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Enhancing soybean (Glycine max (L.) Merr.) yield on Inceptisol through the application of organic fertilizers to promote sustainable agriculture

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Abstract. Organic fertilizers have been considered as environmentally friendly fertilizers in promoting sustainable agriculture, being supported by the abundant natural resources. The study was conducted to determine the effect of type and level of dosage of organic fertilizers on soybean yield. The 4-month study was carried out in West Papua Province, Indonesia, compiled using factorial randomized block design (RBD). The factors were the types of organic fertilizer and two doses of the organic fertilizer. Parameters assessed include number of grains per pod, weight of 100 grains and weight of grains per plot. Pointed out the results of the analysis of variance, the various types of organic fertilizers used (F1, F2, F3 and F4) were significantly different in almost all components of growth and production. However, the type of goat manure (F4) gave the highest yield, while the type of fertilizer that gave the lowest yield was compost (F2). Fertilizer doses were significantly different in almost all yield parameters, namely D1 (5 tons/ha) compared to D0 (without fertilizer). The interaction with the highest yield was goat manure (F4D1), while the interaction that gave the lowest yield was without the use of compost fertilizer (F2D0). Given that high soybean yield can be achieved by balanced fertilization. One way to increase soil fertility in terms of providing nutrients for plants and harmless toward land and plant is by providing organic fertilizers.

Keywords: *Glycine max* (L.) Merr, inceptisol, organic fertilizers, sustainable agriculture, yield

Introduction

The role of soybean (Glycine max (L.) Merr.) as the third food source after rice and corn, is needed to provide a sufficient source of vegetable protein (Islas-Rubio & Higuera-Ciapara, 2002). It has also crucial potential as the best source of vitamins, fats, minerals and fibre among other legumes (Hueda, 2017) as well as being a functional food because it contains secondary

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metabolites, which are very beneficial for human health including isoflavones and saponins (den Hil & Nout, 2011; Kim et al., 2021; Martino et al., 2012; Palomo et al., 2011; Yesim et al., 2011).

In the latest years, soybean major producers in the world are the United States (Soystats, 2017), followed by Brazil, Argentina and India (Voora et al., 2020) where the top three countries together accounted for 80% of total production in 2017 and dominated world exports. In Asia, China is leading in productivity at 15,724 in 1000 metric tons and subsequently followed by India and Indonesia (APAC, 2020). However, Indonesia has been facing the shortages in soybean production, thus importing is the sole solution to meet the gap between consumption and production (Malik & Nainggolan, 2020; Roessali et al., 2017).

The type of utilization varies from country to country, resulted from the increase in population and demand for soybeans. In Indonesia, soybean is mostly consumed as soy-foods especially in fermented products, for instance, tempeh, tofu and soy sauce (Shurtleff & Aoyagi, 2010). These have brought an impact on efforts to increase soybean production in production centers. Increasing soybean production can be done by optimally improving crop cultivation systems (FAO The United Nations, 2014), which include the use of quality grains of improved varieties, pest control of plant diseases, irrigation management and cultivation techniques such as fertilization (Monsanto, 2016)

In order to fulfill the demands of soybeans, agricultural practitioners use large doses of chemical fertilizers aiming to increase soybean production. This is in accordance with the statement that fertilizer is the main production input affecting crop yields (Mofunanya et al., 2015). In fact, fertilizer has played its large role in Indonesia and has recently increased rapidly, especially the use of agrochemical such as inorganic fertilizers. However, excessive and unbalanced use of agrochemicals has led to increase production costs and dependence on external inputs and energy, decline in soil productivity, contamination of surface and ground water, and adverse effects on human and animal health (Silva, 2000). Therefore, there is a growing emphasis on sustainable agriculture in response to concerns about the adverse environmental and economic impacts of conventional agriculture.

High soybean production can be achieved by balanced fertilization. Balanced fertilization refers to the fertilizers application into soils where dose and type of nutrients matching into soil nutrient status and plant requirements aiming to reach optimal yield. Even though soybean has an important characteristic in which it is a legume and create a symbiotic relationship with Bradyrhizobium japonicum (commonly referred to as rhizobia) bacteria to form nodules on the roots resulting a major advantage of soybean because of nitrogen fixation that it does not require any nitrogen fertilizer (Purcell et al., 2010). It contrasts with the theory that N (Nitrogen) fixation and soil residual N may not supply enough N for soybeans to maximize seed yield, especially during reproductive development when they are grown in high-yield environments (Ribeiro, 2014; Sabilu, 2016). Recent studies provided the effectiveness of using N fertilizer to soybean (Hergert et al., 2012; Mrkovački et al., 2008). Therefore, balanced fertilization in soybean plays an important role in soybean cultivation.

One way regarding balanced fertilization is to increase soil fertility in terms of providing nutrients for plants that do not harm the soil and plants by providing organic fertilizer. Organic fertilizers are fertilizers whose sources are easily available in nature and economically affordable (Hutasoit, 2012). Organic fertilizers do not only contain macro elements such as

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nitrogen (N), phosphate (P) and potassium (K), but organic fertilizers also contain micro elements such as calcium (Ca), magnesium (Mg), and manganese (Mn) needed by plants and their role in maintaining nutrient balance in the soil. Besides, organic fertilizer has a long-term sustainable impact and is influential for a long time and become a nutrient source for plants (Yusuf & Tukur, 2013).

Rice husk is an important by-product from the milling process of paddy rice, with a huge amount being produced worldwide each year (Zou & Yang, 2019). It is a natural and renewable biomass source plays a significant role as soil amendments in the form of rice husk ash. While compost fertilizer has been utilized to improve soil physical properties and microbiology (Elpawati et al., 2016), parallel with chicken manure in which it has been employed as a source of micronutrients (Nunes et al., 2015) as well as goat manure. All of these natural resources could be used as organic fertilizers. The application of organic fertilizers is able to improve the structure of the soil to enhance roots growth, increase the absorption and water holding capacity of the soil and improve the life of organisms in the soil, thus they will affect plant growth and can subsequently enhance crop yield This study aims to determine the effect of organic fertilizers (husk ash, compost fertilizer, chicken manure fertilizer and goat manure fertilizer) and their interactions on soybean yield.

Materials and Methods

Study Site

The 4-month experiment was conducted from May to August 2018 at the Food Crop Protection Center, Prafi District, Manokwari Regency, West Papua Province, Indonesia with geographic coordinates at Lat 0°55'S and 133°52'E (Figure 1).

Fig.1 Study site, adapted from Google Maps

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Treatments and Experimental Design

Treatments included a factorial arrangement of four organic fertilizers namely husk ash (F1), compost (F2), chicken manure (F3) and goat manure (F4), with two levels of organic fertilizer application of zero dose (D0) and 5 tons/ha (D1). Thus, it employed a completely randomized block design with three replications. Completely randomized design the levels of the primary factor are randomly assigned to the experimental units. By randomization, the run sequence of the experimental units is determined randomly with the model response below:

$$Y_{ij}=\mu+T_i+\text{random error}$$ (Statistics Department, 2021)

with : Yi,j being any observation for which X1 = I (i and j denote the level of the factor and the replication within the level of the factor, respectively): μ (or mu) is the general location parameter; Ti is the effect of having treatment level i

Cultural Practices

Prior to soybean planting, the land was cleared and harrowed with the size was 25 m x 13 m or 325 m^2 in total. Dena-1 as soybean sertified Grains was used as tested plant obtained from The Centre of Research on Nuts and Tubers Malang, East Java, Indonesia (Balitkabi, 2013). Dena-1 was released in the period of 2014-2016, therefore it has been grown widely since that time. For the purpose of the study, it has been chosen to initially grown in the experimental site because of its superior morphology and agronomy traits in particular its typical of tolerant-shading variety (Balitbangtan, 2019). It is in accordance with the enlargement of the field to the lands dominated by stands that require varieties to adapt to low light intensity. The individual plots sized in 3m x 2m (length x width). Plots were maintained by keeping them weed free, water adequate and pest-disease controlled complied with local practices for high-yield production. Organic fertilizers of husk ash, compost, chicken manure and goat manure were gained from commercial shops in a specific state of readiness and applied at 3 weeks after sowing (WAS). Fertilizers were broadcasted in a band on the soil surface approximately 5 cm from soybean rows according to each treatment on individual plots. The plots were regularly observed to record data relating to the experiment.

Data Collection

Sampling were derived from 5 plants of each plot. Parameters were observed after harvest including number of grains per pod, weight of 100 grains and weight of grains per plot with the following procedures. Number of grains per pod was done by collecting the pods from each soybean sample and counting the number of grains contained in each pod afterwards. The weight of 100 grains was gained by randomly picking 100 grains from sampling, and then weighted. Meanwhile, weight of grains per plot was gained from weighing all grains from each plot.

Statistical Analysis

The data collected was subjected to analysis of variance (ANOVA), using the `F' test. Where such treatments were found to be significantly different, the means were compared using Least Significance Difference (LSD) at 5% test level.

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Results and Discussion

The study site was managed as rainfed production systems and the soil belongs to Inceptisols. Inceptisols are soils formed due to the accumulation of silicate clay but have not met the argillic requirements consisting of 2 suborders, namely, Aquepts which includes the Humaquepts, Halaquepts, and Endoaquepts groups. They were developed from clay precipitated material and gives a positive reaction to αα dipyridyl. Soil reaction (pH) in the field <6.0, and the soil is gray (Nunuela, 2014; Palmer, 2005). The stages of soybean development due to the application of various organic fertilizers is presented in Figure 2. The means of yield parameters are displayed in Table 1.

Fig. 2 Stages of soybean development at Experimental Site (from the left to right: initial stage, flowering and pods development)

Table 1. The means of number of grains per pod, weight of 100 grains and weight of grains per plot

Treatment	Yield parameters measured of each replication					
	Number of grains per pod					
	Replication			Total	Mean	Standard Deviation
	I	II	III			
F_1D_0	2.8	2.8	2.6	8.2	2.73 c	0.12
F_1D_1	3	3	2.8	8.8	2.93 ab	0.12
F_2D_0	2.8	3	2.8	8.6	2.87 b	0.12
F_2D_1	3	3	3	9	3.00 a	0.00
F_3D_0	3	3	3	9	3.00 a	0.00
F_3D_1	3	3	3	9	3.00 a	0.00
F_4D_0	3	3	3	9	3.00 a	0.00
F_4D_1	3	3	3	9	3.00 a	0.00
	Weight of 100 grains (gr)					
F_1D_0	21.28	19.32	21.71	62.31	20.77 ab	1.27
F_1D_1	22.62	19.57	22.60	64.79	21.60 ab	1.76

F_2D_0	20.74	20.73	22.83	64.3	21.43 ab	1.21
F_2D_1	21.48	22.80	21.75	66.03	22.01 ab	0.70
F_3D_0	20.65	19.30	21.32	61.27	20.42 b	1.03
F_3D_1	21.75	20.85	23.82	66.42	22.14 ab	1.52
F_4D_0	21.04	23.74	19.98	64.76	21.59 ab	1.94
F_4D_1	21.45	22.23	26.50	70.18	23.39 a	2.72
Weight of grains per plot (gr)						
F_1D_0	1760	1700	2310	5770	1923.3 a	336.2
F_1D_1	1680	2360	1760	5800	1933.3 a	371.7
F_2D_0	1500	1920	1960	5380	1793.3 a	254.8
F_2D_1	1850	2000	1780	5630	1876.7 a	112.4
F_3D_0	1840	2150	1850	5840	1946.7 a	176.2
F_3D_1	2160	2350	1880	6390	2130.0 a	236.4
F_4D_0	1640	1950	2060	5650	1883.3 a	217.8
F_4D_1	1800	1940	2740	6480	2160.0 a	507.1

Number of Grains per Pod

The number of grains per pod was significantly different in the type of fertilizer (F1, F2, F3 and F4), fertilizer dosage (D0 and D1) and the interaction between fertilizer types and fertilizer dosage (F1D0, F1D1, F2D0, F2D1, F3D0, F3D1, F4D0 and F4D1) (Figure 3).

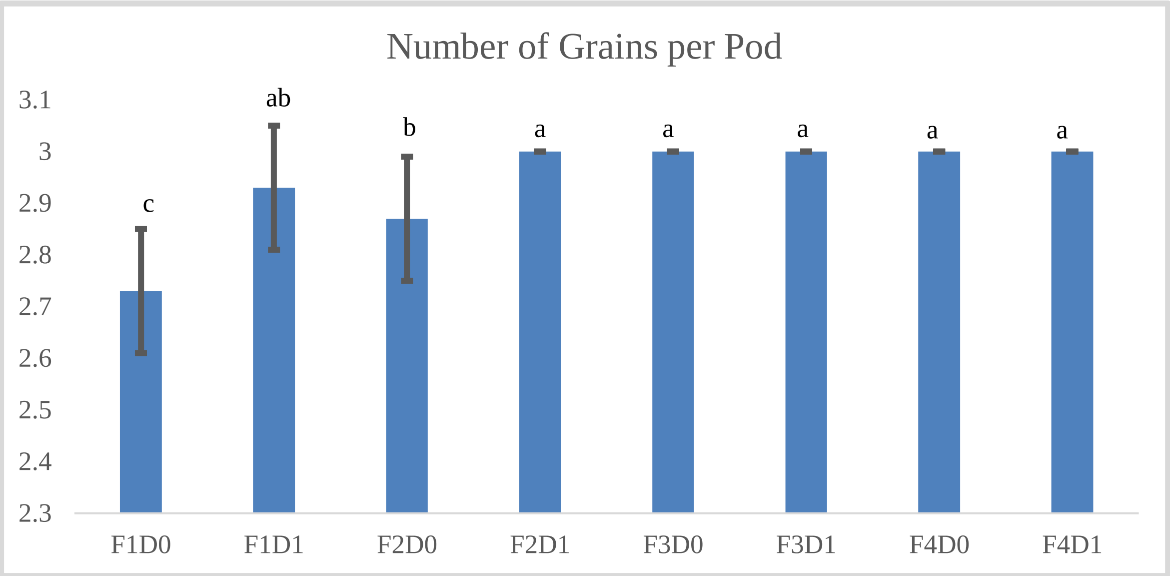

Fig. 3. Number of grains per pod of soybean. Different lowercase letters indicate significant differences at $p < 0.05$ using Fisher's Least Significance Difference

Organic matter plays a prominent role in increasing soil fertility and will determine soil productivity and nutrient supply for plants because organic matter contains a low C/N ratio, where low C/N is very favorable for growing plants, because it is easier when absorbing nutrients (Zhang et al., 2020; Zhang et al., 2015). While Aisah et al. (2020) suggests that varieties play an important role in the development of a plant, since achieving high productivity is largely determined by the yield potential of superior varieties grown, where soybean seed varieties used are soybean grains of Dena-1 variety which is one of the best grains or superior grains.Phosphorus is one of the macro elements contained in organic fertilizer which is very helpful in arranging the components of every living cell, such as the formation of proteins and minerals that are very important for plants, and in turn it is stimulating the formation of flowers, fruits, and grains. In line with the statement that phosphorus is even able to speed up fruit ripening and increase grains weight (Aulakh et al., 2003; Dodd & Mallarino, 2005; Ekaette, 2017; Hansel et al., 2017).

Weight of 100 grains

The production component of the weight of 100 grains was not significantly different in the type of fertilizer (F1, F2, F3 and F4) and fertilizer dosage (D0 and D1) (Figure 4). However, it can be seen that the production component of the weight of 100 grains which provides the highest yield in the type of fertilizer (F1, F2, F3 and F4) is goat manure fertilizer, then followed by chicken manure fertilizer, compost fertilizer and manure ash fertilizer. Whereas the fertilizer dosage (D0 and D1) which gives the best results is D1 (5 tons / ha).

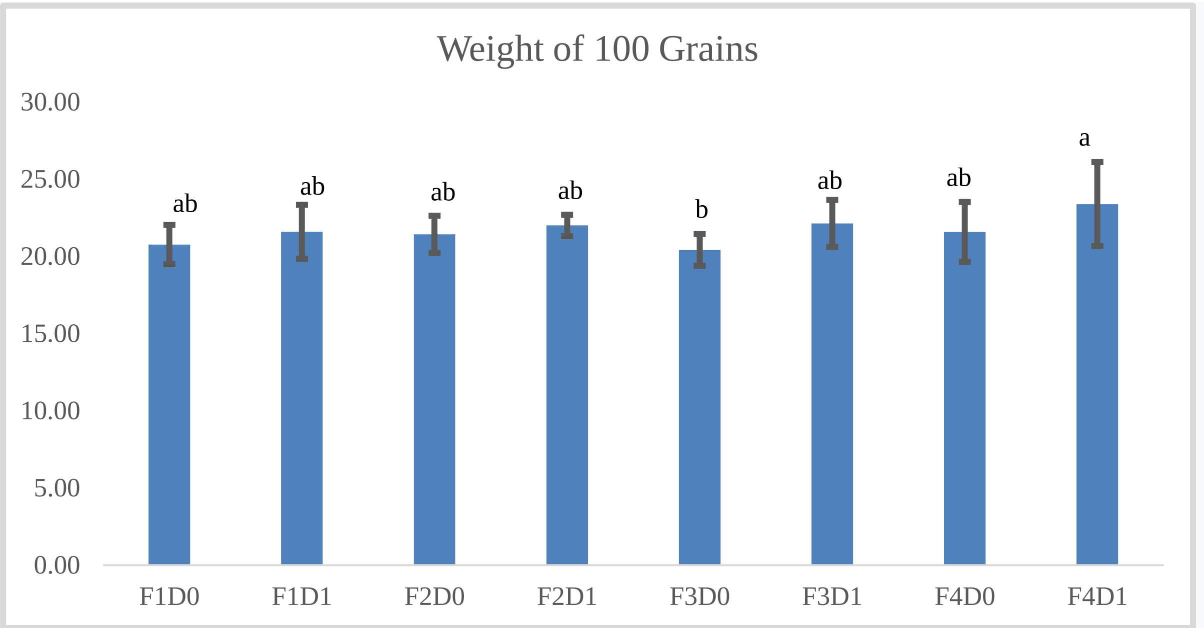

Fig. 4. Weight of 100 grains of soybean. Different lowercase letters indicate significant differences at $p < 0.05$ using Fisher's Least Significance Difference

The addition of organic material into the soil is expected to form loose soil structures. This allows the water and air needed for nutrient extraction and root respiration to be available sufficiently and balancing. It will result the ease roots breakthrough through the soil, favorable water movement, sufficient water retention and active soil organisms, so that the overhaul of organic material will be smooth creating the release of nutrients N, P and K in both soil and nutrient availability increases (Lal and Stewart, 2012). While the interaction between the types of fertilizers and fertilizer doses (F1D0, F1D1, F2D0, F2D1, F3D0, F3D1, F4D0, and F4D1) differed significantly at the weight of 100 grains.

Apart from being a source of nutrients, organic fertilizer can stimulate root growth and improve plant health (Bhardwaj et al., 2014) which is enabling plants to grow better and increasing the absorption and binding capacity of the soil to water, so that the availability of water for plants is fulfilled which will further affect plant growth and production. P element uptake by plants is also influenced by the presence of N elements. The application of P elements combined with N has not been able to increase P uptake by plants. Plants need the P element in each growth stages (Abbasi et al., 2010).

Weight of grains per plot

Components of seed weight production per plot in fertilizer type (F1, F2, F3 and F4), fertilizer dosage (D0 and D1) and interaction between fertilizer types and fertilizer dosages (F1D0, F1D1, F2D0, F2D1, F3D0, F3D1, F4D0 and F4D1) is not significantly different (Figure 5). However, it can be seen that among the four types of organic fertilizer, which gives the best results in the component production weight of grains per plot namely goat manure fertilizer, then followed by chicken manure fertilizer, husk ash and compost fertilizer.

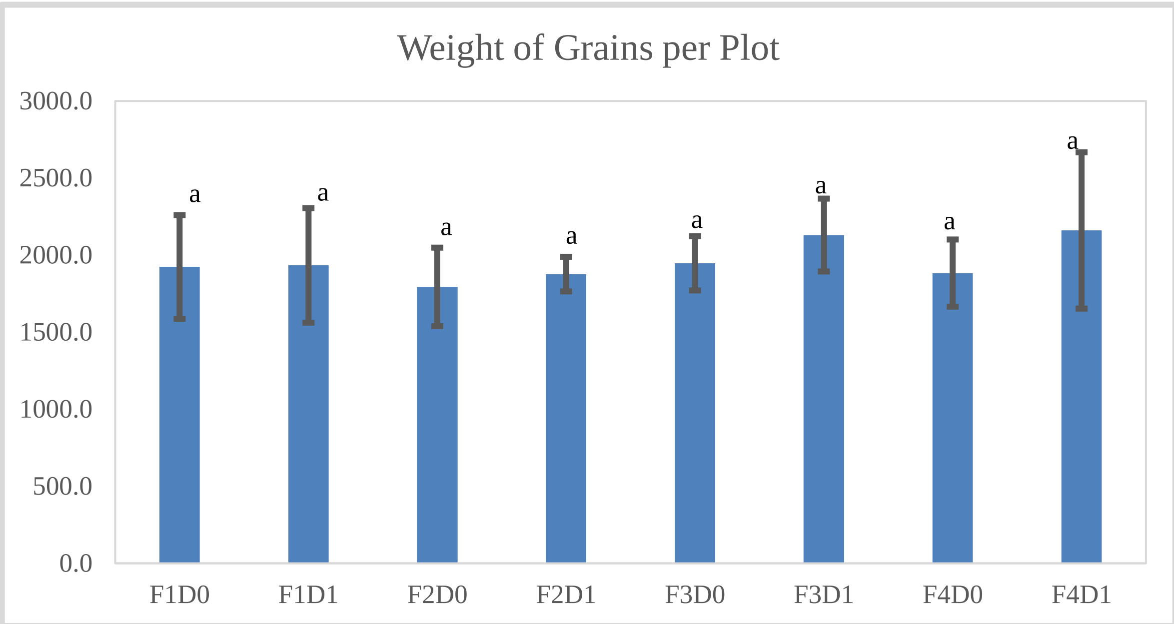

Fig. 5. Weight of grains per plot of soybean. Different lowercase letters indicate significant differences at $p < 0.05$ using Fisher's Least Significance Difference

The difference in growth and yield of plants in the treatment with various organic fertilizers is presumed because the fertilizer given is different from one another in terms of nutrient content in each organic fertilizer. As stated by Zerihun et al. (2013) that the nutrient content of each organic fertilizer is different from one another. In addition, the proper way and time of fertilizer application and accompanied by good soil management can help increase the availability of nutrients needed by plants. If a plant lacks of fertilizer nutrient content, the growth rate of the plant will be slow and not optimal in the production of a plant (Bindraban et al., 2015).

Based on the results of the analysis of the variety obtained between the various types of organic fertilizers used (F1, F2, F3 and F4), which gave the best results in almost all components of

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growth and production was a type of goat manure (F4). While the type of fertilizer that gives the lowest yield is compost (F2). This is thought to occur because the soybean plant is one of the legume plants that can be symbiotic with N-fixing bacteria to fix N2. Nitrogen in legume plants is fixed in nodules and occurs when there is a symbiotic relationship between bacteria and legume plants. Symbiosis between rhizobia with legume plant roots will produce nitrogen-fixing organs, namely root nodules. The development of nodules on soybean plants begins when the root cortex cells are stimulated to divide mitotically to form nodules and are followed by the entry of Rhizobium bacteria into these cells (Miransari et al., 2013).

The dose of fertilizer that gives the best results in all components of growth and production is D1 (5 tons / ha) while the dose of fertilizer that gives the lowest results is D0 (without fertilizer). Fertilization aims to increase the nutrients needed by plants because the nutrients found in the soil are not always sufficient to stimulate plant growth optimally. Organic fertilizer is one of the most important inputs in efforts to improve soil fertility. Organic fertilizers are formed due to the cooperation of decomposing microorganisms with the weather and human treatment. These microorganisms are the key players in translating or digesting coarse-grained organic matter to become smoother and available to plants (Metwally et al., 2018).

Interaction between types of organic fertilizers and organic fertilizer dosages (F1D0, F1D1, F2D0, F2D1, F3D0, F3D1, F4D0 and F4D1) which provide the best results in almost all components of growth and production, namely goat manure (F4D1), because goat manure fertilizer contains nutrients that are better than other organic fertilizers. This is consistent with the statement of Suparhun et al., (2015) that goat manure fertilizer has higher K nutrient content compared to other manure fertilizers and N and P nutrients which are the same as other manure fertilizers. Kakraliya *et al*., (2018) describes that manure as one of the sources of nitrogen (protein) will first experience decomposition into amino acids known as the aminization process, which then by a large number of heterotrophic microbials break down into ammonium known as ammonium ammonification process. This ammonification can take place in almost any circumstances, therefore, ammonium can be the major form of inorganic nitrogen (mineral) in the soil. Ammonium produced can be directly absorbed and used by plants for growth. Whereas the interaction that gave the lowest yield was almost all growth components and production components, which was without the use of compost (F2D0). This happens because no additional nutrients are given to the soybean plants.

Based on the results of the analysis variance obtained between the various types of organic fertilizers used (F1, F2, F3 and F4) significantly different in almost all components of growth and production. But the type of goat manure (F4) gives the highest yield, while the type of fertilizer that gives the lowest yield is compost (F2). The dose of fertilizer is significantly different in almost all components of yield, namely D1 (5 tons/ha) compared to D0 (without fertilizer).

Pointed out the results of the analysis of variance, the various types of organic fertilizers used (F1, F2, F3 and F4) were significantly different in almost all components of growth and production. However, the type of goat manure (F4) gave the highest yield, while the type of fertilizer that gave the lowest yield was compost (F2). Interestingly, fertilizer dosages were significantly different in almost all components of growth and production, namely D1 (5 tons/ha) compared to D0 (without fertilizer). The same trends were true in the interaction between types of organic fertilizers and doses of organic fertilizers (F1D0, F1D1, F2D0, F2D1, F3D0, F3D1, F4D0 and F4D1) in which they were significantly different in almost all components of growth and production. Yet, goat manure (F4D1) gave the highest yield, while the interaction that gave the lowest yield was without the use of compost (F2D0).

Conflict of Interest

The authors declare no conflict of interests.

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