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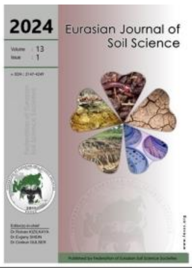

Efficacy of solid and liquid Biolistics in improving the nutrients in latosol soil from Bali, Indonesia

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Abstract

The increase in household organic waste during the COVID-19 pandemic was a source of pollution, especially in soil. The high pollution intensity in various sectors causes the soil to degrade and lose nutrients. This study aimed to analyze the efficacy of solid and liquid biolistics for improving the nutritional status of latosol soil collected from Bali, Indonesia. The experimental design was a completely randomized design. Efficacy testing by providing solid and liquid *biolistics* to latosol soils in polybags at different concentrations was performed five times. Macro- and micronutrient testing was carried out three months after the application of the treatments. One-way ANOVA and the LSD test (p<0.05) were used to assess the results. The results revealed significant differences between the treatment groups in terms of N, P, K, the C/N ratio, water content, and pH, with a probability value of 0.000 (p<0.05). Thus, solid and liquid biolistics s are efficacious at increasing the fertility of latosol soils. The contents of N, P, K, moisture content, pH, macronutrients (P_2O_5, K_2O, C-Organic, N-Total, and C/N ratio) and micronutrients (Fe, Mg, Mn, Na, Zn) contribute significantly to improving soil aggregates and structures; improving the physical, chemical, and biological properties of the soil; and improving the bioavailability of nutrients and soil quality. The presence of microorganisms is involved in accelerating the process of biodegradation and decomposition in soil. Thus, solid and liquid biolistics s deserve to be developed as natural soil repairers.

Keywords: Biofertilizer, Biolistics, soil repairer, local microorganisms, domestic waste.

Introduction

The COVID-19 pandemic has harmed the environment, especially through the increase in household domestic waste quality caused by large-scale social restrictions throughout Indonesia, including the Province of Bali (Putro, 2020). The work-from-home policy contributes to an increase in organic waste and food every day (Pappalardo et al., 2020; Arumugam et al., 2021). In addition, the impact of the COVID-19 pandemic reportedly resulted in a decrease in waste management and management by relevant agencies (Roy et al., 2021). According to data from the National Waste Management Information System in 2020, waste generation in 9 districts/cities in Bali reached 904,924.34 tons/year, with an average of 2,479.24 tons/day. Waste generation increased in 2021, reaching 915,482.46 tons/year, with an average of 2,508.17 tons/day (Ministry of Environment and Forestry, 2020, 2022). Household organic waste accounted for 40.91%, the market accounted for 16.04%, and other waste accounted for 43.05%, with 1,178.13 tons/day left untreated (Waste for Change, 2021), resulting in environmental pollution, including a decrease in soil fertility rates (El-Ramady et al., 2020; Adnan et al., 2022; Yang et al., 2022).

Every day, an increase in waste generation negatively impacts soil quality (Putro, 2020). This is because poorly handled domestic organic wastewater enters and permeates the soil, worsens soil conditions, threatens the survival of soil microbiota, and has implications for decreasing soil nutrients and causing environmental degradation (Tsukiji et al., 2020; Waste for Change, 2021). Recent research reveals that the pollution intensity from various sectors results in soil degradation and nutrient loss (Dehghani et al., 2021; Suriyaprakash et al.,

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2021). Furthermore, inorganic fertilizers containing nitrogen and phosphorus significantly contribute to soil pollutants, lowering physical, chemical, biological, and soil permeability (Eugenio et al., 2018; El-Ramady et al., 2020). Continuous degradation of soil results in a low number of remodeled microorganisms in the soil, resulting in a decrease in agricultural land productivity (Geisseler and Scow, 2014; Kashyap et al., 2017; Pappalardo et al., 2020).

In light of these concerns, it is crucial to implement integrated waste management, including agricultural land, to minimize land degradation in Bali. The use of synthetic fertilizers in the community harms the environment, so new efforts have been made to use household and market organic waste (leaves, fruits, and vegetables) enriched with local microorganisms and fungi (*Trichoderma* sp.) as soil repellents and soil fertility enhancers called *biolistics*. Solid and liquid *biolistics* products were made to stop the use of inorganic fertilizers, which kill microorganisms in the soil and cause the nutrients in the soil to run out (Du et al., 2020). Raw materials are sourced from waste and passed through the fermentation system (Suthar et al., 2017; Vassileva et al., 2021). They are useful for increasing microbial biomass and bioconversion of microbial substrates, enzymes, and primary and secondary metabolites (Vassileva et al., 2021). In addition, bacterial and fungal inoculations of the main ingredients of biofertilizers reportedly increase the bioavailability of soil nutrients through nitrogen fixation and mobilization of phosphorus, potassium, and iron nutrients and improve the soil structure by improving its aggregation and stability (Rashid et al., 2016).

This study aimed to evaluate and analyze the efficacy of solid and liquid *biolistics* for improving the nutritional status of latosol soil in Bali, Indonesia. Type land latosols are spread throughout the Bali region and have a relatively low fertility rate. This research is expected to contribute to the use of waste as a useful soil remediation agent.

Material and Methods

Study design: This study utilized an experimental design with a completely randomized design. There were six treatment groups, and each group was replicated five times, as determined using the Federer equation (Darwin et al., 2021). In this study, solid and liquid biolistics were applied at different levels in latosol soils with low fertility rates in large polybags; 20 polybags were given solid biolistics with different levels of P1 (157 g/polybag), P2 (314 g/polybag), P3 (471 g/polybag), and P4 (628 g/polybag); five pure positive controls (PCs) were given 100% NPK; and five negative controls (NCs) were given without treatment. Moreover, liquid biolices that are ready for use are then applied to the soil utilizing 1 L of liquid biolases mixed in 5 L of clean water and poured into 20 polybags at different concentrations, namely, P1 (208.4 mL/polybag), P2 (417 mL/polybag), P3 (533.8 mL/polybag) and P4 (834 mL/polybag). Moreover, five pure positive controls (PCs) were given 100% NPK, and five negative controls (NCs) were not treated. A total of 60 polybags with a total of 30 polybags were given solid biolistics, and 30 polybags were given liquid biolistics. The intensity of soil fertilization was carried out once every two weeks for a duration of three months. The soil fertility rates were measured using the parameters nitrogen (N), phosphorus (P), potassium (K), the C/N ratio, moisture content, and acidity level (pH) one week after the treatment ended. Macro- and micronutrients in solid and liquid biolistics were measured in integrated testing laboratories.

Sample: Federer's formula was used to determine the number of samples and tests used (Adnyana, 2021). The formula used was (n-1) (t-1) ≥ 15, and the results were obtained for six treatment groups with five replicates each; 30 samples were used for solid biochemical testing, and 30 samples were used for liquid biochemical testing.

Laboratory testing: After solid and liquid *biolistics were applied*, soil nutrient testing was conducted in the laboratory via several tests. The soil N (%) levels were determined using a spectrophotometer set to a wavelength of 636 nm and the following standards for testing organic fertilizer. At a wavelength of 651 nm, Walkley and Black used a spectrophotometer to measure the levels of C-organic (%). The amounts of significant (P and K) and minor (Fe, Mn, Zn, and Na) nutrients in the soil were measured using Morgan Wolf extract. Spectrometry was used to measure P_2O_5, K_2O total, and N-total (Kjeldahl), and a pH meter was used to measure the pH. The Regulation Number 01 of 2019 of the Minister of Agriculture of the Republic of Indonesia on organic fertilizers, biological fertilizers, and soil reformers was used to guide all tests (Ministry of Agriculture, 2019).

Time and Location: This research was conducted at Greenhouse Tanam.id, Denpasar, for six months (January–June 2021) at the Treatment and Technical Implementation Unit of the Biosciences and Biotechnology Laboratory and the Soil Chemistry and Fertility Laboratory of Udayana University to test macro, micro, and soil fertility nutrients based on predetermined parameters.

Instruments and Materials: The instruments used in this study consisted of personal protective equipment, needles, trays, hoes, punches, analytical scales, acid chambers, buckets, hammers, hacksaws, paralons, knives, measuring cups, electric stoves, destilators, spectrophotometers, beker glasses, Erlenmeyer flasks, ovens, hanging scales, digital scales, large polybags, timba, gadgets, and stationery. The research materials used were 40 kg of kitchen and market organic waste (fruit, leaf, and vegetable), 5 kg of bamboo leaf, 5 kg of rice laundry water, coconut water, sack, trash bag, plastic, Trichoderma sp. isolate, methyl red-methyl blue, 40% boric acid, granulated sugar, 0.1 N NaOH, 0.1 N HCl, H_2SO_4 and latosol soil taken from Suwung landfill, Denpasar, Bali.

Research procedures

1. In the media preparation, latosol soil was inserted into a large polybag (40 cm) with a filling of 3/4 of the total polybag weighing 4-6 kg. There were 60 polybags per row of media provided.
2. At this stage, the preparation of *the biolistic* materials was performed. It consists of preparing kitchen organic waste and markets in the form of rotten fruit waste, vegetables, and leaves obtained from various places, weighing as much as 20 kg. Isolate samples were obtained from the Food and Horticulture Plant Protection Center (BPTPH) Semarang. A 250 g isolate of *Trichoderma* sp. mushrooms was propagated in rice media.
3. At this stage, as much as 5 kg of fruit and vegetable waste was weighed and then refined using a blender. Subsequently, 1 kg of granulated sugar and one bunch of leaves were chopped as a source of microbes, 2 L of coconut water, and 15 L of rice laundry water. The material is a microbial growth medium containing carbohydrates (source C), proteins (source N), minerals, and vitamins. The media was subsequently added, and the plants were curdled for 3-5 days until fragrance. The solution was filtered and stored in a bottle, after which the resulting gas was discharged. If the gas is removed, a solution containing microorganisms from the area is ready to use.
4. At this stage, 20 kg of organic waste is prepared. A large bucket was prepared, and then, organic waste, *Trichoderma* sp., and MOL were isolated so that the volume was as high as 0.2 L. Dopped organic waste was spread, covered with sacks or other materials, and fermented for 2-3 weeks. The mixture was opened every ten days, a local microorganism solution was added, and the mixture was closed again. After three weeks, the fertilizer is disassembled by paying attention to the black or brown color of the soil, after which the solid *biolistics* are ready to use.
5. At this stage, 15 kg of organic waste was chopped, and as much as 500 mL of *Trichoderma* sp. isolates and local microorganism solutions were added. The mixture was subsequently squeezed for one week, after which the fragrant fragrance was filtered, after which the liquid *biolistics* were ready to use.
6. To test the soil and *biolistics* that are ready for use, polybags filled with latosol soil were added. Twenty polybags were given solid *biolistics* at different concentrations—25% (157 g/polybag), 50% (314 g/polybag), 75% (471 g/polybag), and 100% (628 g/polybag); five pure positive controls were administered 100% NPK, and five negative controls were administered without treatment. Moreover, liquid *biolases* that are ready for use are then applied to the soil utilizing 1 L of liquid *biolases* mixed in 5 L of clean water and poured into 20 polybags at different concentrations, namely, 25% (208.4 mL/polybag), 50% (417 mL/polybag), 75% (533.8 mL/polybag) and 100% (834 mL/polybag). Moreover, five pure positive controls were given 100 NPK, and 5 negative controls were not treated. Solid and liquid biologics were added once every two weeks, and the experiments were carried out in the afternoon. Fertilization rates were based on guidelines for the use of biological fertilizers and soil repellents. After three months of testing the fertility of the soil, the fertility level was determined.
7. Fertility rate testing was performed by submitting soil samples and solid and liquid *biolistics* to an integrated testing laboratory, after which the data were further analyzed and test results obtained; this process ended with statistical analysis and interpretation of the data.

Data analysis

The soil fertility rates in each group were determined using statistical analysis to assess the efficacy of solid and liquid biolistics at different levels. Parameters The following elements were analyzed using SPSS, Inc., software version 25.0, with one-way ANOVA and LSD tests: nitrogen (N), phosphorus (P), potassium (K), carbon/nitrogen ratio, moisture content, and acidity level (pH). The macro- and micronutrient contents were analyzed descriptively and are presented in the graphs and narratives. The interpretation of the laboratory results followed the standard guidelines of the National Standardization Agency of the Republic of Indonesia (SNI) 19-7030-2004 on composting from domestic organic waste (National Standardization Agency of the Republic of Indonesia, 2004) and the Regulation of the Minister of Agriculture of the Republic of Indonesia No. 01 of 2019 concerning organic fertilizers, biological fertilizers, and soil repairers (Ministry of Agriculture, 2019).

Results and Discussion

Efficacy of solid biolistics in increasing the fertility of latosol soils

Based on solid *biolistics* efficacy test findings on the fertility rate of latosol soil collected in Bali, Indonesia, Table 1 shows five parameters, namely, N, P, K, the C/N ratio, and the moisture content. The results of the one-way ANOVA test showed that nitrogen content (N) had an F value of 32,151, with a probability value of p= 0.000<0.05. Therefore, there was a significant difference between the treatment groups. The least significant difference (LSD) was obtained only with the P3 treatment. This was very true for P4, whereas the other treatments did not significantly differ. An F count of 33.683 was obtained for the phosphorus content (P), with a probability of p= 0.000<0.05. Thus, there were significant differences between the treatment groups. The LSD test results revealed significant differences between the NC treatment and the PC, P2 treatment and P3, and P3 treatment and P4. K was tested, and an F count of 28,540 was obtained, with a probability value of p= 0.000 <0.05. Thus, there was a significant difference between the treatment groups. The LSD test results showed a noticeable difference in the PC treatment with P1, P2 with P3, and P3 with P4. Testing the ratio of carbon to nitrogen (C/N) yielded a calculated F count of 21,844, with a probability value **of p**= 0.000 < 0.05. Thus, there was a significant difference between the treatment groups. The LSD test results revealed significant differences between the NC and PC groups and between the P3 and P4 groups. Furthermore, the water content test obtained an F value of 168,499 with a probability value of p= 0.000 < 0.05. Thus, there were significant differences between the treatment groups. The LSD test revealed significant differences among the NC+PC treatment, PC+P1 treatment, PC+P2 treatment, and PC+P3 treatment groups.

Table 1. Fertility of the latosol soil caused by the addition of solid *biolistics*

Parameter/Unit	Treatment	Mean ± SD	Shapiro-Wilk	Levene Statistic	F	p value
N (%)	Negative control (NC)	0.240 ± 0.089[a]	0.831	9.021	32.151	0.000*
	Positive control (PC)	0.774 ± 0.261[a]				
	P1 (157 g/polybag)	0.884 ± 0.185[a]				
	P2 (314 g/polybag)	1.894 ± 0.351[a]				
	P3 (471 g/polybag)	3.304 ± 0.666[b]				
	P4 (628 g/polybag)	6.014 ± 1.923[c]				
P (%)	Negative control (NC)	0.320 ± 0.192[a]	0.904	2.397	33.683	0.000*
	Positive control (PC)	3.344 ± 0.831[b]				
	P1 (157 g/polybag)	3.606 ± 0.196[b]				
	P2 (314 g/polybag)	3.714 ± 0.391[b]				
	P3 (471 g/polybag)	4.580 ± 0.540[c]				
	P4 (628 g/polybag)	5.594 ± 1.261[d]				
K (%)	Negative control (NC)	0.162 ± 0.087[a]	0.888	3.858	28.540	0.000*
	Positive control (PC)	1.666 ± 0.150[a]				
	P1 (157 g/polybag)	0.724 ± 0.595[c]				
	P2 (314 g/polybag)	0.570 ± 0.155[c]				
	P3 (471 g/polybag)	2.292 ± 0.894[d]				
	P4 (628 g/polybag)	3.452 ± 0.643[e]				
C/N Ratio	Negative control (NC)	2.506 ± 0.879[a]	0.902	15.205	21.844	0.000*
	Positive control (PC)	5.980 ± 0.238[b]				
	P1 (157 g/polybag)	6.480 ± 0.571[b]				
	P2 (314 g/polybag)	7.000 ± 0.748[b]				
	P3 (471 g/polybag)	7.760 ± 0.876[b]				
	P4 (628 g/polybag)	11.358 ± 2.959[c]				
Water Content (% [w/w])	Negative control (NC)	6.456 ± 0.741[a]	0.843	2.835	168.499	0.000*
	Positive control (PC)	20.004 ± 2.251[b]				
	P1 (157 g/polybag)	22.052 ± 1.093[c]				
	P2 (314 g/polybag)	21.896 ± 1.306[c]				
	P3 (471 g/polybag)	25.354 ± 0.759[d]				
	P4 (628 g/polybag)	28.740 ± 1.154[e]				

Abbreviations: * = significant difference (p<0.05); different letters = significant difference according to the LSD test (p<0.05); same letter = no significant difference according to the LSD test (p> 0.05); N= nitrogen; P= phosphorus; K= potassium; C/N = carbon-to-nitrogen ratio.

Efficacy of liquid biolistics in increasing the fertility of latosol soils

The efficacy of liquid *biolistics* on the fertility rate of latosol soil collected from Bali, Indonesia, was evaluated using five criteria, namely, the concentration of N, P, and K; the C/N ratio; and the acidity level (pH), as shown in Table 2. The statistical test results showed that the nitrogen content (N) obtained from the F count was 140,511 ($p = 0.000 < 0.05$). Thus, there was a significant difference between the treatment groups. The LSD test results showed a very noticeable difference in all treatment groups, NC, PC, P1, P2, P3, and P4, with values of $p<0.05$. The phosphorus content (P) was tested, and a calculated F count value of 35,380 was obtained, with a probability of $p = 0.000 < 0.05$. Thus, there was a significant difference between the treatment groups. The LSD test results revealed noticeable differences between P2 and P3 and between P3 and P4. K was obtained from an F count of 111,935, with a probability value of $p = 0.000 < 0.05$. Thus, there was a significant difference between the treatment groups. According to the LSD tests, there were clear differences between the negative control (NC) and positive control (PC) groups and between the PC treatment and P1, P1 treatment and P2, and P3 treatment and P4. Testing the ratio of carbon to nitrogen (C/N) yielded an F count of 188,959 with a probability value of $p = 0.000 < 0.05$. Thus, there was a significant difference between the treatment groups. The LSD test results showed very noticeable differences in the negative control treatment (NC) compared to the positive control (PC), P1 treatment with P2, P2 treatment with P3, and P3 treatment with P4. Furthermore, acidity level (pH) testing yielded a calculated F value of 11,555, with a probability value of $p = 0.000 < 0.05$. Thus, there was a significant difference between the treatment groups. The LSD test results showed a noticeable difference between the negative control treatment (NC) and the positive control (PC).

Table 2. Fertility of the latosol soil caused by the addition of liquid biolistics

Parameter/ Unit	Treatment	Mean ± SD	Shapiro-Wilk	Levene Statistic	F	p value
N (%)	Negative control (NC)	0.560 ± 0.181^{a}	0.933	3.233	140.511	0.000*
	Positive control (PC)	12.586 ± 0.805^{b}				
	P1 (208.4 mL/polybag)	6.418 ± 1.516^{c}				
	P2 (417 mL/polybag)	7.922 ± 1.321^{d}				
	P3 (533.8 mL/polybag)	12.874 ± 1.331^{e}				
	P4 (834 mL/polybag)	16.698 ± 0.727^{f}				
P (%)	Negative control (NC)	0.802 ± 0.272^{a}	0.913	6.804	35.380	0.000*
	Positive control (PC)	8.338 ± 0.842^{a}				
	P1 (208.4 mL/polybag)	5.818 ± 1.810^{a}				
	P2 (417 mL/polybag)	7.864 ± 1.150^{b}				
	P3 (533.8 mL/polybag)	13.196 ± 4.591^{c}				
	P4 (834 mL/polybag)	17.106 ± 1.023^{d}				
K (%)	Negative control (NC)	1.300 ± 0.187^{a}	0.823	2.437	111.935	0.000*
	Positive control (PC)	14.658 ± 1.960^{b}				
	P1 (208.4 mL/polybag)	8.986 ± 0.406^{c}				
	P2 (417 mL/polybag)	12.516 ± 0.626^{d}				
	P3 (533.8 mL/polybag)	12.546 ± 0.956^{d}				
	P4 (834 mL/polybag)	14.050 ± 1.159^{e}				
C/N Ratio	Negative control (NC)	5.540 ± 1.054^{a}	0.955	0.129	188.959	0.000*
	Positive control (PC)	13.124 ± 0.706^{b}				
	P1 (208.4 mL/polybag)	14.382 ± 1.360^{b}				
	P2 (417 mL/polybag)	16.598 ± 1.072^{c}				
	P3 (533.8 mL/polybag)	19.720 ± 0.955^{d}				
	P4 (834 mL/polybag)	25.090 ± 6.189^{e}				
pH	Negative control (NC)	4.540 ± 0.763^{a}	0.961	0.632	11.555	0.000*
	Positive control (PC)	6.000 ± 0.612^{b}				
	P1 (208.4 mL/polybag)	5.900 ± 0.418^{b}				
	P2 (417 mL/polybag)	6.200 ± 0.836^{b}				
	P3 (533.8 mL/polybag)	7.000 ± 0.790^{b}				
	P4 (834 mL/polybag)	7.500 ± 0.500^{b}				

Abbreviations: * = significant difference ($p< 0.05$); different letters = significant difference according to the LSD test ($p<0.05$); same letter = no significant difference according to the LSD test ($p> 0.05$); N= nitrogen; P= phosphorus; K= potassium; C/N = ratio of carbon to nitrogen; pH = hydrogen power.

Macro and micronutrient contents in solid and liquid biolistic

The results of laboratory tests on the content of solid and liquid biolistic macro- and micronutrients are presented in Figures 1 and 2. The macronutrients contained in solid and liquid biologics include C-organic substances; total N, P_2O_5, and K_2O; the C/N ratio; and hydrogen. The micronutrients contained in solid and liquid biolistics include iron (Fe), magnesium (Mg), mangan (Mn), sodium (Na), and zinc (Zn). The results indicate that all the parameters tested related to the contents of macro- and micronutrients contained in solid and liquid *biolistics* meet the minimum standards required for biological fertilizers, soil repairers, and solid organic fertilizers; the raw materials used are from domestic organic waste according to the Indonesian National Standard 19-7030-2004 and the Regulation of the Minister of Agriculture of the Republic of Indonesia number 01 of 2019. The content is very useful for increasing soil fertility; improving the microbiological, physical, and chemical structure of the soil; and accelerating the growth of organisms to help improve the process of biodegradation and the availability of nutrients in the soil.

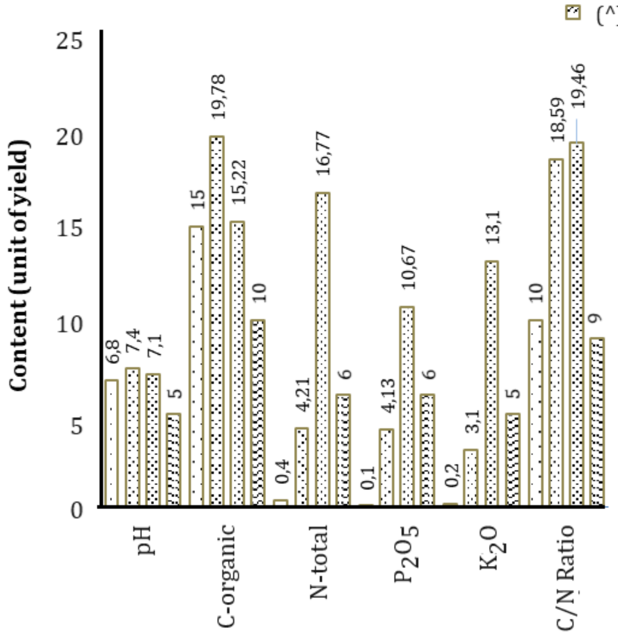

Figure 1. The macronutrients contained in *biolistics* are solids and liquids.
Information: (*) = Indonesian National Standard (SNI) Reference 19-7030-2004; (^) Minister of Agriculture of the Republic of Indonesia Number 01 of 2019; pH = Power of Hydrogen; P_2O_5 = Phosphorus pentaxide; K2O = Potassium Oxide; C/N = Ratio of carbon to nitrogen.

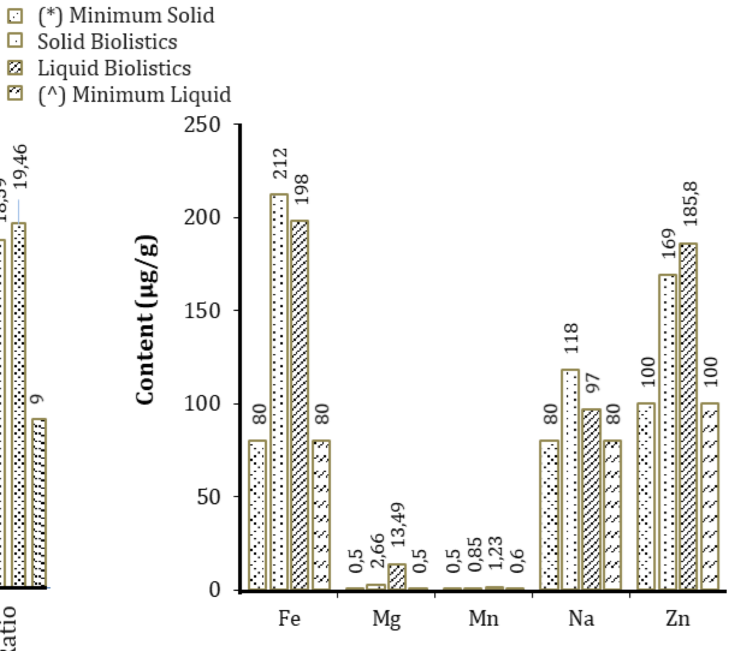

Figure 2. The micronutrients contained in the *biolistics* are solids and liquids.
Information: (*) = Indonesian National Standard (SNI) Reference 19-7030-2004; (^) Minister of Agriculture of the Republic of Indonesia Number 01 of 2019; Fe = Iron (µg/g); Mg = Magnesium (%); Mn = Manganese (µg/g); Na = Sodium (%); and Zn = Zinc (µg/g).

Discussion

Research on the efficacy of solid and liquid *biolistics* in latosol soils showed that nitrogen (N), phosphorus (P), potassium (K), the C/N ratio, moisture content, and acidity level (pH) in all treatment groups significantly improved the aggregation and biological structure of the soil, increasing the capacity and number of microorganisms for organic matter biodegradation and opening up the soil. These results are in line with the findings of Lazcano et al. (2021) and Rashid et al. (2016), who revealed that the inoculation of bacteria and microorganisms in organic fertilizers can improve physical, chemical, and microbiological properties and improve soil aggregates so that they can be applied.

Tables 1 and 2 show that there is a significant difference between soils given solid and liquid *biolistics* treatments at different concentrations and those given a negative control (NC) or positive control (PC). The N, P, K, C/N ratio, water content, and pH positively affected the fertility of the latosol soil. This occurs because of the enrichment of local microorganisms and fungi by *Trichoderma* sp., which can increase nutrients from solid and liquid biolistics. When applied to the soil, biochar can increase the availability of nutrients and increase aggregation (Mahanty et al., 2016; Mitter et al., 2021). Enrichment by adding *Trichoderma* sp. isolates were enriched by the addition of biological fertilizer products, organic fertilizers, and soil repellents because this fungus has many advantages and positive impacts on soil improvement (Pandey and Chandra, 2016; Mącik et al., 2020; Fasusi et al., 2021).

Trichoderma spp. can produce antibiotics that are used naturally to kill parasites found in the soil (Al-Suhaibani et al., 2020; Bhandari et al., 2021). This fungus produces several secondary metabolites in the form of nonribosomal peptides, terpenoids, pyrones, and indolic derivatives with toxic effects on breeding soil parasites (Kashyap et al., 2017). In addition, *Trichoderma* sp. can produce indole-3-acetate acid, which contributes to plant acceleration and increased growth time (Asghar and Kataoka, 2021). *The* organic matter of *Trichoderma* can accelerate the process of nitrogen mineralization by increasing the effectiveness of soil phosphatase (Al-Suhaibani et al., 2020; Asghar and Kataoka, 2021; Mayo-Prieto et al., 2021), increasing nutrient absorption, and increasing soil tolerance to abiotic and biotic acidity (Bhardwaj et al., 2014; Fasusi et al., 2021).

In solid and liquid *biolistics*, pollination with local microorganisms and *Trichoderma* sp. increases the activity of microbial exoenzymes that help to breakdown carbon, nitrogen, and phosphorus (Abbasi and Yousra, 2012; Francioli et al., 2016). Scientists are attempting to accelerate the breakdown of nutrients, biomass growth, and absorption of organic and inorganic substances (Mehetre and Mukherjee, 2015; Bononi et al., 2020). This efficiency in the use of microand macronutrients culminates in increased soil productivity (Zhao et al., 2018; Szczałba et al., 2019; Vassileva et al., 2021), transforming the soil environment of the rhizosphere, plant growth-boosting agents, natural decomposition agents, and bioremediation biological agents (Halifu et al., 2019; Zin and Badaluddin, 2020), increasing the provision of soil nutrients in the form of N, P, and K, and other nutrients such as antibiotics, auxin hormones, cytokinins, and vitamins that enrich the root rhizosphere (Contreras-Cornejo et al., 2016; Yadav and Sarkar, 2019; Bhandari et al., 2021), and improving the biological properties of soils by dissolving phosphate compounds, nitrogen propagation, and phosphate activity (Fitriatin et al., 2021).

The macronutrients in the biolistic solid and liquid contents met the quality standards of fertilizers and soil reformers required by the Regulation of the Minister of Agriculture of the Republic of Indonesia number 01 of 2019. Figure 1 shows that the pH in solid *biolistics* is classified as neutral to alkaline (7.4), while in liquid *biolistics*, it is classified as neutral (7.1). The C-organic content was very high at 19.78% in solid *biolistics* and 15.22% in liquid *biolistics*. The N-total value in liquid *biolistics* (16.77%) is higher than that in solid *biolistics* (4.21%) but is classified as meeting the minimum requirements. Furthermore, for the P_2O_5 content, the same result was obtained, namely, from liquid *biolistics* (10.67%) and a high length from solid *biolistics* (4.13%). At K_2O, the content of solid *biolistics* (K) was 3.1% lower than that of liquid *biolistics* (13.1%), and the C/N ratios in solid *biolistics* (18.59) and liquid *biolistics* (19.46) were very high.

Relatively good results were obtained for improving the soil nutrients in the latosol soils. In line with the findings of Arthanawa et al. (2022), research on the effects of natural biofertilizers with a pH of H_2O (8.19), C-organic material (25.18%), N-total material (1.49%), P (2.01%), and K (1.99%) was classified as very high, with a field capacity of 29.16%, so that the use of natural materials can increase soil fertility. Kai and Tamaki (2020) revealed that obtaining similar higher total cholesterol (TC), total nitrogen (TN), and C/N ratios in soils fed organic fertilizers seems to increase bacterial biomass, leading to improved nutrient circulation through N and P circulation.

The macro- and micronutrients contained in solid and liquid *biolistics* indicate that *biolistics*, both solid and liquid, are suitable for use as soil repellents and soil fertility enhancers, especially in latosol soils that have low fertility rates. Both solid and liquid *biolistics* can add C-organic matter to soils and plants. Thomas and Singh (2019) revealed that high or low levels of C-organic matter in the soil are influenced by the amount of organic matter contained in fertilizers. Soil organic matter can be maintained, which contributes to an increase in the biological activity of soil, nutrients, and water transportation so that the decomposition process progresses well (Siddiquee et al., 2017). The total N content also contributes to the need for nutrients in the soil. Nitrogen is useful for increasing the growth of roots, stems, and leaves; for increasing chlorophyll production; for increasing protein levels; and for accelerating the growth of shoots at the roots (Yadav and Sarkar, 2019; Beeby et al., 2020; Bononi et al., 2020).

Elemental N in solid and liquid *biolistics* can improve and control the growth and development of microorganisms in low-fertility soils (Raimi et al., 2017; Lazcano et al., 2021). In addition, the P_2O_5 and phosphorus contents of *biolistics* are important for the bioconversion of sunlight into chemical energy via photosynthetic absorption of CO, which has an impact on the availability of carbohydrate sources in soils with an abundance of organic matter (Islam et al., 2014; Fitriatin et al., 2021). Furthermore, carbohydrates under abundant conditions are synthesized into proteins with the elements N and S. Thus, the formation of cells, tissues, and organs in the soil and in prospective shoots will occur faster, contributing to improved soil quality

(Li et al., 2017). An increase in K_2O in solid and liquid *biolistics* deregulates the translocation of assimilated K_2O to all plant roots. This represents the accumulation of N in the soil, which triggers a decrease in soil quality (Baldi et al., 2016).

The micronutrients contained in the solid and liquid *biolistics* met the quality standards of fertilizers and soil reformers required according to the Regulation of the Minister of Agriculture of the Republic of Indonesia number 01 of 2019. Figure 2 shows that the Fe (iron) content is greater in solid *biolistics* (212 µg/g) than in liquid *biolistics* (198 µg/g). The content of magnesium (Mg) was greater in liquid *biolistics* (13.49%) than in solid *biolistics* (2.66%). Furthermore, for manganese (Mn), the same results are obtained for both liquid biolistic (1.23 µg/g) and solid biolistic (0.85 µg/g) sorbents. For Na, the solid biolistic content (118%) was greater than the liquid biolistic content (97%). Finally, the zinc (Zn) content was greater in liquid *biolistics* (185.8 µg/g) than in solid *biolistics* (169 µg/g).

The micronutrients contained in solid and liquid *biolives* have functions and benefits when their quantities meet normal standards. Iron (Fe) is indispensable for enzymes in the soil (Mitter et al., 2012; Mitter et al., 2021). Fe functions in soil oxidation, respiration, and photosynthesis. As an enzyme catalyst, Fe is associated with the formation of chlorophyll and soil aggregates. In addition, Mn aids in the formation of chloroplasts. Mn is involved in the activity of enzymes involved in photosynthesis and respiration and in the metabolism of N. Mn can inhibit the formation of phenolic and lignin materials for the defense of plants from fungal infections (Contreras-Cornejo et al., 2016; Zhao et al., 2018; Mącik et al., 2020). Furthermore, magnesium (Mg) plays a role in nitrogen metabolism (Lazcano et al., 2021). Ca and Zn in solid and liquid *biolistics* are obtained from the market and from household waste in the form of leaves, vegetables, and fruits that contain many minerals that are good for increasing soil nucleation. Ca, Zn, and Na synergize and are involved in water (osmosis) movement and ion balance in the soil (Abbasi and Yousra, 2012; Mayo-Prieto et al., 2021).

In this study, we found that all parts of the solid and liquid biosystems improved the quality of the latosol soils. This finding is new because the development of organic waste alone as a soil improvement agent has not been able to directly provide good results. Nutrients such as N, P, and K need to be stable for a long time, so improvements in the quality of *biolistics* need to be evaluated. In addition, the results of this study are different from those of previous studies in which substantial amounts of Effective Microorganism-4 (EM-4) were used as a fertilizer decomposition inoculant; however, these studies obtained less significant results in improving soil nutrients but focused on the yield of the plant produced (Chantal et al., 2010; Hidalgo et al., 2022). In this study, the use of macronutrients such as carbon and potassium was improved by maintaining the quality of the raw materials used in biolistic manufacturing, while the use of microelements such as manganese and naphthalene was improved by maintaining the quality of the production materials used. The hope is that the *biolistics* produced comply with established quality standards and can improve soil nutrients appropriately and efficiently.

The use of solid and liquid *biolistics* to increase soil fertility is better than the use of synthetic fertilizers. Physically, organic matter improves the structure and increases the capacity of the soil to store water. Chemically, organic matter increases the resistance of soil to pH changes, increases the exchange capacity of cations, decreases fixation factors, and acts as a reservoir of secondary nutrients and microelements. Biologically, as an energy source for soil microorganisms, nitrogen plays an important role in the decomposition and release of nutrients in soil ecosystems. The microbial community contained in the *biolistics* was determined through microbiological examination; these included *Rhizobium* sp., *Azospirillum* sp., *Bacillus* sp., and *Trichoderma* sp. All the nutrient components met the Indonesian National Standard (SNI) 19-7030-2004 (National Standardization Agency of the Republic of Indonesia, 2004) and the Regulation of the Minister of Agriculture of the Republic of Indonesia Number 01 of 2019 (Ministry of Agriculture, 2019).

Conclusion

Solid and *liquid biolistics* are effective at increasing the fertility of latosol soils. The nitrogen content (N), phosphorus (P), potassium (K), carbon-to-nitrogen ratio (C/N ratio), moisture content, and pH contribute significantly to improving soil aggregates and structures; improving the physical, chemical, and biological properties of soils; and improving the bioavailability of nutrients in the soil. Macro- and micronutrients are beneficial for maintaining and improving soil quality, and the presence of *Rhizobium* sp., *Azospirillum* sp., *Bacillus* sp., and *Trichoderma* sp. is involved in accelerating the process of biodegradation and decomposition in soil. However, further research is needed to determine the stability of macro- and micronutrients in relation to biologics and their impact on the soil. In addition, it is necessary to compare the length of time needed to store nutrients in biolistic-treated soils with that needed for other soil reformers on latosol soils or other soils. Moreover, related research is needed on how well solid and liquid *biolistics* work in soils with different fertility levels and how they can be used directly in soil and plant care on a larger scale.

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