Application of organic materials to improve the growth and yield of maize in an acid soil of Southeast Sulawesi

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Abstract. The experiment was conducted consisting of three different sources of organic materials (plant bokashi: PB; soaked outer shell coconut: SOC; and arbuscular mycorhiza: AM) using four treatments and four rates of organic materials including control. Maize was grown in mixed soil-organic materials in the polybags and observed at 14, 28, 42 and 72 days after planting (DAP). The results showed that the application of PB, AM and SOC significantly increased growth and yield of maize. Increasing the effects depend on the type of source and rate of organic material additions. PB had the greater effects than AM and SOC. The use of PB at 150 g polybag¹ improved 53% plant height, 131% plant diameter and 92% leaf number at 14 DAP; and increased 47% cob length, 43% cob diameter and 78% of cob weight at 72 DAP. The application of organic materials improved organic C, total N, P-and K-availables. This experiment demonstrated that PB produced higher nutrients than AM and SOC. Thus, PB which originated from bokashi of 1:1 weight ratio of leaves of ‘gamal’ (Gliricidia sepium) and ‘komba-komba’ (Eupatorium odoratum) could be used as organic fertilizer for growth and yield of maize in an acid soil.

1. Introduction

Maize (Zea mays L.) is the second most important staple food after rice in Indonesia [1]. However, the improvement of its production is constrained by several factors including soil acidity and low soil fertility [2]. Acidic soils occupy about 60% (1.38 million ha) of land area in Southeast Sulawesi of Indonesia [3]. This soil is characterized by inherently low fertility status, particularly for soil chemical properties and plant nutrient availabilities. The poor fertility of acidic soils is usually due to a combination factors of: low pH (< 5.5), low organic matter, aluminium (Al) toxicity, deficiencies of fosfor (P), potassium (K), calcium (Ca) and magnesium (Mg) and low cation exchange capacity (CEC) [4].

The growth and production of maize are significantly low in acid soils and it may reach reduction from 2.8 to 71% in grain yield [5-6]. Efforts to obtain higher growth and yield of plant
would be necessary to meet crop’s requirement and maintain soil fertility. Research has shown that one of the potentials measures of ameliorating acidic soils is the application of organic materials [7-9]. This study assesses three selected sources of organic materials, namely: plant bokashi, coconut outershell and arbuscula mycorhiza and evaluated their effects on maize growth in an acid soil of Southeast Sulawesi.

2. Materials and Methods

2.1. Materials

The soil sample classified as Typic Udult [10] was collected from Muna District at 0-30 cm of depth, air dried, sieved in 5 mm diameter was prepared for conducting the experiment in a green house of Faculty of Agriculture of Halu Oleo University. A composite of air-dried soil of 2 mm particle size was prepared for soil analysis.

Three potential sources of organic materials were used in this study. They were plant bokashi (PB), arbuscular mycorhiza (AM) and soaked outershell of coconut (SOC).

2.2. Methods

Soil pH was determined in 1:5 soil : water and 1:5 soil : 1N KCl suspension using a pH meter, organic carbon was determined by Walkley-Black method, total nitrogen (N) was measured by Kjeldahl method, available phosphorus (P$_2$O$_5$) was extracted using the Bray I method, available K (K$_2$O) was determined by Morgan method, cation exchange capacity (CEC) was extracted using ammonium acetate 1N at pH 7.0 and determined by atomic absorption spectrophotometer (AAS), and exchangeables of aluminum (Al) and hydrogen (H) were measured by Titration method [11].

Plant bokashi (PB) was prepared using fresh-mixed leaves in 1:1 ratio of ‘gamal’ (Gliricidia sepium) and ‘komba-komba’ (Eupatorium odoratum). The leaves of ‘gamal’ and ‘komba-komba’ were cut to approximately 5 mm length and placed in a vinyl plastic bag. Activator solution (made from 500 mL + 1 kg white sugar + 6 L water) was added to organic materials and incubated for 42 days in an aerob condition. Soaked outershell coconut (SOC) was made by shredding the dried outer-shell of coconut (Cocos nucifera) to small pieces then it was placed in a big plastic bucket. Water of 100 mL was added into bucket. The SOC was incubated for 42 days before treatment. AM was prepared by isolating of mycorhiza from the rhizosphere of ‘kirinyu’ (Chromolaena odorata L.) to obtain indigenous mycorhiza which used as an inoculum. This inoculum was mixed with maize seeds and placed in seed-holes in the plastic bag containing 5 kg of soil. Chemical characteristic of PB and SOC were determined following the procedure by [11]; while arbuscular mycorhiza (AM) was observed its effect in soil treatments.

The experiment was organized using randomized block design with three factors. First factor was PB using 0, 50, 100, and 150 g polybag$^1$ for PB-1, PB-2, PB-3 and PB-4 treatments. The second factor was SOC using 0, 20, 40, and 60 mL for SOC-1, SOC-2, SOC-3 and SOC-4 treatments. The third factor was AM using 0, 20, 30, and 40 g polybag$^1$ for AM-1, AM-2, AM-3 and AM-4 treatments. All 12 treatments were arranged for 4 replicates of each treatment to obtain 48 total polybags. One seed of maize was grown in each polybag. Soil condition was maintained at field capacity.

The vegetative growth was observed by measuring plant height, leaf number, and leaf diameter of maize at 14, 28, and 42 days of planting (DAP); while the generative growth was observed for length, diameter and weight of cob without husk at 72 DAP.

3. Results and Discussion

3.1. Chemical characteristics of soil and organic materials

The chemical characteristics of soil and organic materials are shown in Table 1. According to the criteria of [11], the soil was acid; organic carbon and total N were very low; C/N ratio was medium; P$_2$O$_5$ was high; K$_2$O was very high; exchangeables of Ca, Mg, K and Na were very low; CEC was low; base saturation was low; and exchangeables of Al and H were very low. The soil sample was identified as the low fertility level recommending improvement to support plant growth and yield [4].
Table 1. Chemical characteristic of the soil and organic materials.

| Chemical analysis                  | Soil sample | PB   | SOC   |
|------------------------------------|-------------|------|-------|
| pH (1:5) Water                     | 5.5         | -    | -     |
| pH (1:5) KCl                       | 4.5         | -    | -     |
| Water content (%)                  | -           | 33.47| 18.19 |
| Organic carbon (%)                 | 0.88        | 42.08| 52.24 |
| Total N (%)                        | 0.08        | 3.64 | 1.16  |
| C/N ratio                          | 11          | 12   | 47    |
| Total P (%)                        | -           | 1.16 | 0.09  |
| Total K (%)                        | -           | 0.02 | 3.09  |
| P₂O₅ (available) (ppm)             | 16          | -    | -     |
| K₂O (available) (ppm)              | 64          | -    | -     |
| Exchangeable Ca (cmolₑ kg⁻¹)       | 2.38        | -    | -     |
| Exchangeable Mg (cmolₑ kg⁻¹)       | 0.46        | -    | -     |
| Exchangeable K (cmolₑ kg⁻¹)        | 0.06        | -    | -     |
| Exchangeable Na (cmolₑ kg⁻¹)       | 0.01        | -    | -     |
| CEC (cmolₑ kg⁻¹)                   | 7.36        | -    | -     |
| Base saturation (%)                | 40          | -    | -     |
| Exchangeable Al (cmolₑ kg⁻¹)       | 0.04        | -    | -     |
| Exchangeable H (cmolₑ kg⁻¹)        | 0.16        | -    | -     |

Note: AM was excluded as it was used for inoculums of maize seed.

As shown in Table 1, the water content, N- and P- totals of PB were much higher than SOC; however, the organic carbon, C/N ratio and total K were greater in the SOC.

The effects of organic materials application on soil chemicals and nutrients are shown in Table 2. Application of organic materials increased soil chemical properties. However, there was a little change when the rate of application was multiplied. The addition of PB increased soil pH. This increase could be due to releasing Ca from PB to the soil through chemical and biological decomposition [2,9]. The exchangeables of Al and H were low as shown by the control soil pH before and after treatments suggesting that Al and H at this pH would be neglected [7].

In particular result, increasing rate of AM application caused the greater effect on exchangeable Al. This may be related to activities of AM in the soil releasing Al from Al-minerals [7]. The effect of PB was greater than SOC and AM in increasing C/N ratio of soil, K₂O, exchangeables of Ca, Mg and K indicating that PB was easier to be decomposed and then releasing essential nutrients to soil [8]. However, the effect of AM was much higher than PB and SOC on P₂O₅ which it might be caused by AM releasing P-available to rhizosphere of maize [12].

3.2. Effect of application of organic materials on maize growth and yield

Application of PB, SOC and AM materials affected the growth of plant height (Figure 1), stem diameter (Figure 2) and leaf number (Figure 3) at 14, 28 and 42 DAP. The greatest effect was found on using PB, AM and the lowest was with SOC. The effects were increased with increasing the rate of applications. All the controls were found to be much lower than those PB, SOC and AM treatments.
Using the greatest rates, at 14 DAP, the highest plant height was shown by AM (50.5 cm) followed by PB (47.3 cm) and SOC (38.2 cm); at 28 DAP AM (110.7 cm), PB (98.3 cm) and SOC (82.7 cm); and at 42 DAP AM (168 cm), PB (156 cm) and SOC (147 cm). Compared to the Control treatments, at the highest rate of PB (150 g polybag\(^{-1}\)) increased 53, 131 and 92%; AM 38, 114 and 92%; and SOC 24, 46, and 33% respectively for plant height at 14, 28 and 48 DAP. Similar trend was indicated for plant diameter and leaf number as shown in Table 2. The resulting of the effects of the application of PB, SOC and AM which might be due to the increasing availability of nutrient to the plant [7-8, 13].

The application of PB, AM and SOC also increased cob length (Figure 4), cob diameter (Figure 5) and cob weight without husk (Figure 6) at 72 DAP. The greater effects on length, diameter and weight of each cob without husk were demonstrated by using PB followed by AM and SOC. The highest effect on diameter of cob was indicated by applying PB (150 g polybag\(^{-1}\)) (13.0 cm) followed by AM (40 g polybag\(^{-1}\)) (10.7 cm) and SOC (60 mL polybag\(^{-1}\)) (10.1 cm). Similar trend of results were indicated when using PB, AM and SOC respectively 10.9, 8.81 and 8.20 for length of cob; and 95.8, 80.9 and 79.9 g for weight of cob.

Compared to the control treatments, at the highest rate of PB (150 g polybag\(^{-1}\)) increased 43%; SOC 16 %; and AM 17% for diameter of cob at 72 DAP. Similar result was indicated for length of cob 47% PB, 24% SOC and 32% AM. Weight of cob 78% PB, 36% SOC and 35% AM. In general, the effect of PB was higher than AM and SOC showing higher percentage effects on the growth of plant height, stem diameter and leaf number at 14 DAP; stem diameter at 42 DAP; and cob length and cob weight at 72 DAP. Soaked outershell coconut (SOC) effect was only dominant on the growth of plant height at 42 DAP and AM was on cob diameter at 72 DAP. The greater effect of PB on plant growth and yields than SOC and AM may caused by the releasing more plant nutrients to the soil as shown in Table 2. The available form of nutrients could be maintained in soil consequently support plant growth and yield [7-8].

| Soil analysis                  | PB\(_1\) | PB\(_2\) | PB\(_3\) | SOC\(_1\) | SOC\(_2\) | SOC\(_3\) | AM\(_1\) | AM\(_2\) | AM\(_3\) |
|-------------------------------|---------|---------|---------|-----------|-----------|-----------|---------|---------|---------|
| pH (1:5) Water                | 5.3     | 6.3     | 6.0     | 5.3       | 5.3       | 5.3       | 5.4     | 5.3     | 5.0     |
| pH (1:5) KCl                  | 4.4     | 5.3     | 5.0     | 4.3       | 4.3       | 4.3       | 4.4     | 4.4     | 4.3     |
| Organic carbon (%)            | 1.01    | 0.96    | 0.88    | 1.02      | 1.03      | 1.09      | 1.06    | 1.01    | 0.93    |
| Total N (%)                   | 0.09    | 0.09    | 0.09    | 0.12      | 0.11      | 0.13      | 0.14    | 0.13    | 0.11    |
| C/N ratio                     | 11      | 11      | 10      | 9         | 9         | 8         | 8       | 8       | 8       |
| P\(_2\)O\(_5\) (available) (ppm) | 18     | 41      | 73      | 42        | 19        | 29        | 54      | 48      | 35      |
| K\(_2\)O (available) (ppm)    | 139     | 247     | 197     | 28        | 30        | 35        | 35      | 27      | 39      |
| Exchangeable Ca (cmol, kg\(^{-1}\)) | 2.02   | 4.31    | 3.37    | 1.78      | 1.60      | 2.08      | 1.84    | 1.31    | 1.22    |
| Exchangeable Mg (cmol, kg\(^{-1}\)) | 0.74   | 1.17    | 0.99    | 0.65      | 0.55      | 0.64      | 0.62    | 0.54    | 0.49    |
| Exchangeable K (cmol, kg\(^{-1}\)) | 0.26   | 0.41    | 0.30    | 0.04      | 0.03      | 0.04      | 0.05    | 0.03    | 0.04    |
| Exchangeable Na (cmol, kg\(^{-1}\)) | 0.05   | 0.04    | 0.01    | 0.02      | 0.03      | 0.01      | 0.01    | 0.01    | 0.08    |
| CEC (cmol, kg\(^{-1}\))       | 6.09    | 6.05    | 5.89    | 6.25      | 6.56      | 6.19      | 6.71    | 6.18    | 6.68    |
| Base saturation (%)           | 39      | 50      | 47      | 34        | 38        | 41        | 38      | 31      | 27      |
| Exchangeable Al (cmol, kg\(^{-1}\)) | 0.20   | 0.00    | 0.00    | 0.30      | 0.26      | 0.20      | 0.18    | 0.59    | 1.04    |
| Exchangeable H (cmol, kg\(^{-1}\)) | 0.16   | 0.04    | 0.06    | 0.18      | 0.20      | 0.16      | 0.16    | 0.33    | 0.31    |

Note: PB:(1:50, 2:100, 3:150 g polybag\(^{-1}\)); SOC:(1:20, 2:40, 3:60 mL polybag\(^{-1}\)); AM:(1:20, 2:30, 3:40 g polybag\(^{-1}\))
Figure 1. Effect of Plant Bokashi (PB), Soaked Outer Shell (SOC) and Arbuscular Mycorhiza (AM) on plant height (cm) at 14, 28 and 42 DAP. Different letters on the same color lines are indicated significantly effects.

Figure 2. Effect of Plant Bokashi (PB), Soaked Outer Shell (SOC) and Arbuscular Mycorhiza (AM) on plant diameter (cm) at 14, 28 and 42 DAP. Different letters on the same color lines are indicated significantly effects.

Figure 3. Effect of Plant Bokashi (PB), Soaked Outer Shell (SOC) and Arbuscular Mycorhiza (AM) on leaf number per plant (leaf) at 14, 28 and 42 DAP. Different letters on the same color lines are indicated significantly effects.
Conclusion

This study has demonstrated the positive effects of the application of plant bokashi, soaked outer shell coconut and arbuscular mycorhiza on the growth and yield of maize. However, degree of the effects depend on the type and rate of organic materials. The increasing plant growth and yield is due to improving soil fertility and plant nutrient as result of organic amendments. It is recommended that the plant bokashi is effective to be used as organic fertilizer for growth and yield of maize in acid soils. The outer shell coconut requires more time to decompose in immersed water to produce a greater effect; while the arbuscular mycorhiza needs more study on its relationship to the specific host-plant.

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