Application of biofertilizers to increase upland rice growth, soil nitrogen and fertilizer use efficiency

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Abstract. High application of inorganic fertilizer has a negative impact on soil health. To reduce the use of inorganic fertilizers, one alternative is using biofertilizers. Biofertilizers are active inoculants made from living organisms that have the ability to mobilize, facilitate and increase the availability of nutrients through biological process. The experiment was conducted to study the effect of biofertilizers and inorganic fertilizers application on growth of upland rice, N-uptake and soil nitrogen. Biofertilizers were mixture of N-fixing bacteria (Azotobacter chroococum, Azospirillum sp.) and phosphate solubilizing microbes (Pseudomonas mallei, P. cepaceae, Aspergillus niger and Penicillium sp.). The field experiment used a Randomized Block Design (RBD) with ten treatments and three replications. The treatments were control, biofertilizers doses (50 kg ha⁻¹ and 75 kg ha⁻¹), inorganic fertilizers (50%, 75% and 100% of recommended doses) and combination of biofertilizers and inorganic fertilizers. The result revealed that 50 kg ha⁻¹ biofertilizers + 50% inorganic fertilizer increased growth of upland rice (the number of tillers). In addition, the application of biofertilizers increased fertilizer use efficiency.

1. Introduction

Upland rice is able to adapt well to dry land and it has good tolerance to acidic soils that contain high aluminum such as Inceptisols [1]. There are several obstacles faced in increasing upland rice yields on Inceptisols dry land, including low soil fertility, susceptibility to erosion, drought, high acidity, high phosphate fixation, poor organic matter and susceptibility to blast disease. Upland rice yields in Indonesia have only reached 5% of national rice yields and only produced 3 to 5 t ha⁻¹ [2].

Some efforts can be made to overcome the problems of dry land productivity for upland rice cultivation in a sustainable manner, such as by applying biofertilizers, biological agents and organic ameliorants [3]. Biofertilizers are inoculants with active living organisms in liquid or solid form that have the ability to mobilize, facilitate and increase the availability of nutrients through biological processes [4].

Biofertilizers play an important role in increasing land productivity in a sustainable manner and can increase plant growth and yield [5, 6]. Those biofertilizers increased sub-optimal soil nutrients including P-solubilizing microorganisms and N-fixing bacteria [7]. The application of inorganic fertilizers can adversely affect soil quality, so it needs to be combined with various kinds of organic or biofertilizers. The application of biofertilizers is expected to increase the efficiency of inorganic fertilizer use. The objective of the research was to study the effect of biofertilizers and inorganic fertilizers application on upland rice growth, N-uptake and soil nitrogen.
2. Materials and methods
The experiment was carried out at the field experiment of Agriculture Faculty, Universitas Padjadjaran, Jatinangor District, Sumedang, West Java Indonesia. The materials used in this experiment were biofertilizers consisting of N-fixing bacteria (Azotobacter chroococcum, Azospirillum sp.) and phosphate solubilizing microbes (Pseudomonas mallei, P. cepaceae, Aspergillus niger and Penicillium sp.) as selected isolates which were obtained from maize and rice rhizosphere, upland rice (variety of Luhur 2), inorganic fertilizers were Urea (46% N) at a dose of 300 kg ha\(^{-1}\), super phosphate (36% P\(_2\)O\(_5\)) at a dose of 100 kg ha\(^{-1}\), KCl (60% K\(_2\)O) at a dose of 100 kg ha\(^{-1}\).

The experiment was carried out with the randomized block design (RBD) consisting of ten treatments and three replications. The treatments were control, biofertilizers doses (50 kg ha\(^{-1}\) and 75 kg ha\(^{-1}\)), inorganic fertilizers (50%, 75% and 100% of recommended doses) and combination of biofertilizers and inorganic fertilizers. The recommended doses of inorganic fertilizers were 300 kg ha\(^{-1}\) Urea, 100 kg ha\(^{-1}\) SP-36 (super phosphate) and 100 kg ha\(^{-1}\) KCl. The observation of soil nitrogen and plant N uptake content used the Kjeldhal method.

Data were collected to analysis of variance (ANOVA) and treatment means were compared using Duncan’s Multiple Range Test.

3. Results and discussion

3.1. Soil nitrogen and nitrogen uptake
Total nitrogen is nitrogen measured from all variations of organic and inorganic nitrogen forms. Based on the results of statistical analysis, the application of biofertilizers and inorganic fertilizers at various levels had no significant effect on the total N content of the soil. In addition, Table 1 showed that the average total N content of soil is included in the low category based on the assessment criteria for the total N results. Nutrient N is easily lost due to evaporation, absorbed by plants and used by soil microorganisms for metabolic processes. The process of losing N in the soil is due to high evaporation [8]. According to climatic data, low rainfall and high humidity cause high evaporation around upland rice plantations. Furthermore, N loss from soil is caused by plant N uptake [9]. Azospirillum sp. and Azotobacter chroococcum can fix N\(_2\) and convert it to NH\(_4\) using nitrogenase enzyme, then convert it again into glutamine or alanine so that it can be absorbed by plants in the form of NO\(_3\) and NH\(_4\) [10]. The level of N content in the soil is influenced by the amount of N input and losses in the N cycle [11]. Based on the results of statistical analysis, the application of biofertilizers and inorganic fertilizers at various levels had no significant effect on N uptake.

The average N uptake is in the low category. The N content in rice plants in the sufficient category is from 2.60% to 3.20%, if the N uptake is below 2.40%, N is included in the low category. Various factors can cause a low N absorption value. A high respiration factor can cause the formation of photosynthate to be inhibited [12], so that the energy supply for the phosphate solubilizing bacteria from plants reduced causing bacteria are not optimally active. Another factor is that the N nutrient is easily lost from the soil due to the low mass flow of solutions containing NO\(_3\) and NH\(_4\)\(^+\) in plant roots caused by the low rainfall that occurred at the time of the study. Based on the data the results of the average N uptake in the biological fertilizer treatment combined with inorganic fertilizers gave the same average yield compared to the treatment without biofertilizers.

3.2. Upland rice growth
Plant growth components affect plant yield components. Based on the data and analysis results of various applications of biofertilizers it was observed that 8, 10, 12 and 14 weeks after planting (WAP), the treatment of biofertilizers and inorganic fertilizers increased the number of tillers significantly.
Table 1. Effect of biofertilizers and inorganic fertilizers on soil nitrogen and nitrogen uptake.

| Treatments                                  | Soil Nitrogen | N-uptake (mg plant\(^{-1}\)) |
|---------------------------------------------|---------------|------------------------------|
| control                                     | 0.23 a        | 1.8 a                        |
| Inorganic 100%                              | 0.24 a        | 1.8 a                        |
| Inorganic 75%                               | 0.21 a        | 2.0 a                        |
| Inorganic 50%                               | 0.23 a        | 2.0 a                        |
| Biofertilizer 75 kg ha\(^{-1}\)             | 0.24 a        | 1.7 a                        |
| Biofertilizer 50 kg ha\(^{-1}\)             | 0.27 a        | 1.8 a                        |
| Biofertilizer 75 kg ha\(^{-1}\) + inorganic 75% | 0.23 a        | 1.8 a                        |
| Biofertilizer 50 kg ha\(^{-1}\) + inorganic 75% | 0.25 a        | 1.9 a                        |
| Biofertilizer 75 kg ha\(^{-1}\) + inorganic 50% | 0.24 a        | 1.9 a                        |
| Biofertilizer 50 kg ha\(^{-1}\) + inorganic 50% | 0.22 a        | 2.0 a                        |

Remarks: The average score followed by the same letter is not significantly different according to the Duncan Test at the 5% level.

Table 2. Effect of biofertilizers and inorganic fertilizers on the number of tillers.

| Treatments                                  | 8 WAP | 10 WAP | 12 WAP | 14 WAP |
|---------------------------------------------|-------|--------|--------|--------|
| Control                                     | 6.55 a| 9.77 a | 6.55 a | 13.33 a|
| Inorganic 100%                              | 8.33 e| 13.33 f| 8.33 e | 17.67 e|
| Inorganic 75%                               | 6.67 ab| 10.00 ab| 6.67 ab| 14.32 bc|
| Inorganic 50%                               | 6.33 a| 9.55 a | 6.33 a | 13.67 ab|
| Biofertilizer 75 kg ha\(^{-1}\)             | 7.00 abc| 10.33 abc| 7.00 abc| 14.78 cd|
| Biofertilizer 50 kg ha\(^{-1}\)             | 7.00 abc| 10.11 ab| 7.00 abc| 14.78 cd|
| Biofertilizer 75 kg ha\(^{-1}\) + inorganic 75% | 7.00 abc| 11.22 bcd| 7.00 abc| 15.67 d|
| Biofertilizer 50 kg ha\(^{-1}\) + inorganic 75% | 7.33 bcd| 11.44 cde| 7.33 bcd| 14.67 c|
| Biofertilizer 75 kg ha\(^{-1}\) + inorganic 50% | 8.00 de| 15.4 ef| 8.00 de| 18.33 e|
| Biofertilizer 50 kg ha\(^{-1}\) + inorganic 50% | 7.67 cde| 12.2 def| 7.67 cde| 17.67 e|

Remarks: The average score followed by the same letter is not significantly different according to the Duncan Test at the 5% level.

This result shows that applying biofertilizers can reduce the use of inorganic fertilizers in increasing the number of tillers. Biofertilizers consortium containing microorganisms may increase macro nutrients of N, P, K and micro nutrients such as Zn, Fe, Mg and Cu which are important to support plant growth. Biofertilizers containing nitrogen fixing microbes and phosphate solubilizing microbes may help nourish the soil and increase soil nutrients [13].
Based on the results of statistical analysis at 14 WAP, all treatments were significantly different from the control except 50% of inorganic fertilizers. Meanwhile, the treatment of biofertilizers of 75 kg ha⁻¹ + 50% of inorganic fertilizers and 50 kg ha⁻¹ of biofertilizers and 50% of inorganic fertilizers were not significantly different from 100% inorganic fertilizers. This result is presumably because each increase in the dosage of nitrogen fertilizer is able to meet the needs of plants for producing productive tillers. Nitrogen fertilization increased the number of productive tillers; in which the higher nitrogen dose given at that time results in a higher number of productive tillers.

4. Conclusions
Application of biofertilizers containing nitrogen-fixing and phosphate solubilizing bacteria on upland rice increased the number of tillers. However, application of biofertilizer has not been able to increase soil nitrogen and N uptake significantly. The result revealed that 50 kg ha⁻¹ biofertilizer + 50% of inorganic fertilizer was the best dose in increasing the number of tillers. The application of biofertilizers increased fertilizer use efficiency up to 50%.

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