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Organic Amendment and Fertilizer Effect on Soil Chemical Properties and Yield of Maize (*Zea mays* L.) in Rainfed Condition

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Abstract

Indonesia contributes 2 % of maize (*Zea mays* L.) production on the global scale, making it the sixth largest producer in the world. Maize is grown mainly (89 %) in rainfed areas. In agriculture management, rainfed areas have problems, such as lack of water and nutrient availability. This study aims to identify the role of organic amendments and NPK fertilizer in rainfed land management. The research was conducted in Karanganyar regency, Central Java, Indonesia, with an average temperature of 30 - 31 °C, relative humidity of 86 %, and rainfall around 2100 mm year^{-1}. The experiment was carried out during May - August (dry season). The experiment consisted of 5 treatments: (i) control (CO); (ii) compost fertilizer (CF); (iii) straw mulch (MC); (iv) legume cover crop (CC), and (v) NPK fertilizer (AF), and was arranged in a randomized complete block design with 4 replicates. The results showed compost and mulch can increase soil organic carbon (62 and 9.8 %, respectively), organic matter (62 and 9.8 %, respectively), plant height, cob weight, and biomass (30 and 18 %, respectively). On the other hand, legume cover crops have an adverse effect on the growth and yield of maize, due to nutrient competition between them. NPK fertilizer treatment has the highest value for growth and yield of corn crop, at 179.6 cm and 83.4 g, respectively, followed by compost, mulch, control, and legume cover crop, because NPK fertilizer can supply all nutrients, which are easy for the plants to absorb. Treatment compost 20 t.ha^{-1} can give the same result as NPK fertilizer 15-15-15 200 kg.ha^{-1} in plant growth and production.

Keywords: Organic amendment, NPK fertilizer, soil chemical properties, growth and yield of maize

Introduction

Maize (*Zea mays* L.) as one of food plant has a sixth larger producer in the world, which has 2 % of global production contributed by Indonesia [1]. In Indonesia, maize is the second most important cereal crop after rice [2]. Rice occupies about 61 % of the total area planted for food crops, with another 20 % used for secondary crops *(palawija)* such as soybeans, peanuts, cassava, and sweet potato. Maize is grown mainly (89 %) in rainfed areas [3]. Rainfed land and can produce the highest yields of agricultural production in several regions of the word. The area is generally dominated by a moderate climate with sufficient rainfall and fertile soil. However, the condition also occurs in tropical regions that have sub-humid and humid climates. Rainfed land can produce up to 5 - 6 t.ha^{-1} of agricultural production [4]. Rainfed areas account for 33 % of the total rice production area in the world, but provides only 19 % of world rice production because the yield is low, at only 2.3 t.ha^{-1} on average, which is lower than that for irrigated rice at 5.0 $t.ha^{-1}$ [5]. Rainfed land has many problems, such as limited water, damaged soil characteristics, and low nutrient availability [6]. Rainfed land management is important to increase crop production through increasing soil nutrient availability using organic amendments [7].

Organic amendments such as animal and green manure [8,9], organic wastes [10,11], composts [12,13], and biochar [14,15], are effective to improve the physical properties and nutrient availability of soil [14]. In general, a better understanding of the types and characteristics of soil input material is necessary for optimizing the positive effects on soil nutrient availability associated with the production of maize. Compost is usually dark brown and has an earthy appearance and smell [16,17]. Compost can be applied once, or annually at moderate application rates well adapted to sustainable agriculture [18,19]. Rice straw mulch (MC) is the vegetative part of the rice plant after the grain and chaff have been removed. The dimensions of MC are 40 - 60 cm long and 0.4 - 0.8 cm wide. Straw mulch treatment can increase soil organic carbon by up to 6.2 % on maize and wheat cultivation [20], and a total yield of sweet potato by up to 40 ton/ha [21].

Legume crops can be useful additions in rice-based rainfed lowland cropping systems with their ability to provide fixed N (nitrogen) [22]. Peanuts (*Arachis hypgaea*) could improve the utilization of phosphorus (P) by root exudation of organic acids from legumes, also improving legume nitrogen (N) uptake by enhanced nodulation of legumes [23,24]. NPK fertilizer is an inorganic compound fertilizer. A combination of NPK fertilizer with compost can increased the yield of maize by up to 7 - 15 % [25]. On the other hand, the 350 $kg.ha^{-1}$ of NPK fertilizer gives the highest N (nitrogen), OM (organic matter), and OC (organic carbon) content [26]. This study aims to evaluate the effect of soil organic amendment and inorganic fertilizers on soil chemical properties and growth of maize under rainfed conditions.

Materials and methods

Experimental material

A field experiment was carried out from May - August 2017 in a single field in Jumantono district (7°37'S, 110°56′E) in Karanganyar regency, Central Java, Indonesia, with average temperatures of 30 - 31 °C, relative humidity of 86 %, and rainfall of around 2100 $mm.year^{-1}$. The soil type of this land is alfisol. Alfisol soil has an argillic, a kandic, or a natric horizon, and a base saturation of 35 % or greater. The experiment consisted of 5 treatments: (i) control (CO), meaning no input or bare soil; (ii) compost fertilizer (CF) with dose 20 $t.ha^{-1}$; (iii) straw mulch (MC) 4 $t.ha^{-1}$ with thickness 15 cm; (iv) legume cover crop (CC), and (v) NPK 15-15-15 fertilizer (AF) 200 $kg.ha^{-1}$, and was arranged in a randomized complete block design with 4 replicates. Twenty raised beds with dimensions of = 3×4 m^2 were prepared for planting. Maize seeds (*Zea mays* L. cv. Bima) were planted in alfisol soils at 15 cm depths.

Analysis of soil and plant

Soil samples were collected every week from the vegetative until the generative phase of maize. Soil samples were collected from 0 to 25 cm of soil depth using soil drills on each treatment [27]. Soil organic carbon was determined by the procedure of Walkley and Black, using the dichromate wet oxidation method [28,29]. The organic matter was determined by multiplying organic carbon by 1.724. The total N was determined by Kjeldahl digestion and distillation techniques [30], and available P was extracted using the Bray method. Thereafter, K was determined using a flame photometer. Soil pH was determined by using a soil-water medium at a ratio of 1:2 using a pH meter [31,32]. Measurement of maize growth and production included stem diameter, plant height, number of leaves, leaf area index, root length, cob weight, cob diameter, number of cobs, and biomass. Plant height as a vegetative indicator was measured weekly basis, with other indicators measured after harvesting the maize.

Statistical analysis

Multiple comparisons were conducted using SPSS 22.0 software to determine the significance of variations. Afterwards, the least significance differences (LSD) test analysis was performed to determine the significance of variations between the treatments at a 95 % significance level. Figures were drawn using Microsoft Excel, 2013 version.

Results and discussion

Impact of organic amendments on soil chemical properties

pH is an important property of fertilizer materials. For most plants, the optimum pH for growth is between 6.5 and 7 [33]. The highest pH was recorded as 7.8 - 7.9 for control (CO), because alfisol has a high base saturation (50 %), but in other treatments (CF, CC, MC, and AF), there was a decline of pH, causing nitrification to nitrates in the AF treatment, decomposition residue in the MC treatment, and legume (CC) acidification in their rooting zone through nitrogen-fixation [34]. Also, pH can influence the uptake of nutrients [35].

The addition of NPK fertilizer and green manure can increase K-total and P availability in soil [36]. **Figure 1** shows that each treatment impacted soil nutrient availability. The highest P availability and K-total were reported for NPK fertilizer (AF) and compost (CF), followed by legume cover crop (CC), control (CO), and rice straw mulch (MC). Peanuts (*Arachis hypogaea*) could improve the utilization of phosphorus (P) by root exudation of organic acids from legumes [37,38].

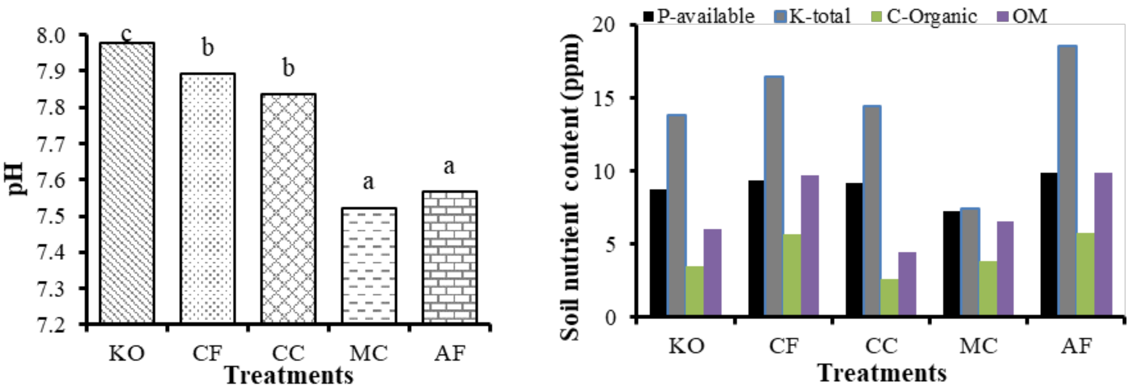

Figure 1 pH and nutrient availability of soil under various treatments.

C-organic and organic matter was increased in compost, mulch, and NPK fertilizer. Mulch can increase crop yield and soil chemical properties, such as total organic carbon and organic matter [39]. NPK or inorganic fertilizer is a major constituent of chlorophyll, carbohydrate utilization, root growth and development, above ground vegetative growth, and stimulation of uptake and utilization of other nutrient elements [40].

Growth and yield of maize in each treatment

Plant height is an indicator of plant growth that is easily observable and measured. The results of variance analysis showed that the effect of the treatments applied had significant effect on plant height. The DMR (Duncan's Multiple Range) test (**Table 1**) showed the highest plant height was reported in plants supplied with NPK fertilizer (179.68 cm) and compost fertilizer (169.05 cm), followed by straw mulch (162.12 cm), control (157.25 cm), and cover crop (117.76 cm). Stem diameter was also influenced by organic amendments and inorganic fertilizer, **Table 1** showed the highest stem diameter was in NPK fertilizer and compost (5.49 cm and 5.48 cm, respectively), followed by straw mulch (4.98 cm), control (4.75 cm), and cover crop (3.78 cm).

Leaf area index is an indicator of plant growth that is also easily observed. Leaf area index is the main parameter for determining leaf area and the rate of photosynthesis of plant unity. The results of the variance test showed that the effect of treatment type had significant effects on leaf area index. The results showed the leaf area index on the treatment of cover crop (CC) and control (CO) use have significantly different results to compost fertilizer (CF), straw mulch (MC) and NPK Fertilizer (AF). Based on **Table 1**, it is known that the highest and lowest LAI are in NPK fertilizer (8.32 cm), compost fertilizer (8.24 cm), treatment of straw mulch (7.34 cm), control (6.79 cm), and treatment cover crop (6.61 cm). The longest root length was found in NPK fertilizer (23.4 cm) but was not different with root length in compost treatment (21.6 cm), with the shortest root length found in cover crop treatment.

Table 1 Growth and yield of maize (*Zea mays* L. var. Bima) under different treatments (mean±standard deviation).

Treatment	Plant height (cm)	Stem diameter (cm)	Leaf Area Index	Root length (cm)	Cob weight (g)	Biomass (g)
Control	157.2 ± 35.3^{b}	4.7 ± 0.2^{b}	6.79 ± 1.5^{a}	20.5 ± 1.9^{b}	39.6 ± 37.6^{ab}	221.8 ± 70^{b}
Compost (CF)	169.0 ± 18.2^{b}	5.4 ± 0.3^{b}	8.24 ± 1^{b}	21.6 ± 1.8^{bc}	74.5 ± 19.9^{cd}	289.3 ± 72^{c}
Cover crop (CC)	117.7 ± 39^{a}	3.7 ± 1.2^{a}	6.61 ± 0.8^{a}	16.5 ± 3.1^{a}	24.1 ± 17^{a}	166.9 ± 66.4^{a}
Straw mulch (MC)	162.1 ± 22^{b}	4.9 ± 0.6^{b}	7.34 ± 0.7^{a}	20 ± 1.4^{b}	55.9 ± 20.2^{bc}	239.8 ± 54.7^{b}
NPK fertilizer (AF)	179.6 ± 25.1^{b}	5.4 ± 0.3^{b}	8.32 ± 0.8^{b}	23.4 ± 1.2^{c}	83.4 ± 42.1^{d}	316.1 ± 65.5^{d}

Table 1 showed that the cob weight in NPK fertilizer (AF) and cover crop (CC) treatment has significantly different results to straw mulch treatment (MC), and compost (CF). The highest and lowest cob weights were found in NPK fertilizer treatment (83.48 g), compost fertilizer treatment (74.55 g), straw mulch treatment (55.96 g), control (39.62 g), and cover crop treatment (24.15 g). For biomass parameter, the highest was found in NPK fertilizer (316.15 g) and compost fertilizer (289.30 g), followed by straw mulch treatment (239.83 g), control (221.85 cm), and cover treatment crop (166.90 g).

Based on **Table 1**, plant growth and production in NPK fertilizer show consistently highest in all variables, because inorganic fertilizers consist of high and complete macro nutrients besides the nutrients promptly available and absorbable by the plants. However, almost no variable in NPK fertilizer and compost is different, except for biomass. On the other hand, NPK fertilizer also increases soil nutrient availability, such as N, P, K, Ca, and Mg, with conditions giving impact to growth, yield, and vitamin C of Okra [41]. Compost decomposes gradually, mineralizing nutrients over many years, depending on its origin, chemical composition, and climate conditions [42]. In addition, compost application may also stimulate root growth by the presence of humic substances released by the decomposing organic matter. These substances exhibit a beneficial effect on root proliferation and on overall plant grow [43]. In other research, cow dung compost significantly increased by 33.09 - 48.54 % the number of leaves and the stem diameter of *Moringa oleifera* Lam. with the dosage of compost 100 - 300 g [44]. Furthermore, cover crop treatment using peanuts (*Arachis hypogaea*) is not suitable to increase maize plant growth and production. Cover crop treatment consistently shows the lowest value for plant growth and plant production of maize, because living cover crop will be a competitor with the main crop (maize) in getting nutrients from the soil. Peanut (*Arachis hypogaea*) is not good for multiple cropping with maize but could possibly be used in crop rotation.

Conclusions

The study demonstrates finding solutions in climate change conditions that lead to drought, especially in rainfed land that have no irrigation channels. The solution offered is to add organic amendment and NPK fertilizer to the soil. Organic amendment and NPK fertilizer affected soil chemical properties, growth, and yield of corn crops. The results showed compost and mulch can increase soil organic carbon (62 and 9.8 %, respectively), organic matter (62 and 9.8 %, respectively), plant height, cob weight, and biomass (30 and 18 %, respectively). On the other hand, legume cover crops have an adverse effect on the growth and yield of maize, due to nutrient competition between them. NPK fertilizer treatment has the highest value for growth and yield of corn crop, at 179.6 cm and 83.4 g, respectively. In this research, compost 20 $t.ha^{-1}$ can give same result as NPK fertilizer, 15-15-15 200 $kg.ha^{-1}$, in plant growth and production.

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