USE OF BIOLOGICAL ORGANIC FERTILIZERS AND PESTICIDES TO IMPROVE POTATO CULTIVATION IN SLOPE ANDISOLS

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ABSTRACT

In the 1990s, potato yield in the Andisols of Dieng, Central Java, Indonesia, was approximately 30 t ha^{-1}, but this value decreased rapidly to 12–15 t ha^{-1} in recent years. This rapid decline could be attributed to the use of unbalanced organic and chemical fertilizers, without the application of conservation techniques. Therefore, this study aimed to sustainably improve the local potato cultivation pattern of farmers on Andisols using biological organic fertilizers and pesticides (BOFP). A randomized block design was used with two factors, namely: 1) 20 t BOFP, 300 kg Urea, 500 kg SP 36, 300 kg KCl, and 200 kg lime ha^{-1}, and 2) comparison with the pattern of farmers, consisting of 20 t of chicken manure, 1–t NPK, and 250 kg ZA ha^{-1}. The potato plant mounds were tilted 10% to the contour direction, and each treatment was carried out with 16 replications. Granola seeds were used to plant potato during the rainy season from March-June 2022. The results showed that the plants cultivated using the local pattern of farmers were affected by wilt from *Fusarium* spp, while the use of BOFP decreased the incidence of the disease by 80%. Furthermore, the BOFP pattern significantly increased Andisols organic-C from 1.78% to 3.83% and total soil P from 5.20% to 11.34%, compared to the pattern of farmers. It also increased potato yields from 12.31 t ha^{-1} to 22.93 t ha^{-1} and the R/C from 0.85 to 1.23, compared to the pattern of farmers. Based on the results, the use of BOFP pattern decreased wilt attacks by *Fusarium* spp, improved the productivity of Andisols, as well as increased potato production and profits of farmers.

Keywords: beneficial microbes, farmer income, manure, potato, soil productivity

INTRODUCTION

Farmers on the Andisols slopes have been cultivating potato using unbalanced organic and chemical fertilizers, without applying conservation techniques. Furthermore, potato plant mounds are often prepared toward the hill (Figure 1), which causes a decrease in soil fertility due to nutrient imbalances and intensive erosion. This planting pattern has also led to a decrease in potato production of 10–15 t ha^{-1} compared to the volume recorded in the 1990s. The decline was due to a reduction in the productivity of Andisols and an increasingly intensive potato plant disease.

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Dieng, Central Java, Indonesia, is situated on Andisols land, which is known to have a high adsorption capacity for phosphorus (P), leading to low availability of P for plants. This high adsorption capacity is due to the presence of aluminol groups (Al–OH and Al–OH_2^+), ferrihydrite, and Al-humus complex (Pizarra *et al.* 2008; Delfim *et al.* 2018). The application of a large amount of P fertilizer to the Andisols does not necessarily increase the availability of P to plants, as the efficiency of P fertilization is low, ranging from 10% to 20% of applied P (SACRC 2004; Elásquez *et al.* 2016). However, the available P can be increased through the use of organic fertilizer enriched with phosphate microbial (PM), organic matter ameliorant (humic-fulvic), and signal quorum sensing (QS), as a regulator of the effectiveness of biological agents.

Figure 1 The potato cultivation system with mounds in the direction of the slopes in Dieng, Central Java, Indonesia

PM, such as *Pseudomonas trivialis, P. putida,* and *P. fluorescens,* has the potential to increase P availability (Arcand and Schneider 2006; Tian *et al.* 2021; Yadav *et al.* 2021) by dissolving inorganic–P and mineralizing organic–P. In Andisols, these microbes have been found to increase the dissolution of inorganic–P by 535–575%, mineralization of organic–P by 336–387%, and reduced adsorbed–P to 15–30% (Tamad *et al.* 2021).

Intensive disease infestation, including late blight, potato bacterial wilt, tuber rot, fusarium wilt, and dry spot caused by *Phytopthora infestans*, *Ralstonia solanacearum*, *Colleotrichum coccodes*, *Fusarium* sp., and *Alternaria solani,* can contribute to low potato production. An alternative for controlling potato disease is the use of Bio P60, a biological pesticide containing crude secondary metabolites of bacterial antagonist *P. fluorescens* P60 (Soesanto *et al.* 2011). Another critical factor that must be considered during cultivation in Andisols is the need for soil amendments.

Humic materials include humin, humic acid $C_{10}H_{12}O_5N$, and fulvic acid $C_{12}H_{12}O_9N$. Humic acid is brownish-black, resistant to degradation, and contains a negative charge that is dependent on pH. Several studies showed that humic-fulvic had the potential to be used for soil amendment (Stevenson 1994; Baveye and Wander 2019). However, the effectiveness of Andisol amendments is greatly influenced by soil microbial activity.

The biochemical process that regulates population density-dependent microbial behavior through crucial signaling molecules is known as quorum sensing (QS) (Teplitski *et al.* 2011; Ma *et al.* 2018; Coquant *et al.* 2020; Ward *et al.* 2001). Gram-negative bacteria typically produce N-acyl–homoserine lactones (AHL) as a QS signal (Ward *et al.* 2001; Muras *et al.* 2020). A previous study also showed that plant root extracts could serve as a source of N–AHL (Tamad *et al.* 2020). The enrichment of organic fertilizers with microbes and signal quorum sensing as biological organic fertilizers effectively increases soil fertility.

Tamad *et al.* (2020a) stated that using biological organic fertilizer (BOF) of up to 20 t ha^{-1} increased potato yields by 2 t ha^{-1} compared to the cultivation pattern of farmers in Kaligua, Central Java, Indonesia. The use of BOF in potato cultivation also increased R/C from 1.13 to 1.53, and profits rose by IDR 29.995.573 ha^{-1} compared to the practice of farmers. Therefore, this study aims to improve the local potato cultivation pattern of farmers on Andisols using BOFP. The results are expected to increase potato production, sustainably improve the quality of Andisols, and increase the income of farmers.

MATERIALS AND METHODS

This study was carried out in Andisol Dieng, Central Java, where the soil had slightly acidic pH H_2O, medium organic–C, high K_2O, high P_2O_5, and medium N of 5.63, 2.39%, 0.4%, 3.20%, and 0.34%, respectively. Furthermore, the region had an area of 3000 hectares and an altitude of 1,000–2,500 m above sea level, which was very suitable for potato cultivation. This study utilized biological organic fertilizers and pesticides, which were applied using conservation techniques in partnership with local farmer groups.

BOFP Formulation

The BOFP formula was produced using chicken manure inoculated with phosphate solubilizing microbial and Bio P60 (10^7 CFU g^{-1})

at a concentration of 0.025% v w^{-1}, followed by the addition of humic-fulvic acids and 1% v w^{-1} QS signal. The BOFP components were then mixed with the granulator under moist conditions, as shown in Figure 2. Subsequently, the product obtained was incubated for four weeks with 15–20% moisture content.

Figure 2 The formulation of biological organic fertilizers pesticides (BOFP)

Preparation of Phosphate Microbial (PM) Culture

PM consortium of *Pseudomonas trivialis, P. putida,* and *P. fluorescens* was grown on molasse culture for one week (end of log phase) (Tamad *et al.* 2020). The Standard Plate Count (SPC) method was then used to determine PM at a minimum population of 10^7 CFU mL^{-1}.

Production of Bio P60 Culture

Bio P60 was an isolate of *P. fluorescens* P60 cultured in snail broth for one week (Soesanto *et al.* 2013). The SPC method was utilized to assess the microbial population at a minimum of 10^7 CFU mL^{-1}.

Humic-Fulvic Acids Extract

Humic-fulvic acids were obtained from harvested top potato plant waste. Furthermore, extraction was carried out by soaking the waste in 1 M technical NaOH for two weeks (modified Tan 1998; Dulaquais *et al.* 2018).

N-AHL Extract

Potato plant root waste was used as a source of quorum-sensing signals for microbes (Tamad *et al.* 2020). N-AHL compound, a quorum sensing signal, was obtained by soaking the waste in 5% acetonitrile for two weeks (Rani *et al.* 2011).

BOFP Application

This study used a randomized block design with two factors, namely: 1) the application of 20 t BOFP, 300 kg Urea, 500 kg SP 36, 300 kg KCl, and 200 kg lime ha^{-1}, and 2) comparison with the application pattern of the farmers, consisting of 20 t of chicken manure, 1–t NPK, and 250 kg ZA ha^{-1}, with 16 repetitions. The potato Granola plant mounds were tilted at a 10% contour coverage rate per ha, as shown in Figure 3. The seed potato was 800 kg ha^{-1}, and the plant was spaced at 30 cm x 70 cm interval total obtain a total population of 47,000 ha^{-1}.

Fertilization was performed every 20 days: a) At 20–40 days after planting (DAP) when tuber growth begins; b) At 40–60 DAP when tuber enlargement begins; c) At 60-90 DAP (plant optimal enlargement); and d) At 90–110 DAP after all the leaves dry up. Furthermore, the variables observed included soil parameters, growth and yield components of potato (10% of the population were sample plants), and farming analysis (revenue and total cost). The variable of pH was measured with a pH meter, EC was assessed with an EC meter, C was analyzed with Walkley and Black, and P was evaluated with the HCl extraction method.

Figure 3 The design of potato mounds cutting a 10% sloping slope in Dieng, Central Java, Indonesia

Statistical Analysis

Variance analysis was carried out on the data on soil, potato growth, and yield using Fisher's test ($P<0.05$). Subsequently, significant differences were determined by calculating the mean value using Duncan's multiple range test. The statistical analysis was performed using the CoStat Ver 6.451 application. The difference in the effect of the treatments on the economic value was carried out by assessing the production costs, income, and profits (R/C ratio).

RESULTS AND DISCUSSION

Soil, Potato Growth, and Potato Yield

The growth of potato appeared normal up to 60 DAP, as shown in Figure 4. However, at 80 DAP, the BOFP pattern demonstrated better growth compared to farmers' pattern, which was infested by diseases, as indicated by the falling and withering of leaves in Figure 5. The plant often faced several challenges during the rainy season, including falling of leaves and intensive wilt disease.

Figure 4 The optimal growth of potato plant at 60 the day after planting (DAP) in Andisols Dieng, Central Java, Indonesia, with mound tilt of 10% contour direction

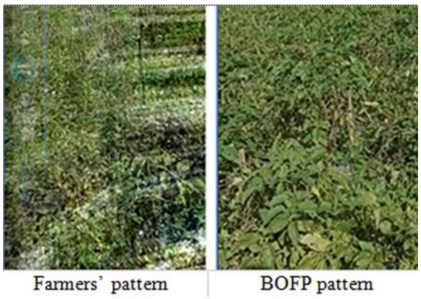

Figure 5 The differences in potato growth at 80 DAP in Andisols between farmers' pattern and BOFP pattern treatments

This study showed significant improvement in soil, potato, and economic variables in BOFP pattern compared to farmers' pattern, as shown in Table 1. It was observed that the plant was susceptible to Fusarium infection, which caused wilt symptoms (Thanaa *et al.* 2018). Furthermore, Fusarium is one of the most important genera of phytopathogenic fungi, causing potato wilt in the field (Azil *et al.* 2021). The results showed that the application of BOFP and conservation techniques to Andisols improved the growth of potato plants and reduced fungi attack. *P. fluorescens* as Bio P60 microbes produced secondary metabolites, which helped to inhibit *Fusarium* sp wilt (Soesanto *et al.* 2011; Deveau *et al.* 2016). A previous study explored the antifungal activity of the extracellular metabolites of the most effective isolates of Fusarium species infecting potato (Trabelsi *et al.* 2016).

Table 1 The effect of BOFP pattern and farmers' pattern treatment in Andisols on soil and potato variables average

No	Variable	N0[a]	N1[b]
1	Soil pH H2O	5.56 a	6.04 b
2	Soil pH KCl	4.68 a	5.30 b
3	Soil electric conductivity/EC (mS cm^{-1})	409.11 a	324.29 a
4	Soil organic–C (%)	1.78 a	3.83 b
5	Soil total–P (%)	2.27 a	4.95 b
6	Plant height (cm)	54.88 a	63.19 b
7	Leave number (pieces)	60.38 a	116.69 b
8	Fall leave age (days)	85 a	100 b
9	*Fusarium* spp attack (%)	80	20
10	Tuber number	5.2 a	6.0 a
11	Tuber diameter (mm)	51.24 a	56.74 b
12	Tuber length (mm)	68.56 a	73.92 b
13	Tuber volume (mmh3)	631.88 a	723.75 b
14	Tuber weight (g plant^{-1})	301.69 a	561.81 b
15	Tuber yield (t ha^{-1})	12.31 a	22.93 b
16	Tuber P uptake (%)	0.23 a	0.23 a
17	Tuber P (g plant^{-1})	5.46 a	8.81 b
18	R/C ratio	0.85	1.23

Note: [a]N0 = Farmers' pattern treatment is 20 t chicken manure ha^{-1}, 1 t NPK ha$^{-1,}$ and 250 kg ZA ha^{-1}
[b]N1 = BOFP pattern treatment is 20 t BOFP ha^{-1}, 300 kg Urea, 500 kg SP 36, 300 kg KCl, and 200 kg calcite ha^{-1}

Enrichment of chicken manure with Bio P60 led to a significant reduction in the intensity of the fusarium wilt attack on potato plants, thereby increasing their productive age. Bio P60 is a secondary metabolite formula derived from the antagonist bacterium *P. fluorescens* strain P60, which has been tested to treat various plant diseases. Furthermore, *P. fluorescens* produced secondary metabolites that contain several bioactive compounds. It also played an essential role in inhibiting microbial growth in the soil, including *Fusarium* sp., the cause of wilt in potato (Soesanto *et al.* 2011; Deveau et al. 2016). *P. fluorescens* is a ubiquitous soil bacterium that promotes plant health, and some of its strains produce secondary metabolites, such as 2,4–diacetyl phloroglucinol (DAPG), phenazines, and hydrogen cyanide, thereby inhibiting soil-borne pathogens (Neidig *et al.* 2011). The strain *P. fluorescens* P60 inhibited fusarium wilt of shallots (Santoso *et al.* 2007) and tomatoes (Soesanto *et al.* 2011), stem rot of peanuts, chili virus, tomato microbe wilt (Soesanto *et al.* 2013), and stem base rot of dragon fruit (Hamarawati *et al.* 2018).

The results showed that BOFP pattern (N1) increased the soil pH (H_2O) from acid to slightly acid and decreased the electrical conductivity compared to the farmers' practice (N0) (Figure 6). Furthermore, it significantly increased soil pH (KCl), organic–C, and total–P. The application of the BOFP pattern was also shown to improve the quality of Andisol by enhancing some chemical characteristics.

The application of BOFP improved the chemical characteristics of Andisols. Furthermore, the enrichment of chicken manure with PM and balanced chemical fertilization improved the soil pH, organic-C, and total–P. Based on the results, the inoculation of phosphate-solubilizing microorganisms increased soil biomass and microbial activity (Wang *et al.* 2022). PM had been reported to mediate the bioavailability of P by mineralizing organic–P and dissolving the inorganic variant. The soluble P in Andisols was affected by inorganic–P solubility, mineralized organic–P, and adsorption–P (Tian *et al.* 2021). Phosphate solubilizing microorganisms as a component of the entire soil community can be manipulated to be more effective for plant nutrition (Raymond *et al.* 2021).

These microbes can increase phosphate availability through the dissolution of inorganic–P and mineralization of organic–P. The dissolution of inorganic–P was often carried out through the production of organic acids, such as sulfuric acid, nitric, and carbonate. The Mineralization of organic–P occurred due to the production of extracellular enzymes, such as phosphatase, phytase, phosphonatase, and C–P lyase by PM. The phosphatase enzyme converts high molecular weight organic phosphate into low molecules by hydrolyzing the bonds with the release of ions (Prabhu *et al.* 2018).

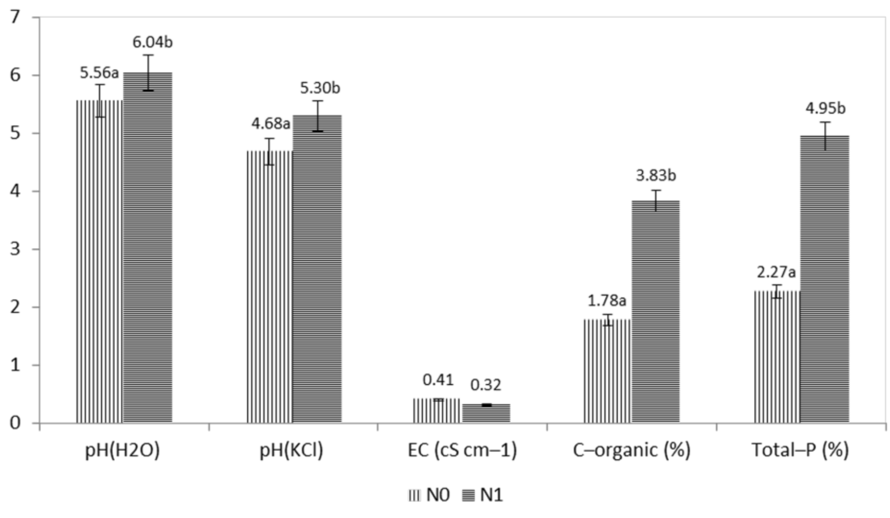

Figure 6 The effect of the farmers' pattern (N0) and the BOFP pattern (N1) treatments on the Andisols variables

PM significantly increased inorganic–P solubility and organic–P mineralization, while significantly reducing adsorption–P in Andisols. The ability of PM ability to dissolve P was influenced by the type of species, P compounds, organic acids released, and microbe population. Furthermore, its capacity to mineralize organic–P depended on the activity of phosphatase and phytase (Tamad *et al.* 2021).

The results showed that PM increased P availability, improved plant growth, and restored soil fertility. Phosphate-solubilizing microorganisms have enormous potential as biofertilizers because they can increase the bioavailability of P for plants, offer sustainability, improve soil fertility, and increase crop yields (Timofeeva *et al.* 2022). The PM isolates *Pseudomonas trivialis, P. putida,* and *P. fluorescence* released citrate, lactate, malonic, oxalic, and acetic acid of 156.25 mg kg^{-1}. The phosphatase and phytase yields obtained from phosphate microbe ranged from 12 to 47 mg PO_4^{3-} dm^{-3} h^{-1}. The amount of P dissolved by PM was higher between 147.66 and 194.61 mg P kg^{-1} compared to the control (31.06 mg P kg^{-1}). Furthermore, PM inoculation produced mineralized organic–P of 63.69 mg P kg^{-1}, compared to the control with 23.7 mg P kg^{-1} (Tamad *et al.* 2021). It also increased the dissolution of P up to 300% compared to the control (Tamad *et al.* 2020). Based on these results, PM can be applied to plants to promote growth or increase P availability, while reducing the dependence on phosphate-based fertilizers and restoring soil fertility (Yadav *et al.* 2021). BOFP pattern significantly increased plant height, number of leaves, and age of potato plants, as well as decreased fusarium wilt attack compared to farmers' pattern, as shown in Figure 7.

BOFP pattern significantly improved tuber quality in terms of diameter, length, and volume, as shown in Figure 8. It also significantly increased the number of potato plants and yield per ha compared to the farmers' practice. The yield obtained in the rainy season from farmers and BOFP patterns was 12 t ha^{-1} and 23 t ha^{-1}, respectively.

BOFP pattern treatment significantly increased the total P of Andisols (Figure 6), which supported the uptake of P by potato grown on the soil. The results showed that P uptake in potato tubers was significantly higher in BOFP pattern. However, the P content obtained from both patterns was the same, as shown in Figure 9. BOFP was found to significantly increase potato yield $plant^{-1}$, as shown in Figure 8.

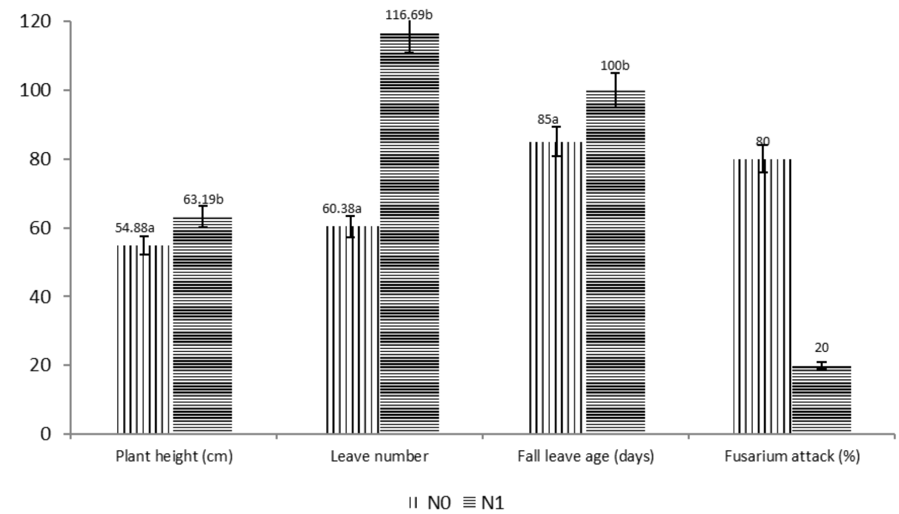

Figure 7 The effect of farmers' pattern (N0) and BOFP pattern (N1) treatments on potato variables in Andisols

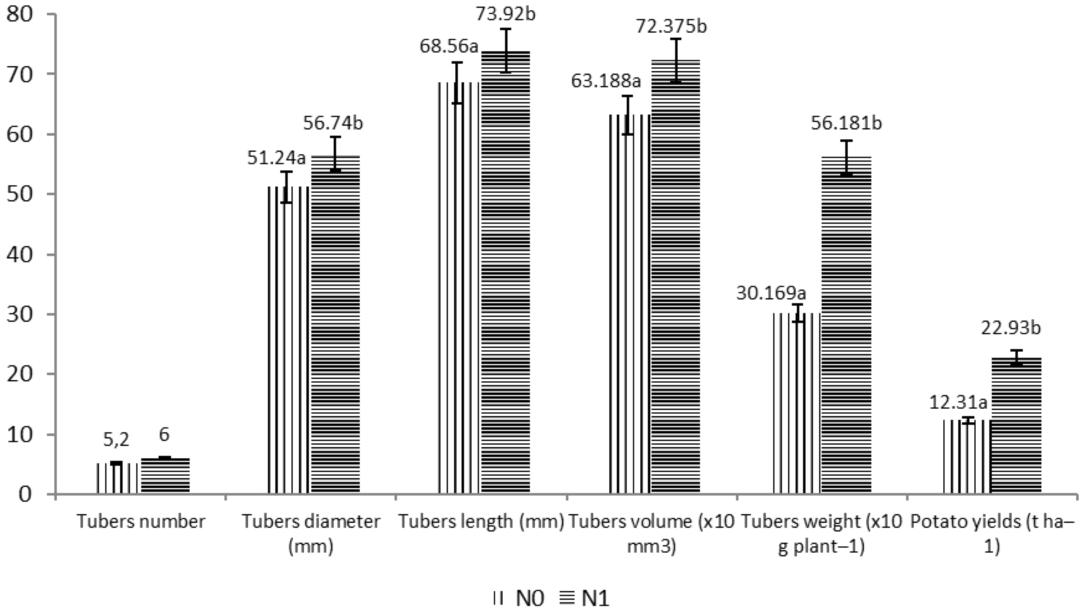

Figure 8 The effect of farmers' pattern (N0) and BOFP pattern (N1) treatments on the potato variables in Andisols

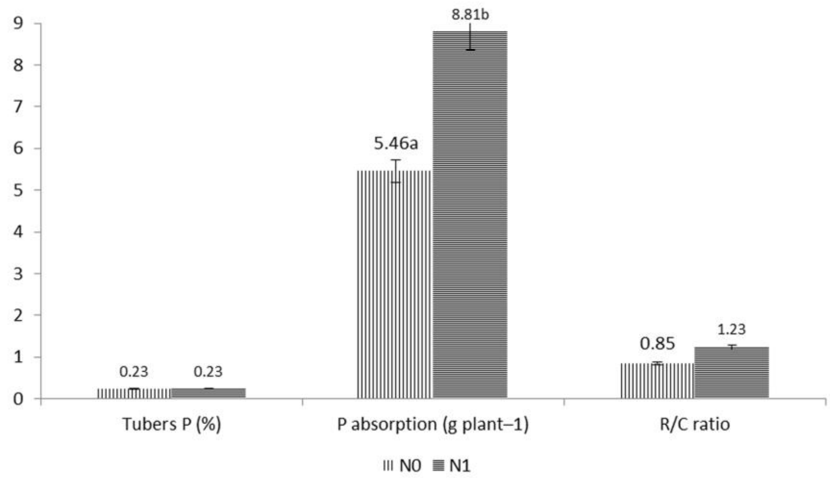

Figure 9 The effect of farmers' pattern (N0) and BOFP pattern (N1) treatments on the potato P variables and the R/C ratio in Andisols

The application of BOFP in Andisols improved P-absorption, the quality of tubers, and the yields of the plant. Biological organic fertilizer (BOF) is a chicken manure enriched with phosphate bacteria, humic–fulvic acid, and N–acyl homoserine lactone to effectively increase P solubility and increase yield. Furthermore, potato yield in Kaligua, Central Java, Indonesia, using a BOF dose of 20 t ha^{-1} increased tuber yield to 2 t ha^{-1} compared to chicken manure (Tamad *et al.* 2020). The application of BOPF technology to potato cultivation in Andisol during the rainy growing season significant;y increased production and farmers' profits.

Profitability of Potato Cultivation Farming

Based on the profitability analysis of potato farming, BOFP pattern increased the R/C ratio compared to farmers' pattern, as shown in Table 2 and Figure 9. Based on the results, the total cost of cultivation with BOFP pattern was greater, namely IDR 5 million ha^{-1}, which was 4% higher than farmers' pattern. The total revenue for cultivation was 51% greater than farmers' pattern. BOFP potato cultivation provided a profit of IDR 31.4 million ha^{-1}, while farmers' pattern led to a loss of IDR 19.5 million ha^{-1}, as shown in Table 2.

Table 2 The difference in potato farming between farmers' pattern and BOFP pattern on revenues, total cost profits, and efficiency per hectare

No.	Differences	Farmers' pattern	BOFP pattern
1	Revenue (IDR)	109.030.000	165.096.000
2	Total cost (IDR)	128.536.667	133.700.667
3	Profits (IDR)[a]	–19.506.667	31.395.333
4	Efficiency[b]	0.85	1.23

Note: [a]Profits = Revenue – Total Cost
[b]Efficiency = Revenue / Total Cost

Farming efficiency was calculated based on revenues and total expenses (Anggraeni *et al.* 2021). Potato cultivation with BOFP pattern had better efficiency compared to the farmer's pattern, as shown in Table 2. The R/C value of 1.23 in BOFP pattern showed that one unit of the cost used to cultivate potato provided 23% of the profit from the cost. Meanwhile, farmers' pattern showed that farming was inefficient, as indicated by R/C < 1.

The results showed that the profits of farmers increased after the application of BOFP. The increase in yield of potato cultivated with BOFP pattern was shown to exceed the additional cost required. The profit obtained for the use of this pattern also exceeded that of farmers' pattern. During the rainy season, the use of farmers' pattern led to losses due to rain factors and intensive fusarium wilt disease. The calculation of potato farming efficiency was aimed at comparing the results with the cost of using resources.

Potato cultivation with BOFP pattern can provide better results than farmers' pattern. The average profit from environmentally friendly farming within a year was also shown to be higher compared to conventional methods (Saem et al. 2016). The yield quantity played a significant role in determining the significant gain from potato farming with BOFP. The application of biofertilizers significantly correlated with increased outcomes (Khoiriyah *et al.* 2018).

CONCLUSION

The application of BOFP pattern on potato cultivation in Andisols decreased *Fusarium* spp wilt attack, improved soil characteristics, enhanced vegetative component, and increased yields from 12.32 to 22.93 t ha^{-1}. During the rainy season, farmers' pattern caused a loss of IDR 19.9 million, while BOFP yielded a gain of IDR 31.4 million. Furthermore, BOFP pattern increased the R/C ratio from 0.85 to 1.23, as well as Andisols' productivity, potato production, and farmers' profits.

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