Research Article

Effectiveness of the combination of biopellet, biochar, chicken manure and fish waste to the improvement of chemical properties of sandy soil and soybean plant growth

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Abstract: Most of the activities of the use of organic fertilizers and natural additions of organic matter in agricultural intensification fields in Indonesia have not been able to compensate for the rate of decline in soil organic matter by the decomposition process. Biochar has a high C level and has the mean residence time in a long period in the soils. It has been proven that biochar applications may increase soil Carbon but have not been able to increase plant production. Therefore, the use of biochar combined with organic waste rich in nutrients is essential to develop. The purpose of this study was to determine the effectiveness of some biochar compositions with sugar cane, chicken manure, fish waste in the form of biopellet fertilizer on improving the chemical properties of sandy soils and the vegetative growth of soybean plants. This study used a completely randomized block design with two factors. The first factor (B) was the composition of biochar consisting of three levels, namely: 70% biochar, 15% chicken manure, 15% fish waste (B1), 50 % biochar, 25% chicken manure, 25% fish waste (B2), and 20% biochar, 40% chicken manure, 40% fish waste (B3). The second factor (D) was the dose of biopellet fertilizers consisting of four levels, namely: control (D0), 2.5 t/ha (D1), 5 t/ha (D2), and 10 t/ha (D3). The results showed that the addition of biopellet fertilizer effectively improved soil chemical properties (pH, C-organic, and CEC) and the availability of N, P, and K of the sandy soil. The effectiveness of increasing the soil total-N varied from 32.42 to 75.79%, P-available varied from 17.46 to 40.69%, and exchangeable K ranged from 8.7 to 25.67%. Improvement of soil chemical properties and the availability of N, P, and K by biopellet fertilizer application increased plant growth but reduced the weight of root nodules.

Keywords: biochar, effectiveness, sandy soil, soil chemistry, soybean

Introduction

Many research results showed that in the humid tropics, including Indonesia, agricultural lands had experienced a continuous decline in the level of organic matter (Gmach et al., 2018; Winarso et al., 2011). Organic matter is one of the keys controlling the ideal soil physical, chemical, and biological properties to support plant growth and sustainability. Most of the activities of using organic fertilizers and natural additions in agricultural intensification fields in Indonesia have not been able to compensate for the rate of decline in organic matter by the decomposition process. Factors that influence the rate of decomposition of soil organic matter were mainly temperature (Ryan et al., 2011), microorganisms (Nicolás et al., 2019), changes in land management (Lei et al., 2019), the composition of

organic matter (Gmach et al*.,* 2018) and others. The use of biochar which has high C level and Means Residence Time (MRT) in a long time had been shown to increase long-term C (Bruun and El-zehery, 2012; Mensah and Frimpong, 2018). However, they were deficient in nutrients (Ilmiawan et al*.,* 2018) so as not to be able to increase crop production. Biochar enriched with NPK nutrients could improve the properties of acid soils and the availability of these nutrients (Winarso et al*.,* 2019). Organic fertilizer is believed to be urgently needed at this time and for the foreseeable future in agricultural inputs because it is one of the effective alternatives to reduce the role of chemical or synthetic fertilizers in agricultural activities. According to Alemi et al. (2010), the use of organic fertilizer in the form of pellets could release nutrients slowly and continuously to support the uptake of wheat plants at different growth stages.

Organic fertilizer in the form of pellets had several advantages over ordinary organic fertilizers, in addition to the slow release of nutrients, it also had a high percentage of durability (91.73%) or low damage (8.27%) when processed. Therefore the use of biochar combined with organic waste rich in nutrients and packaged in pellets was essential to be developed as a source of organic fertilizer. The purpose of this study was to determine the effectiveness of some biochar compositions of sugar cane, chicken manure, and fish waste in the form of organic biopellet fertilizers on improving the chemical properties of sandy soils vegetative growth of soybean plants.

Materials and Methods

Production of biopellet fertilizers and soil sampling

The study was conducted at a Greenhouse and Soil Fertility Laboratory of the Faculty of Agriculture, the University of Jember in 2019. Biochar was made using the Kon Tiki method with the raw materials derived from corn waste in the form of corncobs. Fish waste and chicken manure used for nutrient enrichment were dried and ground, which was then mixed with biochar to become a homogeneous mixture. The percentage of each ingredient adjusted according to treatments. The making of biopellet fertilizer done using a mixture of these materials to form pellets using a concentration of 4% molasses adhesive. The process of moulding into biopellet fertilizer was made using a meat grinder with a diameter of 5 mm. Biopellet fertilizers that had been formulated entirely were then dried in the oven for 4 hours at a temperature of 60-70°C (Lamanda et al*.,* 2015). The chemical properties of each biopellet fertilizer based on different biochar levels presented in Table 1.

Table 1. Chemical properties of biopellet fertilizers.

Chemical Properties	Unit	Biochar Concentration (%)			Explanation*)
		70	50	20	
pH	-	7.22	7.41	7.12	Comply to standard (4-9)
Total N	%	1.65	3.08	3.85	Comply to standard ($N+P_2O_5+K_2O >2$)
Available P	ppm	0.5	1.24	1.51	Comply to standard ($N+P_2O_5+K_2O >2$)
Exchangeable K	%	0.75	0.9	0.83	Comply to standard ($N+P_2O_5+K_2O >2$)
Cation Exchange Capacity	cmol/kg	33.2	30.8	19.6	
Organic C	%	20.8	24.57	29.4	Comply to standard (15)

*) Based on Decree of the Minister of Agriculture of the Republic of Indonesia No. 261/KPTS/SR.310/M/4/2019 concerning Minimum Technical Requirements of Fertilizers Organic, Biofertilizers, and Soil Enhancers, Minister of Agriculture of the Republic of Indonesia.

Based on the results of the test, all biopellet fertilizers met the technical requirements of organic fertilizer according to the Decree of the Minister of Agriculture of the Republic of Indonesia No. 261/ KPTS/SR.310/M/4/2019 about Minimum Technical Requirements of Fertilizers Organic, Biofertilizers, and Soil Amendments, the Ministry of Agriculture of the Republic of Indonesia. The soil used as planting media and biopellet fertilizer test was a sandy soil (Regosol) which has low cation exchange capacity (CEC), total-N, and organic-C. The soil, however, has a very high exchangeable K (available) (Table 2).

Table 2. Chemical properties of the soil used as planting media and biopellet fertilizer test.

Variable Soil Chemical Properties	Unit	Value	Status (*)
pH	-	7.63	Somewhat Alkaline
Total -N (Kjeldahl)	%	0.13	Low
Available P (Olsen)	ppm	0.19	Very Low
K exch (NH_4-As, pH 7, AAS)	%	1.01	Very High
CEC (NH_4-As, pH 7)	cmol/kg	9.6	Low
Organic-C (Kurmis)	%	1.17	Low

*) Based on Soil Analysis Results Assessment Criteria, Soil Research Institute (2005).

Implementation of the experiment

This study used a completely randomized block design with two factors. The first factor (B) was the composition of biopellet materials consisting of 3 levels, namely: 1) 70% biochar, 15% chicken manure, 15% fish waste (B1), 2) 50% biochar, 25% chicken manure, 25% fish waste (B2), and 3) 20% biochar, 40% chicken manure, 40% fish waste. The second factor was the dose of biopellet fertilizers (D) consisting of 4 levels, namely: 1) control or without the addition of biopellet (D0), 2) 2.5 t/ha (D1), 3) 5 t/ha (D2), and 4) 10 t/ha (D3). Plant media, 8 kg of sandy soil that passed through a 2 mm sieve, was put into a polybag and treated with biopellet fertilizer according to the above treatments. The planting media were supplied with water to the field capacity condition and incubated for four weeks. Plants parameter observed when the plant entered the final vegetative phase on the 40th day after planting. The preparation of the samples was carried out by carefully removing the plants and their roots from the polybag to avoid the damage of roots and root nodules. Observation variables for testing the effectiveness of biopellet fertilizers on improving soil chemical properties and soybean plant growth were C-organic, N-total, P-available, K-available, Cation Exchange Capacity (CEC) (Soil Research Institute, 2005), plant height, number of leaves, root length, fresh weight and dry weight of plants, and number and weight of nodules. Effectiveness was measured based on the difference in changes in the value of the variables treated to control, divided by the values of the variables treated.

Results and Discussion

Effectiveness of Regosol soil improvement and N, P, and K nutrients availability

The treatment of biopellet fertilizers (a combination of biochar, fish waste, and chicken manure) in sandy soil significantly increased soil organic-C content. In general, the increase of organic-C content followed the dose of biopellet fertilizer, except for the application of 10 t/ha, which seemed to be decreasing (Figure 1). Differences in composition or percentage of biochar, fish waste, and chicken manure did not give a significant difference. The effectiveness of increasing soil organic-C was very high. The addition of 2.5 t/ha and 5 t/ha increased soil organic-C content by 33.4% 41.1%, respectively. However, the increase of soil organic C content due to the application of 10 t/ha was less than that of the addition of 5 t/ha, and the increase was only slightly above the addition of 2.5 t/ha of 35.9%. Addition of biopellet fertilizer up to 10 t/ha was thought to enhance the decomposition of soil organic matter so that more C was lost from the soil through CO_2 emissions. In addition, the combination of the three ingredients in an amount of 10 t/ha indicated an ideal combination for decomposition. Ge et al. (2013) reported that there was a close relationship between soil nutrients, the quality of organic matter media, and decomposition. The supply of nutrients from the soil or mixtures of organic matter was an important factor controlling the rate of decomposition, because essential nutrients in the soil or litter affect the community and decomposer activities in the soil. This also corresponds to an important variable in the decomposition of organic matter, namely the C/N ratio. Based on the calculation of the C/N ratio of biopellet fertilizer with biochar 70% that was 12.61 (ideal according to the soil), there was no concern about the impact of the immobilization process; while 50% and 20% mixtures had lower C/N ratios of 7.98 and 7.64, respectively than that of 70% mixture. Based on many research results showed that the lower the C/N ratio of organic matter (organic fertilizer), the higher or faster the decomposition processes (Gezahegn et al., 2016). This decomposition of biopellet fertilizer will further affect the decrease in pH because it releases organic acids (Winarso et al., 2011) and will open new sorption sites thereby increasing soil CEC (Berkeley, 2009). Based on the data obtained from this research, the soil organic-C content had a very significant negative correlation with soil pH (r= -0.65**) which means that the

increase of the level of soil organic-C would be followed by the decrease in soil pH value. Regarding biochar decomposition, Wang et al. (2015) reported that the biochar decomposition stage begins with increasing logarithmically and decreasing with time. In addition, the mean residence time of C biochar based on unstable and recalcitrant pools is estimated to be around 108 days and 556 years with pool sizes of 3% and 97%, respectively. The addition of biopellet fertilizer up to 10 t/ha was thought to enhance the decomposition of soil organic matter so that more C was lost from the soil through CO_2 emissions. Besides, the combination of the three ingredients in an amount of 10 t/ha indicated an ideal combination for decomposition.
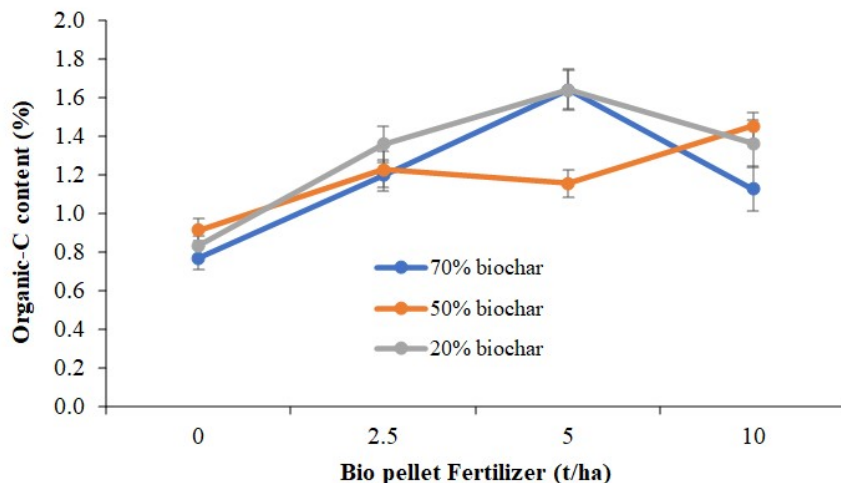

Figure 1. The average increase in soil organic-C content by the treatment of biopellet fertilizers with some biochar levels.

Ge et al. (2013) reported a close relationship between soil nutrients, the quality of organic matter media, and decomposition. The supply of nutrients from the soil or mixtures of organic matter was an important factor controlling the decomposition rate because essential nutrients in the soil or litter affect the community and decomposer activities in the soil. This also corresponds to an important variable in the decomposition of organic matter, namely the C/N ratio. Based on the calculation of the C/N ratio of biopellet fertilizer with biochar 70% that was 12.61 (ideal according to the soil), there was no concern about the impact of the immobilization process; while 50% and 20% mixtures had lower C/N ratios of 7.98 and 7.64, respectively than that of 70% mixture. Based on many research results showed that the lower the C/N ratio of organic matter (organic fertilizer), the higher or faster the decomposition processes (Sun et al., 2019; Gezahegn et al., 2016). This decomposition of biopellet fertilizer will further affect the decrease in pH because it releases organic acids (Winarso et al., 2011) and will open new sorption sites, thereby increasing soil CEC (Berkeley, 2009). Based on the data obtained from this research, the soil organic-C content had a very significant negative correlation with soil pH (r= -0.65**), which means that the increase of the

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Soil pH

The treatment of biopellet fertilizer containing biochar, shrimp waste, and chicken manure in sandy soil with an initial pH of 7.63 (slightly alkaline) could reduce the soil pH to near ideal values for most plant growth (pH of slightly below 7). The magnitude of decrease in pH of the treated soils (a combination of biochar, shrimp waste, and chicken manure) varied between 1.99 to 3.43%. The most considerable decrease or could be said to be the most effective in lowering the pH which was close to ideal was a combination of 70 % biochar + 15% chicken manure + 15% fish waste with a total dose of 10 t/ha. The treatment of biopellet fertilizer had not achieved the ideal soil pH, which was around 6-7 so that the treatment of this material needs to continue in the next planting season. The application period and duration were important to

know so that they could maintain their ideal conditions. The ideal soil acidity would affect the availability of nutrients needed by plants, especially the P and B nutrients which their solubility directly controlled by soil pH. The decrease in soil pH based on increasing the dose was quadratic, with a very high R^2 value ranging from 0.89 to 0.99 (Figure 2). These decreases in pH indicated the decomposition of the added materials (fish waste and chicken manure) into the biopellet compound released organic acids that could increase the amount of H^+ ions which in turn, could reduce soil pH (Iyamuremye et al., 1996; Winarso and Taufiq, 2011; Sari, 2017). The treatment of biopellet fertilizers containing biochar, shrimp waste, and chicken manure could decrease in soil pH by increasing the dosage or concentration of biochar. The application of the bio-pellet 10 t/ha with 70% biochar concentration effective 3.43% reduces soil pH, while the dose of application up to 2.5 t/ha would reduce the effectiveness up to 3.09%. The lower concentration of biochar (20%) would reduce the effectiveness of reducing soil pH by only 2.48%.
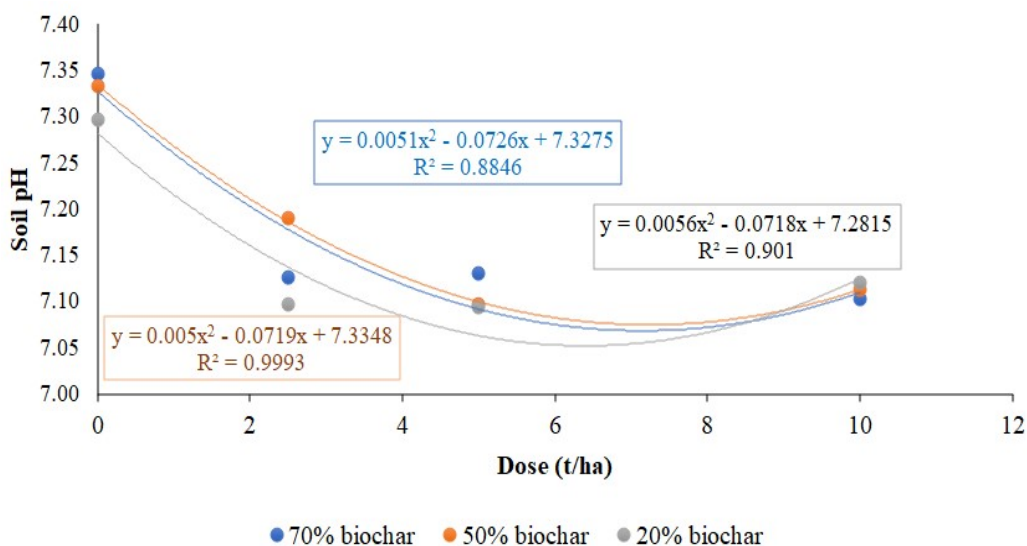

Figure 2. The average decrease in soil pH by the treatment of biopellet fertilizers with some biochar levels.

Soil cation exchange capacity

The combination or interaction of the composition and dosage of bio-pellet fertilizer on the soil's ability to exchange cations in the soil was not statistically significant. However, the single factor of biopellet fertilizer dosage significantly increased the value of soil cation exchange capacity (CEC). A statistical test on a single treatment factor of the dose of biopellet fertilizer could significantly increase the CEC of sandy soil from 9.6 cmol/kg to 18.27 cmol/kg (application of 5 t biopellet fertilizer/ha) (Figure 3). The application of 2.5 t biopellet fertilizer/ha and a high biochar concentration of 70% further increased the value of soil CEC compared to that applied with 50 and 20%. Combination treatment of 10 t/ha dosage and 50% biochar concentration increase the highest in soil CEC (34.66%). Similar to soil pH variable, reducing the dose of biopellet fertilizer given and lowering biochar levels would reduce the effectiveness of increasing soil CEC values. Decreased effectiveness by decreasing the dose of biopellet fertilizer up to 2.5 t/ha (biochar concentration of 50%) reached up to 18.86% while decreasing by biochar concentration to 20% (biopellet dose of 10 t/ha) reached up to 28.35%. Based on many works of literature, the soil CEC value is influenced by the texture and organic-C content of the soil (Mishra et al., 2019). The dominant soil particle size that influences CEC's value is clay fraction, followed by silt and sand fractions. As the soil used in this study is sandy, the soil texture did not contribute significantly to the soil CEC value. Organic matter greatly influenced The CEC of this soil (Siregar et al., 2017), and its value can vary depending on pH or is said to be a variable charge. The relationships between CEC with soil pH and C-organic were categorized strong, which were represented by the equation of y = 6.87x + 6.5 (for CEC vs C-org) and y = 18.24x + 145.71 (for CEC vs pH) with correlation coefficients (r) of -0.72** (n = 36) and 0.69** (n = 36), respectively (Figure 4).
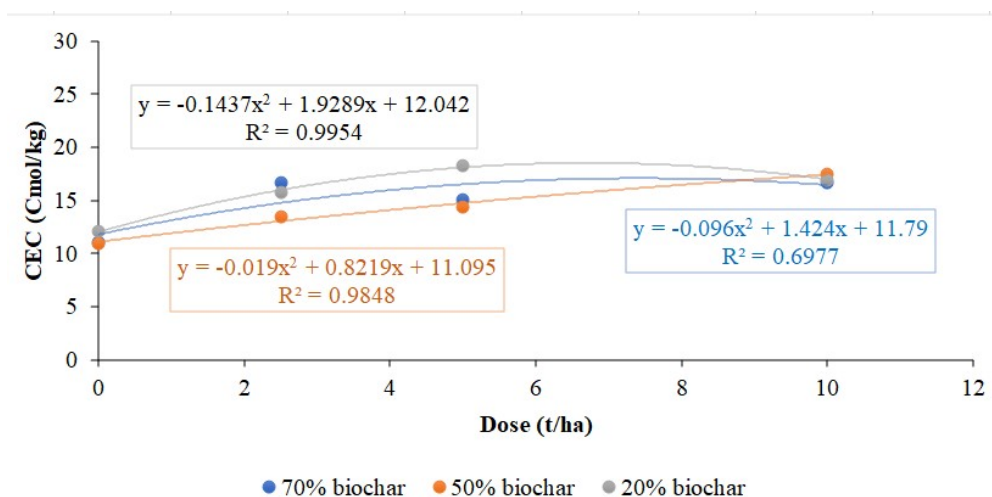
Figure 3. The average increase in soil cation exchange capacity (CEC) by the treatment of biopellet fertilizers with some biochar levels.
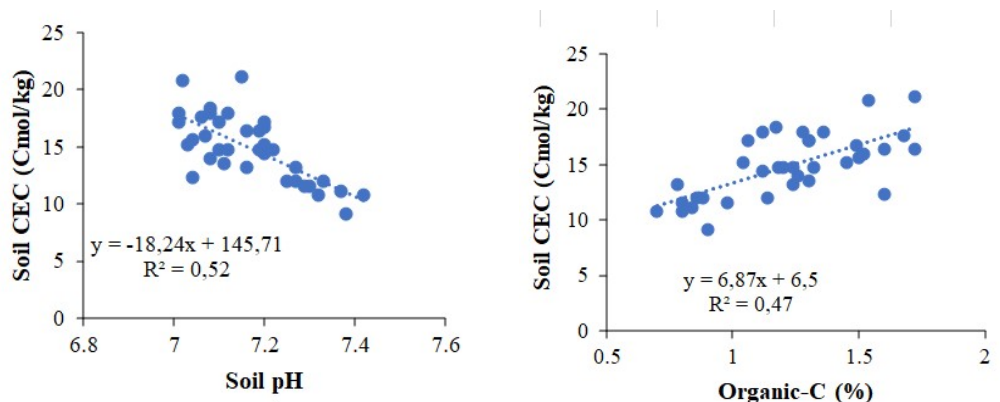

Figure 4. Relationships between CEC with pH and C-organic of sandy soil treated with biopellet fertilizer and biochar.

Decomposition will increase the charge (carboxylate, phenolics, etc.), which are generally variable depending on pH. In conditions of relatively high pH, the charge will be more negative so that it will create new sorption sites or increase the soil CEC's value. In sandy soils, CEC is determined by organic matter content, i.e., the higher the organic matter content, the higher the CEC contribution. The contribution of CEC from organic matter varies depending on the pH. In a low pH, the soil organic matter charge will be positive, thereby reducing CEC. Conversely, in a high pH, the soil organic matter charge will be negative, or CEC will increase.

Availability of soil N, P, and K nutrients

The application of biopellet fertilizer increased the availability of both N, P, and K (Table 3). The effectiveness of increasing nutrient availability in the soil was highest for the N (represented by soil total-N), ranging from 32.42 to 75.79%, followed by available P, which ranged from 17.46 to 40.69, and K-exch which ranged from 8.7 to 25.67%. Those values that are often said to be the efficiency of fertilization were categorized high. The creation of the combined materials into biopellets may cause the high value of the effectiveness or efficiency of fertilization, which was also included as organic fertilizer. It also proved that biochar could increase the effectiveness of fertilization in the soil, especially in sandy soils, which generally have very low fertilization efficiency. Data presented in Table 3 show that the highest efficiency of fertilization was at the addition of 2.5 t biopellet/ha, be followed by 5 t biopellet/ha. The addition of biopellets up to 10 t/ha began to have symptoms sloping. This phenomenon might be following the

law of diminishing return fertilization. The low dose of biopellet (2.5 t/ha) and 50% biochar concentration appeared to have the highest increase in effectiveness compared to the others.

If the dose of biopellet increased to 5 t/ha, the effectiveness also increased, even the increase due to the application of 10 t biopellet/ha tended to be similar to that of 5 t/ha.

Table 3. Percentage of increase in the availability of N, P, and K in the soil or the effectiveness of the combination of biochar and biopellet fertilizer.

Biochar (%)	Application of Biopellet Fertilizer (t/ha)								
	2.5			5			10		
	N	P	K	N	P	K	N	P	K
	....%...								
70	52.73	24.91	13.19	48.00	17.46	12.22	50.94	21.80	14.59
50	58.18	22.12	13.02	75.79	23.58	8.70	69.74	40.69	14.53
20	32.43	20.49	25.67	54.55	23.15	20.57	65.69	19.63	14.72

Effectiveness of increasing soybean plant growth

Fresh and dry weight of plants

Previously it had been explained that in general, the application of biopellet fertilizer containing biochar, shrimp waste, and chicken manure with various compositions could effectively improve the chemical properties of sandy soil. Improvement of soil properties (Table 3) also increased the effectiveness of soybean growth, as presented in Figure 5. The addition of biopellet fertilizer up to 10 t/ha increased fresh weight and dry weight of soybean plants, especially for the composition of 50% biochar, 25% shrimp waste, and 25% chicken manure. It concluded that the composition was the most effective treatment for improving the chemical properties of sandy soil and soybean plant growth. There was a pattern of the response of the growth of soybean plants to low doses of biopellet fertilizer (2.5 t/ha).

Increasing the addition of biochar would increase wet weight. This pattern occurred if the addition of the dose to 5 t/ha increased, which showed a tendency to decline if the percentage biochar increased, even there was a sharp decline in the dose of 10 t/ha.

Number and fresh weight of root nodules

The growth of plant root nodules did not follow the increase in plant growth shown by both fresh and dry weight. Figure 6 shows that the treatment of adding 10 t biopellet fertilizer/ha to sandy soil as a growing medium for soybean plants reduced the fresh weight of root nodules. The sharpest reduction occurred in the combination of 20% biochar and fish waste and chicken manure 40% each. This combination was the most valuable biopellet fertilizer, which had the highest levels of N and P, innate from fish waste and chicken manure (Table 1).
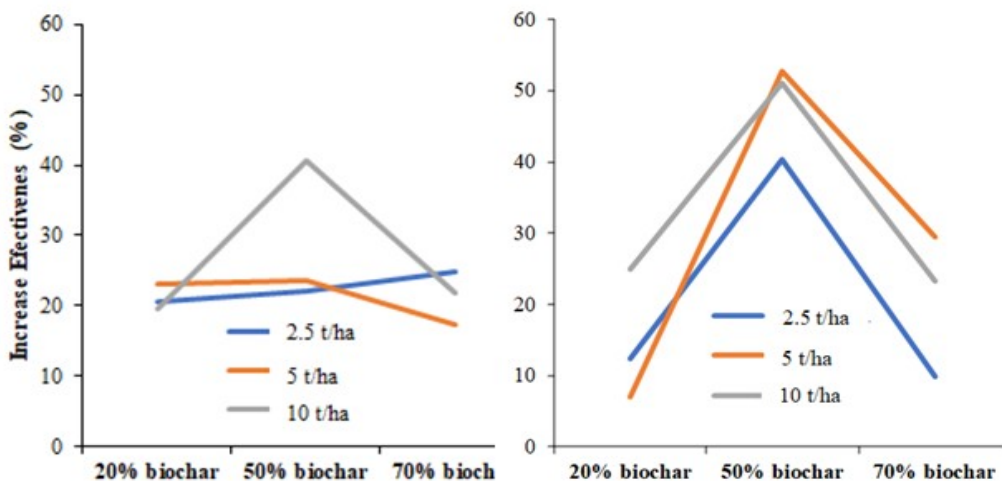

Figure 5. The average increase in wet weight (left) and dry weight (right) soybean plants (5 weeks after planting) by the treatment of biopellet fertilizer with some biochar levels.
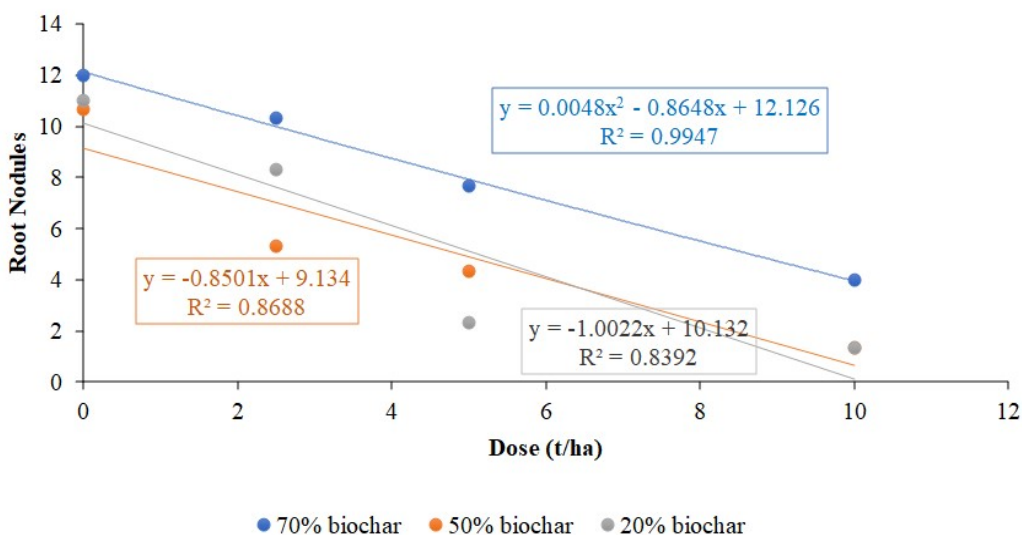
Figure 6. The average reduction in the number of soybean root nodules by biopellet fertilizer treatment with some biochar levels.

Based on the statistical analysis, the relationship between the fresh weight of root nodules and plant growth was very weak, but strong to very strong when associated with soil chemical properties (pH, r = 0.5 and organic-C, r = -0.62**) and availability of N and P (-0.76** and -0.56*, respectively). The relationship of fresh weight of root nodules with the availability of nutrients had a negative correlation; namely, the higher availability of nutrients reduced the fresh weight of root nodules. Conversely, the relationship of soil pH by the addition of biopellet fertilizer was proportional to or positively correlated to the fresh weight of root nodules.

Conclusion

Biopellet fertilizer with several biochar compositions, fish waste, and chicken manure had proven to be effective in improving soil chemical properties (pH, C-organic, and CEC) and the availability of N, P, and K of sandy soil. The effectiveness of increasing the availability of nutrients in the soil was highest in the soil total N soil that ranged from 32.42 to 75.79%, followed by available-P and exchangeable K. The improvement of soil chemical properties and the availability of N, P, and K improved soybean growth.

Acknowledgements

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