield was increased from about 7.1 ton ha^{-1} to 7.9–10.1 ton per ha.

1. Introduction

Indonesia is facing a crucial challenge and dilemma to produce sufficient food and other agricultural products to meet the need of a rapidly growing population and to run agricultural practices in sustainable ways. The excessive use of inorganic fertilizers and other agrochemical products since the adopting of green revolution in Indonesia not only increases the food production and other agricultural products but also gives a significant effect on land degradation, environmental problems, and the increasing of rice yield losses (pest and diseases). The Indonesian rice production and productivity by adopting a technology package comprising improved high-yielding varieties of rice, irrigation or controlled water supply, improved moisture utilization, fertilizers and pesticides, and associated management skills has been increased sharply from 2.5 tons per ha in the 1960–70s to 5–6 ton per ha in 2015 (Hazell 2009; Simarmata *et al.* 2011)

It is strong indication that a high use of inorganic fertilizers has reached a leveling off (plateau) of productivity increment. The average growth rice productivity from 1970 to 1984 was about 3.7% per year, and in the period of 1985–2008, it was only 0.95% per year. Most of the agricultural soils, either wetland or dryland ecosystems, in Indonesia have been degraded and exhausted because of intensive cultivation and overexploitation. The latest data revealed that about 70% of paddy soils have a low organic carbon (less than 1.5%), and about 90% of dry land belong to sick soils (low organic carbon and high acidity) (Simarmata *et al.* 2011; Turmuktini *et al.* 2012). The status of essential plant nutrients of most

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agricultural lands such as macronutrients and micronutrients is low, especially in nitrogen, phosphorus, and potassium. However, continued heavy use of imbalance chemical fertilizers may promote the intensity of rice diseases and may cause about 15–30% of yield losses. The major rice diseases in Indonesia are rice blast, bacterial leaf blight (BLB), and brown spot (BS) (IRRI 2002). Rice blast disease reduced plant growth, number of tillers, and grain yield. The losses in rice yield was as high as 50%, and if infection at tillering stage can lead to total losses (Koutroubas *et al.* 2009; IPB 2011; Purwanto *et al.* 2016).

The locally available organic ameliorant (straw compost) can be used to remediate the soil health, increase the efficiency of fertilizers, and crop rice productivity. Straw compost not only is rich in energy (carbon) but also has the relative nutrient contents, especially potassium and silicon. The key success of rice cultivation depends on soil organic matter management for maintaining the carbon level in the soil. The rice straw is composted by using consortia of decomposer (*Streptomyces* sp., *Trichoderma* sp., *Cytophaga* sp., *Pseudomonas* sp., *and Bacillus* sp.) to accelerate the composting process to control the potential pathogen in straw and increase the straw compost quality.

The application of straw compost (bioaugmented straw compost) combined with consortia of biofertilizers (CB) has a great prospect to remediate and improve the soil health and increase the rice productivity in sustainable ways (Simarmata *et al.* 2015). In addition, the application of augmented straw compost will boost the biodiversity of beneficial microbes in rhizosphere and promote the induced systemic resistance (ISR). ISR emerged as an important mechanism by which selected plant growth-promoting bacteria and fungi in the rhizosphere prime the whole plant body for enhanced defense against a broad range of pathogens and insect herbivores. The induced resistance in plants is triggered by biological or chemical inducers, which protect no exposed plant parts against future attack by pathogenic microbes and herbivorous insects (Kuc 1982; Gaind and Nain 2011). The induced state of resistance is characterized by the activation of latent defense mechanisms that are expressed on a subsequent challenge from a pathogen or insect herbivore. Induced resistance is expressed not only locally at the site of induction but also systemically in plant parts that are spatially separated from the inducer, hence the term ISR. Generally, induced resistance confers an enhanced level of protection against a broad spectrum of attackers (Walters *et al.* 2013). Induced resistance is regulated by a network of interconnected signaling pathways in which plant hormones play a major regulatory role (Pieterse *et al.* 2012). Microorganisms that have been demonstrated to contribute to the disease suppressiveness of soils include *Trichoderma* sp., *Fusarium* sp., *Streptomyces* sp., *Bacillus* sp., *Actinomyces* sp., and *Pseudomonas* sp. (Weller *et al.* 2002; Gaind and Nain 2011; Mendes *et al.* 2011).

Biofertilizers can be defined as natural fertilizers that contains a large population of specific or a group of beneficial microorganisms for enhancing the productivity of soil either by fixing atmospheric nitrogen or by solubilizing soil phosphorus or by stimulating plant growth through synthesis of growth-promoting substances or latent cells that activate the biological process render to form a fertilizer compound or make the unavailable form of elements to be available or to facilitate availability of nutrients for plants (Singh and Purohit 2011; Bhattacharjee and Dey 2014). Its application under proper condition increases the yield of various crops by about 25% and reduces the application of inorganic fertilizers until 25–50% for nitrogen and about 25% for phosphor nutrient (Aggani 2013; Ghany *et al.* 2013; Simarmata 2013). Moreover, biofertilizers can improve soil health and provide protection against drought and some soil-borne diseases (Ellafi *et al.* 2010; Singh and Purohit 2011). The application of composted straw (CS) and CB is expected to be used to improve the soil health, reduce the intensity of major rice diseases (rice blast, BLB, BS, and other diseases) by promoting the ISR, and increase the efficiency of fertilizers and rice grain yield.

2. Materials and Methods

The field studies to investigate the effectiveness of CS using consortia of decomposer (bioameliorant), CB inoculants, and CB combined with *Trichoderma* sp. (CB-T) on the intensity of rice diseases and the rice yield was conducted from March until October 2012 at Research Station for Agricultural Development of Padjadjaran University in Bandung, located about 600 m above sea levels. The experiment arranged as a randomized block design consisted of 12 treatments (0, 2.5, 5.0, and 7.5 ton of CS per ha combined with 400 g of CB and 200 g inoculant of CB + 200 g inoculant of *Trichoderma* sp. [CB-T]) and was provided with three replications. Consortia of decomposer and biocontrol agent (*Streptomyces* sp., *Cytophaga* sp., *Bacillus* sp., Pseudomonas sp., and *Trichoderma* sp.) have been used for in situ aerobic composting of the straw. About 5 m^3 of the straw was inoculated with 500 g of consortia of decomposer agents, and the heap was composted from 30 days aerobically (Simarmata *et al.* 2011). CB was formulated using solid form organic-based carrier containing the isolate of *Azotobacter* sp., *Azospirilum* sp., *Pseudomonas* sp., *Bacillus* sp., and *Acinetobacter* sp. The population of each isolate was at least 10^8–10^9 cfu/g. Either the isolate for consortia of decomposer or bacterial isolates of CB were obtained from the culture collection of Soil Microbiology Laboratory of Agriculture Faculty of Padjadjaran University in Bandung. Isolate of *Trichoderma* sp. was obtained from the collection of Plant Diseases Laboratory of Department of Plant Protection.

The CS (0, 2.5, 5.0, and 7.5 ton per ha) was deployed 1 week on soil surface of plots (4 × 5 m) homogeneously before the land cultivation or preparation (incorporating). About 400 g of biofertilizers inoculant consortia (CB) or 400 g of biocontrol agent-biofertilizer (200 g of CB + 200 g of *Trichoderma* sp. inoculant) was mixed with 40 kg of compost and distributed evenly on the rice plots shortly before the transplanting of rice seedling. Two single young rice seedlings (15 days) of Ciherang variety were planted with plant spacing about 30 × 35 cm in line about 5 cm distance from each other at point of planting cross section (Simarmata *et al.* 2011). The seedling was planted by slipping in sideways rather than plunging it into the soil vertically making the shape of the transplanted seedling more like an L than like a J. With an L shape, it is easier for the tip of the root to resume its growth downward into the soil (Simarmata *et al.* 2011). The inorganic fertilizers were applied, as follows: fertilizers consisted of 25 kg urea, 50 kg SP-36, and 25 kg KCl shortly before transplanting; 100 kg of urea applied at 21 days after transplanting (DAT) or after weeding; and finally, 50 kg urea and 50 kg KCl per hectare are applied at 42 DAT. The water-saving technology is adopted by using the water-level indicator for watering the rice field (Simarmata *et al.* 2011; Antralina *et al.* 2015). Weeding and pest managements were done during the planting season. The rice was harvested at 100 DAT. The intensity of rice diseases was observed at 7 weeks after transplanting (WAT) using 0–9 scale of the standard evaluation system for rice (IRRI 2002). The intensity of diseases was calculated using the following formula.

$$I = \Sigma\left\{\frac{(nixi)}{NxV}\right\}x100\%$$

where I = disease intensity, n = number of plants in each category, i = scales of disease severity, V = the higher scale of disease severity, and N = number of plants observed.

The observed respond was analyzed by using F test, when significant, and then continued with Scott-Knott test at $p < 0.05$.

3. Results

3.1. Intensity of rice diseases

The intensity of rice diseases was reduced significantly by the application of CB or biofertilizers-*Trichoderma* sp. combined with CS (Table 1). The highest reduction of BS was obtained by 400 g CB-T and 2.5–7.5 ton per ha of straw compost. Similarly, results were obtained for narrow brown spot (NBS), sheath rice blight (SRB), and BLB. In general, highest reduction of rice diseases was obtained by the application of CS combined with biofertilizers and *Trichoderma* sp. (CS-BT). The intensity of BS diseases was reduced from 16.7% to 3.3–8.0%, NBS diseases from 20% to 4–10%, SRB from 24% to 2.7–4.7%, and BLB from 20.7% to 8–14.0% at 7 WAT. The highest reduction of intensity of BS was obtained by the application of biofertilizer and Trichoderma combined with 2.5–7.5 ton per ha of CS. Compared with control, the intensity of BS, NBS, SRB, and BLB was about 3–5, 3–4, 10–18, and 2–2.5 times lower, respectively. The increase of straw compost dosage from 2.5 to 7.5 ton per ha of treated plot with 400 g of CB-T resulted in a nonsignificant difference on the intensity of diseases.

3.2. Rice grain yield

The rice grain yield was increased significantly either by the application CB, CB-*Trichoderma* sp. (CB-T), or its combination with CS (Table 2). Compared with the control plot, the rice grain yield was increased from 7.1 ton per ha to 8.4–10.1 ton per ha (11.3–42.3% higher). Generally, the increasing dosage of composted rice straw has a tendency in increasing of the rice grain yield. The obtained rice grain yield about 8–10 ton per ha was highly satisfied compared with control. In addition, the applied dosage of inorganic fertilizers was reduced about 25% of recommended dosage of fertilizers on all plots as a basic fertilizer.

Table 1. Effect of composted straw, consortia of biofertilizers, and combination of consortia of biofertilizers with *Trichoderma* species on intensity of brown spot (*Helminthosporium oryzae*), narrow brown spot (*Cercospora janseana*), sheath rice blight (*Rhizoctonia solani*), and bacterial leaf blight diseases (*Xanthomonas oryzae*) of rice at 7 weeks after transplanting

Treatments	Intensity of diseases (%)			
	BS	NBS	SRB	BLB
Control	16.7 a	20.0 a	24.0 a	20.7 a
2.5 ton per ha CS	14.0 a	18.7 a	22.0 a	22.0 a
5 ton per ha CS	16.0 a	16.7 a	24.0 a	22.7 a
7.5 ton per ha CS	14.7 a	17.3 a	17.3 b	24.0 a
400 g per ha of CB	14.7 a	18.0 a	18.0 b	22.7 a
400 g per ha of CB + 2.5 ton per ha CS	14.0 a	10.0 b	16.0 b	18.0 a
400 g per ha of CB + 5 ton per ha CS	11.3 a	7.3 b	16.0 b	12.0 b
400 g per ha of CB + 7.5 ton per ha CS	8.0 b	5.3 b	2.7 c	10.0 b
400 g per ha of CB-T	8.7 b	4.0 b	4.7 c	14.0 b
400 g per ha of CB-T + 2.5 ton per ha CS	4.7 c	5.3 b	1.3 c	8.0 b
400 g per ha of CB-T + 5 ton per ha CS	3.3 c	7.3 b	3.3 c	10.0 b
400 g per ha of CB-T + 7.5 ton per ha CS	3.3 c	6.7 b	2.7 c	8.0 b

BLB = bacterial leaf blight; BS = brown spot; CB = consortia of biofertilizers; CB-T = consortia of biofertilizers combined with *Trichoderma* sp; CS = composted straw; NBS = narrow brown spot; SRB = sheath rice blight
Note: weeks after transplanting and the value within column followed by the same letter are not different significantly ($p < 0.05$)

Table 2. Effectiveness of composted straw, consortia of biofertilizer, and consortia of biofertilizer-*Trichoderma* species in increasing the rice grain yield

Treatments	Grain yield (t per ha)	Increment (%)
Control	7.1 a	—
2.5 ton per ha CS	7.7 a	8.5
5 ton per ha CS	7.7 a	8.5
7.5 ton per ha CS	7.3 a	2.8
400 g per ha of CB	8.6 b	21.1
400 g per ha of CB + 2.5 ton per ha CS	7.9 b	11.3
400 g per ha of CB + 5 ton per ha CS	8.4 b	18.3
400 g per ha of CB + 7.5 ton per ha CS	9.0 b	26.8
400 g per ha of CB-T	8.7 b	22.5
400 g per ha of CB-T + 2.5 ton per ha CS	8.8 b	23.9
400 g per ha of CB-T + 5 ton per ha CS	9.4 b	32.4
400 g per ha of CB-T + 7.5 ton per ha CS	10.1 b	42.3

CB = consortia of biofertilizers; CB-T = consortia of biofertilizers combined with *Trichoderma* sp.; CS = composted straw
Note: weeks after transplanting and the value within column followed by the same letter are not different significantly ($p < 0.05$)

4. Discussion

Reducing rice diseases and increasing yield are important indicators to detect the impact of bioameliorant and biofertilizers on improving the soil and rice health. The ISR was enhanced significantly either by the application of CB and biofertilizers-*Trichoderma* sp. (CB-T) or in combination with CS (bioameliorant). The application of compost increases biodiversity and activity of soil organisms in rhizosphere, which contribute to the increase of ISR (Kloepper *et al.* 2004; Oliveira *et al.* 2016). In addition, *Trichoderma* sp. is well known to biocontrol agent and enhances ISR and reduces various diseases (Kloepper *et al.* 2004; Devendra *et al.* 2007; Pieterse *et al.* 2014). These results also indicated that the application of bioameliorant, biofertilizers, and biofertilizers-biocontrol agent (biofertilizers-*Trichoderma* sp.) has the ability to improve the soil health and increase the efficiency of fertilizers. As reported by Simarmata *et al.* 2011, application of 2.5–5.0 ton per ha of ameliorant had increased the soil organic carbon significantly and improved the soil health status from fairly sick soils to fairly health soils. Previous studies revealed that the returning of rice straw as CS of 2.5–5.0 ton per ha will increase the soil organic carbon about 20% or about 0.1–0.2 unit. Consequently, there is a need of about 3 year or 6 year planting season to improve the organic carbon of degraded soil from 1.5% to become 2.0–2.5% (Simarmata *et al.* 2015). These results confirm that the application of biofertilizer either combined *Trichoderma* sp. or CS (bioameliorant) can be adopted to increase the ISR and rice productivity. It seems that the increase of ISR plays an important role in enhancing the plant health by suppressing the major rice diseases. Moreover by promoting the activity and biodiversity of plant growth-promoting rhizobacteria will contribute to the efficiency of fertilizers and plant health (Kloepper *et al.* 2004; Sharma *et al.* 2004; Simarmata 2013; Malusa *et al.* 2016).

Briefly, it can be concluded that application of 400 g per ha of CB or 400 g of biofertilizers-*Trichoderma* (CB-T) combined with 2.5–7.5 ton per ha of CS (bioameliorant) had enhanced the ISR and rice productivity; the intensity of BS diseases was reduced from 16.7 to 3.3–8.0%, NBS diseases from 20% to 4–10%, SRB from 24% to 2.7–4.7%, and BLB from 20.7% to 8–14.0% at 7 WAT, whereas the obtained rice grain yield (7.9–10.1 ton per ha) was increased by 11.3–42.3% compared with the control (7.1 ton per ha); economically, application of 2.5 ton per ha of CS combined with 400 g per ha of CB and 400 g of biocontrol agent (biofertilizers-*Trichoderma*) can be applied to reduce BS, NBS, SRB, and BLB rice diseases and increase the rice productivity in sustainable ways; and the intensive researches are urgently needed to improve the quality of biofertilizers and biocontrol agents (isolates of biofertilizers, consortia formulation, carrier composition, persistence of biofertilizers in soils, quality control, and regulation of biofertilizers, etc.) and to develop appropriate technology for mass production of decomposer biofertilizers and to make an access easy to users.

Conflict of interest

There is no conflict of interest.

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