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Effect of manure, Phosphate Solubilizing Bacteria, and chemical fertilizer application on the growth and yield of soybean

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Abstract. *Kuntyastuti H, Sutrisno. 2017. Effect of manure, Phosphate Solubilizing Bacteria, and chemical fertilizer application on the growth and yield of soybean. Nusantara Bioscience 9: 126-132.* This study aimed to determine the dosages of organic, chemical and biological fertilizers for optimum growth and yield of soybean grown in acidic dryland. Treatments applied were twelve combinations of inorganic fertilizer, phosphate solubilizing bacteria (PSB), and manure. These treatments were arranged in a randomized block design, each was three replicates. The growth variables of plant height and chlorophyll index were observed in every two weeks interval, started at two weeks after planting. Root length and number of nodules were observed at 45 days after planting when the maximum vegetative growth occurred. Stem and root dry weight, number of filled and empty pods, pod dry weight, grain weight, and number of seeds per plant were observed at harvest. Optimum soybean growth and yield were achieved when soybean plants were treated with a combination of 1500 kg ha^{-1} of manure + PSB +150 kg ha^{-1} of NPK chemical fertilizer.

Keywords: Chemical fertilizer, dry acid soil, manure, phosphate solubilizing bacteria, soybean

Abbreviations: NPK = nitrogen, phosphate, potassium, PSB = Phosphate solubilizing bacteria, DAP = day after planting, WAP = week after planting, LCI = leaf chlorophyll index, CEC = cation exchange capacity

INTRODUCTION

Soybean is one of important food crops in Indonesia since the soybean grain is an affordable protein source for most Indonesian people. Soybean has been used as the main raw material of staple foods such as tofu, fermented soybean (tempeh), soy sauce, and soybean sprouts. The domestic soybean production in Indonesia is insufficient to meet the national demand because of limited planting areas, diminished fertile soils, and low adoption of good production technology. Therefore, expansion of planting area and adoption of suitable cultivation technology become an integrated way to solve these problems.

Ultisol dryland is one of the potential areas for expanding soybean crops in Indonesia. This land covers approximately 29% of total Indonesian lands and spreads across Sumatra, Java, Kalimantan, Sulawesi and Papua Islands. In these regions, soybean crops had not been extensively developed yet due to some constraints such as high soil bulk density, poor soil porosity, low water holding capacity, low organic matter content, inadequate macro-nutrient content, low soil pH, and high aluminum content (Pamukas 2006; Indrayatie 2009), all of which have resulted in stunted soybean growth and low yield. This low soybean production could be improved by, among others, application of NPK fertilizer. It is very obvious that as a source of nutrients, the application of NPK fertilizer at planting time is considered to be an effective and efficient way for increasing soybean yield. In the long term, however, the application of NPK fertilizer alone will not be able to solve these limited nutrient problems. This is because the application of NPK fertilizer decreases water holding capacity, influences soil macro-aggregates stability, and reduces the soil ability to maintain soil moisture (Liu et al. 2013), reduces the soil pH (Belay et al. 2002), and decreases organic matter and nutrient (total N) content (Zhang et al. 2008, 2012). Several studies revealed that continuous application of chemical fertilizers reduced the soil microbe population (Qin et al. 2015) and earthworm activity (Guo et al. 2016), which in turn, decreased the quality of soil fertility.

Soil fertility could be improved by applying organic matter as organic fertilizer. This organic material contains beneficial compounds that play important roles in improving the physical and chemical properties of soil such as increasing soil pore spaces and water holding capacity (Xu et al. 2013), increasing soil pH, and improving soil organic matter content (Yan et al. 2007), total N content, and soil microbial population (Zhong et al. 2010). Application of organic fertilizer also improves the content of secondary metabolites such as phenols, flavonoids and vitamin C of the plants. These compounds are responsible for plant resistance to pests and diseases, as well as for improvement of human health (Salama et al. 2015). Unfortunately, the increase of soybean yield following organic matter application could not be achieved instantly since the manure needs a long time to have its nutrients available to the plants.

The combined application of organic and chemical fertilizers would be the best practice to maintain soybean yield, and ultimately soil fertility in supporting the sustainable agricultural systems as it reduces the continuous application of chemical fertilizer without lowering the yield potential of the crop. In addition, organic fertilizer increases the organic matter content and soil microbe population (Hao et al. 2007). Applying both chemical and organic fertilizers resulted in higher crop yield (Yang et al. 2015) and higher phenols, flavonoids and vitamin C contents (Salama et al. 2015) compared to those obtained by each fertilizer when applied individually.

Despite the success of combined fertilizer application on yield, the different soil conditions consistently give different effects of that practice. For instance, application of 30:26:25% kg ha^{-1} NPK + 4000 kg ha^{-1} manure in India effectively yielded higher soybean productivity (Bandyopadhyay et al. 2010), meanwhile other studied reported that application of 2500 kg ha^{-1} poultry manure significantly improved soybean yield and seed quality (Behera et al. 2007). The difference dosage effect of manure on every plant cultivated actually was affected by the nutrient content of manure and the soil. However, in Indonesia especially on Ultisol dryland, information about the effect of organic and inorganic fertilizers application on soybean grain yield is still lacking and, therefore, needs to be more explored. The difference of soil fertility would result in difference response in manure application, NPK, biofertilizers, and their combinations. Therefore, this study aimed to determine the proper combination of manure, PSB, and chemical fertilizer for optimum growth and yield of soybean grown in acidic Ultisols.

MATERIALS AND METHODS

Materials and experimental design

The present study was conducted in the greenhouse of Indonesian Legumes and Tuber Crops Research Institute in Malang, East Java Province, Indonesia in 2014. The soil was obtained from acidic dryland of Lebak District, Banten Province. The study was laid out in a Completely Randomized Design with eleven treatment combinations of organic and inorganic fertilizers, each was three replicates. The treatments are listed in Table 1.

Table 1. The detail of treatments tested in the present study

Code	Treatments
T0	Control (No manure, no NPK fertilizer, no PSB)
T1	Phosphate solubilizing bacteria (PSB) 5g PSB kg^{-1} seed
T2	150 kg ha^{-1} NPK fertilizer (15:15:15 percent of N, P, K)
T3	300 kg ha^{-1} NPK fertilizer
T4	1500 kg ha^{-1} manure
T5	3000 kg ha^{-1} manure
T6	PSB + 150 kg ha^{-1} NPK fertilizer
T7	PSB + 1500 kg ha^{-1} manure
T8	1500 kg ha^{-1} manure + 150 kg ha^{-1} NPK fertilizer
T9	1500 kg ha^{-1} manure + PSB + 150 kg ha^{-1} NPK fertilizer
T10	3000 kg ha^{-1} manure + 150 kg ha^{-1} NPK fertilizer
T11	3000 kg ha^{-1} manure + PSB + 150 kg ha^{-1} NPK fertilizer

Procedures

A total of eight kg air-dried soils was packed in a polyethylene bag. Manure was applied before the seed was planted, and PSB was applied as a seed treatment. PSB Formulation was mixed with enough water until sticky. The formulation was used to cover seed coat with a dosage of 5 g PSB kg^{-1} seed. NPK fertilizer was applied at five weeks after planting (WAP).

Observation and data analysis

Observations were carried out on plant height, leaf chlorophyll index, root length, number of nodules, number of branches, number of fertile nodes, stem dry weight, root dry weight, number of filled pods, number of empty pods, number of seeds, pod dry weight, and seed dry weight per plant. Observation of each variable was carried out on two representative plants in each pot and then the average was worked out. Plant height was measured at 2, 4, 6, 8, 10 WAP and harvest time while LCI was recorded at 2, 4, 6, 8 WAP. Destructive sampling was done at 45 days after planting (DAP) to record number of nodules and root length. Root length was also measured at harvest time. Other variables that were also observed at harvest time included number of branches, number of fertile nodes, stem dry weight, root dry weight, number of filled pods, number of empty pods, number of seeds per pod, pod dry weight, and seed dry weight per plant. All observed variables were subjected to Analysis of Variance (ANOVA) that was conducted by using Statistic Tool for Agriculture Research (STAR) package from IRRI. Comparisons among the treatment means were made by the Honesty significant difference (HSD) at $\alpha < 0.05$.

RESULTS AND DISCUSSION

Plant height

Plant height at various fertilizer treatments since 2 WAP until harvest was presented in Table 2. The study revealed that the treatments significantly affected plant height since 4 WAP (Table 2). In this period, the tallest plant was obtained from plants provided/treated with 3000 kg manure + PSB + 150 kg NPK fertilizer ha^{-1} (T11). These plants grew 53% taller than that of control treatment. Meanwhile, the shortest plant was obtained from that received PSB only (T2). This PSB treatment consistently resulted in the shortest plant along the growing season (4 WAP until harvesting time), whereas the highest plant was the ones treated with NPK fertilizer (T3) and other fertilizer combination treatments. Starting at week 6 until harvesting time, the combinations of manure, NPK fertilizer, with or without PSB (T8, T9, T10, T11) as well as NPK fertilizer treatment (T3) generated similar high plant height, which were about 12-25% higher compared to that of other treatments (T2, T4, T5, T6, T7).

The higher plant height in treatment combinations of manure, NPK fertilizer with or without PSB (T8, T9, T10, and T11) was probably because NPK fertilizer supplied macro nutrients quicker to the plants compared to that of manure and PSB although this PSB provided both macro and micro nutrients. Stainer et al (2007) reported that manure application increased nutrient uptake such as P, Ca, and Mg. Lentz and Ippoli (2012) and Gunes et al (2014) also mentioned that manure application could increase the availability of N, P, K, Mg, Na, Cu, Mn, and Zn. Manure also improved the activity of enzyme present in the soils, where this enzyme influenced the availability of soil nutrients both direct and indirectly (Saha et al. 2008) as well as significantly increased plant height of soybean (Devi et al 2013).

Application of PSB alone (T1 treatment) resulted in the lowest plant growth, presumably because the plants might receive phosphate nutrient only. This finding showed that application of PSB alone was less effective in supporting plant growth. Phosphate solubilizing bacteria (PSB) would be more effective when it is combined with manure or with NPK fertilizer. This is revealed by the observed higher plant growth on application of 1500 kg ha^{-1} manure + 5g PSB kg^{-1} seed + 150 kg ha^{-1} NPK fertilizer, and 3000 kg ha^{-1} manure + 5g PSB kg^{-1} seed + 150 kg ha^{-1} NPK fertilizer than that of 1500 kg ha^{-1} manure + 150 kg ha^{-1} NPK fertilizer and 3000 kg ha^{-1} manure + 150 kg ha^{-1} NPK fertilizer. This result was in agreement with results of the previous study (Noor, 2003) that application of PSB was less effective in increasing plant growth, and it would be more effective when it is combined with manure.

Leaf Chlorophyll Index (LCI)

Leaf chlorophyll index (LCI) was measured by using Minolta SPAD 502. The chlorophyll index was quantified at the completely open leaf or approximately at the fourth leaf from the plant shoot. The measurement of chlorophyll index was done at all the trifoliate leaves. All fertilization treatments resulted in a bit higher LCI than that of control treatment (no organic and inorganic fertilizers were applied). This difference appeared after 4 WAP (Figure 1). Among single treatments, The PSB treatment (T1) resulted in the lowest LCI while the NPK fertilizer treatment (T3) resulted in the highest LCI. It was clear that NPK fertilizer treatment (T3) increased more LCI than those of single manure (T4, T5) and 5g PSB kg^{-1} seed (T1). The LCI of T3 was also higher than that of some of these treatment combinations. However, the highest LCI was achieved by plants receiving 1500 kg ha^{-1} manure + 5g PSB kg^{-1} seed + 150 kg ha^{-1} NPK fertilizers (T9). This result showed that treatment combination such as 1500 kg ha^{-1} manure + 5g PSB kg^{-1} seed + 150 kg ha^{-1} NPK fertilizer obviously resulted in a higher LCI compared to that of single fertilizer treatments such as 300 kg ha^{-1} NPK fertilizer. This presumably because the addition of manure to any inorganic fertilizer treatment improved soil fertility, increased nutrient availability, and intensified enzyme activity as it effectively increased leaf chlorophyll index (Khadem et al. 2010) and chlorophyll content (Amujoyegbe et al. 2007).

Root length and number of nodules

There was no significant difference in root length and nodule number among treatments tested when the plants were cultivated under the acidic soil. High concentrations of Fe, Mn, Zn, and Cu, as well as low Ca and P in the soil (Table 1) might have inhibited the growth and development process of roots and nodules (Table 4). Previous studies revealed that the low Ca and the high Al concentrations in acid soil suppressed and inhibited nodulation of cowpea (Alva et al. 1990), and also inhibited root growth and number of nodules of biserrula, French serredella, and arrow leaf clover (Guo et al. 2012; Liang et al. 2013). Other studies also revealed that acidic condition generally could inhibit root growth, decreased the concentrations of nitrate, ammonium, and malondialdehyde as well as peroxidase activity, and increased activity of nitrite reductase (Wang et al 2013). Acidic soil condition also inhibited the role and the growth of nodules (Ferguson and Gresshoff 2015), and hindered root growth and yield (Caires 2008).

Vegetative growth

The number of branches and fertile nodes increased differently according to the fertilizer treatment. Among single fertilizer treatments, the single manure treatment (T5) resulted in a higher number of branches and fertile nodes compared to the single NPK fertilizer (T3 and T2) and the single PSB treatment (T1). The increase of the number of branches and fertile nodes growth in the T5, T3, T2 and T1 was 67%, 65%, 40%, 19%, respectively. Interestingly, T5 also resulted in the number of branches and fertile nodes that were equal to that of treatment combinations of T8, T9, and T11. The high number of branches and fertile nodes growth in T5 or other treatment combinations might be because the manure provided more beneficial nutrients to plant growth than NPK or PSB treatments did. It might also because the application of manure could increase synthesis of a hormone that stimulated the growth of shoot branches and growth of pods in every node.

Root and stem dry weights were significantly varied among the treatments. Treatment combinations seemed to be more effective in increasing the root and stem growth than those of single fertilizer treatments. Among the single fertilizer treatments, the highest root and stem growth were produced by application of 300 kg ha^{-1} NPK and 3000 kg ha^{-1} manure, respectively, by 67% and 60% higher than control. The lower dosage of manure and NPK also reduced root and stem growth compared to other treatment combinations while application of PSB alone resulted in the lowest growth. The increased growth of soybean plants at 150 kg ha^{-1} NPK and 1500 kg ha^{-1} manure treatment was about 42% while that in the PSB treatment was only about 11%. Furthermore, the combination of NPK + manure actually was better than manure + PSB or NPK + PSB. The combination of 1500 kg ha^{-1} manure + 150 kg ha^{-1} NPK fertilizer (T8) produced the highest root and stem growth. A lower, but not significantly different from T8, root and stem growth was obtained by the combination of manure + PSB while the combination of NPK + PSB was not recommended due to the lowest root and stem growth it produced.

Table 2. Soybean plant height at various combinations of manure, organic and inorganic fertilizers from two to 10 weeks after planting

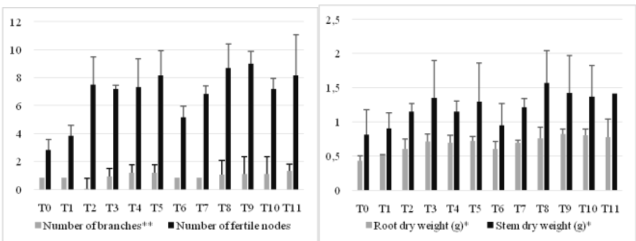
Treat-ments	Plant height (cm)					
	2 WAP	**4 WAP**	**6 WAP**	**8 WAP**	**10 WAP**	**Harvest**
T0	14.33a	25.20ab	29.83cd	30.60b	32.67bc	29.03b
T1	13.08a	24.12 b	28.40d	29.47b	30.83c	27.92b
T2	14.67a	30.28ab	34.22b-d	36.73ab	37.17a-c	35.28ab
T3	14.65a	32.40ab	45.83ab	46.28a	46.53a	44.28a
T4	14.80a	28.05ab	36.45a-d	37.58ab	37.87a-c	36.55ab
T5	13.08a	32.27ab	39.08a-d	40.42ab	41.33a-c	39.77ab
T6	13.07a	28.18ab	39.72a-d	39.98ab	40.85a-c	38.83ab
T7	14.12a	26.27ab	38.10a-d	38.67ab	39.22a-c	38.12ab
T8	13.20a	33.72ab	42.73a-c	43.83a	44.78ab	43.43a
T9	14.22a	33.48ab	45.00ab	45.38a	45.83a	44.38a
T10	14.70a	34.40ab	42.70a-c	45.53a	46.27a	43.95a
T11	14.47a	36.88a	47.60a	48.08a	49.78a	46.72a
Average	14.03	30.44	39.14	40.21	41.09	39.02
Coefficient of Variation	7.34	13.60	11.15	11.05	10.79	11.53

Notes: Numbers in the same column followed by the same letter were not significantly different based on HSD test at α 0.05. Note: T0-T11 can be seen in Table 1

Table 3. Leaf chlorophyll index of soybean plants at various combinations of manure and inorganic fertilizer from two to 10 weeks after planting

Treatments	Leaf chlorophyll index (LCI)			
	2 WAP	**4 WAP**	**6 WAP**	**8 WAP**
T0	30.23a	27.53a	28.13b	28.43c
T1	28.93a	28.60a	31.13ab	31.13bc
T2	31.67a	29.80a	33.57ab	37.13a-c
T3	33.40a	29.70a	32.33ab	41.53ab
T4	30.37a	29.53a	34.83a	37.13a-c
T5	29.30a	27.57a	35.50a	36.83a-c
T6	32.27a	28.50a	30.87ab	39.20ab
T7	31.30a	29.27a	35.63a	40.57ab
T8	30.43a	26.97a	33.07ab	41.53ab
T9	31.03a	30.27a	36.40a	43.53a
T10	31.30a	29.93a	36.23a	34.03a-c
T11	30.90a	28.07a	36.57a	34.60a-c
Average	6.77	28.81	33.69	37.14
Coefficient of Variation	30.93	9.13	5.72	9.73

Notes: Numbers in the same column followed by the same letter were not significantly different based on HSD test at α 0.05. Note: T0-T11 can be seen in Table 1



A B

Figure 1. The character of soybean vegetative growth in the various combinations of manure, NPK chemical fertilizer and PSB, Malang 2014. Error bars represent standard deviation from measurements in triplicate. Note: *) Transformation √ 1x **) Transformation √ 2x. Note: T0-T11 can be seen in Table 1

Table 4. Root length and number of nodules of soybean plants at various combinations of manure, chemical fertilizers, and PSB at 45 days after planting

Treatments	**Number of nodules****	**Root length at 45 DAP**	**Root length at harvest (cm)**
T0	0.67a	05.84a	7.72a
T1	1.00a	05.14a	7.55a
T2	1.33a	05.27a	7.85a
T3	0.67a	05.70a	6.78a
T4	0.67a	05.27a	9.47a
T5	0.83a	05.61a	8.32a
T6	1.00a	05.77a	6.78b
T7	0.67a	05.95a	7.40a
T8	1.67a	06.08a	7.52a
T9	0.83a	05.63a	7.80a
T10	0.33a	05.64a	9.95a
T11	0.33a	05.44a	7.67a
Average	0.83	05.61	7.90
Coefficient of variation	15.23	10.68	17.81

Note: The values in the same column followed by the same letter were not significantly different based on HSD test at α 0.05; **) Transformation √ 2x. Note: T0-T11 can be seen in Table 1

The combination of manure and NPK fertilizer produced a better plant growth compared to that of all single treatments since the manure added in the treatment combination may have increased the available amount of nutrients, which in turn enhanced nutrients uptake by the plant's roots. Sharma et al. (2013) found that addition of manure in the NPK treatments combination improved soil fertility. These treatments also increased cation exchange capacity (CEC), soil enzyme activity (Piotrowska and Wilczewski 2012), and soil microbial biomass (Lu et al 2015), enhanced nutrients uptake, and increased photosynthetic rate (Jannoura et al 2013; Jannoura et al 2014), enhanced diversity of microorganism and supported plant growth (Zhang et al. 2012; Hamm et al. 2016).

The application of biological microorganism of 5g PSBkg^{-1} seed (T1 treatment) did not enrich the soil nutrient content. This treatment failed to support the vegetative growth of plants under acidic soil condition since the PSB treatment only supplied phosphate nutrient to the plants. The limited nutrient supply in this treatment caused the poor vegetative growth of the crop. The role of PSB would be more effective in supporting crop growth when manure was added, for instance in the treatment combinations of 3000 kg ha^{-1} manure + 5g PSB kg^{-1} seed + 150 kg ha^{-1} NPK fertilizers (T11 treatment) and 1500 kg ha^{-1} manure + 5g PSB kg^{-1} seed + 150 kg ha^{-1} NPK fertilizer (T9 treatment). These two treatments resulted in higher vegetative growth than those obtained at treatments without PSB such as 1500 kg ha^{-1} manure + 150 kg ha^{-1} NPK fertilizers (T8) and 3000 kg ha^{-1} manure + 150 kg ha^{-1} NPK fertilizers (T10) treatments. Previous studies also reported that combination of PSB and organic manure increased the vegetative growth of wheat (Afzal et al. 2005; Lu et al. 2015).

Number of pods

It was observed in the present study that all treatments considerably increased the number of filled pods but did not increase the number of empty pods (Figure 2A). The number of empty pods in all treatments was about one while the number of filled pods per plant was three to 15 pods. The number of filled pods in manure application, either in single or in combination with NPK fertilizers, was higher than those of single NPK fertilizer treatments. The number of filled pods of each treatment of 3000 manure kg ha^{-1} (T5) and 1500 kg ha^{-1} manure + 150 kg ha^{-1} NPK fertilizer (T8) was 14 pods while that at the single NPK fertilizer treatments (T2 and T3) was only 10 and 11 pods, respectively. Furthermore, application of PSB showed an inconsistent response. Combination treatment between PSB and NPK fertilizer yielded lower number of filled pods than that of NPK fertilizer treatment without PSB. This was shown in treatment T6 that resulted in 6 filled pods while T2 resulted in 10 pods. However, integration of PSB + manure + NPK fertilizer treatments slightly increased the number of filled pods although this increase was not significant. For example, number of filled pods in the treatment of 1500 kg ha^{-1} manure + PSB + 150 kg ha^{-1} NPK fertilizer (T9) was 15 while that in the treatment of 1500 kg ha^{-1} manure + 150 kg ha^{-1} NPK fertilizer (T8) was 13.

Number of seeds per plant

The number of seeds per plant of the plants treated with various fertilizers was presented in figure 2B. There was increased in the number of seed per plant in almost all treatments compared to that of control treatment. Number of seeds per plant of five treatments i.e. single manure of 3000 kg ha^{-1} (T5) and combinations of manure + NPK fertilizer with or without PSB (T8, T9, T10, T11) were similar but were higher than that of other treatments (T2, T3, T4, T6, T7). The increased number of seed in single manure treatment of 3000 kg ha^{-1} (T5) and combination of manure + NPK fertilizer with or without PSB (T8, T9, T10, T11) were about 371%, 322%, 369%, 330%, and 372% higher than control, respectively. The high number of seeds per plant in single manure 3000 kg ha^{-1} (T5) might be due to composite nutrients preserved by manure fertilizer. Composite nutrients contained in manure supported the plant to maximize generative growth than vegetative growth so that the seed yield was higher than the plant biomass (stem and root dry weight, Figure 1). Previous studies also reported that the application of dried chicken manure improved soybean yield (Tagoe et al. 2008; Mehran et al. 2011).

The higher number of seeds per plant produced in treatments of manure + NPK fertilizers was due to the availability of complementary nutrients. The NPK fertilizers supplied nutrients that were absorbed quickly by the plant's root while that of manure took a longer time to be absorbed by the roots. An effective combination of manure and NPK fertilizer eventually produced high vegetative and generative growth. Conversely, the less amount of fertilizer applied also resulted in low vegetative and generative growth as shown at both single treatment of 150 kg NPK ha^{-1} and 1500 kg manure ha^{-1} that probably because these fertilizers provided less nutrient available to the plants. Moreover, low vegetative and generative growth due to low nutrient available was also showed by the application of single PSB.

Pod and seed dry weight

Pod dry weight and seed dry weight significantly increased in all treatments except the PSB single treatment. At the single treatments, 3000 kg ha^{-1} manure produced higher pod and seed dry weight than that of NPK fertilizer treatment alone. Furthermore, the treatment combination of manure + NPK fertilizer seemed to produce higher pod and seed dry weight compared to that of NPK fertilizer + PSB or manure + PSB. The highest pod and seed dry weight were produced in the treatment of 1500 kg ha^{-1} manure + PSB + 150 kg ha^{-1} NPK fertilizer (T9). Meanwhile, application of PSB alone could only increase the pod dry weight slightly.

The application of manure could increase soybean yield in the acid soil of dryland. Although the manure treatment was unable to improve vegetative plant growth optimally compared to the NPK fertilizer treatments, this manure treatment was able to improve the plant generative traits. Application of manure seemed to produce lower vegetative growth such as plant height but this treatment produced higher number of filled pods, number of seeds, pod dry weight, and seed dry weight. This presumably occurred due to the slowly available and higher complex nutrients it contains. Improved soybean yield resulted from manure application has also been reported from the previous study by Tagoe et al. (2008).

The application of manure and NPK fertilizer in combination with PSB provided abundant nutrients availability around the crops. NPK fertilizer rapidly provided nutrients while manure complements the availability of others nutrients. The addition of PSB together with NPK fertilizer increased nutrients supply, especially the phosphate, so that soil condition was more favorable to the plants. This favorable environment increased nutrients absorption, photosynthesis process, and enzyme synthesis and activities that ultimately resulted in higher vegetative and generative growth. The vegetative and generative growth of soybean in the manure and NPK fertilizer combination treatments were three or fourfold higher than those of control (Figure 2).

The success of fertilizers treatments on generative growth was also reported from the previous study by Bandyopadhyay et al. (2010), who found that the highest soybean yield was obtained by the application of manure + inorganic fertilizers. Another study also reported that maximum growth and yield of wheat was achieved when the crops were fertilized with manure and inorganic fertilizer (Mandal et al. 2007). Kannan and Ganesan (2011); Yang et al. (2015) also reported that the highest productivity of wheat (*Triticuma estivum* L), maize (*Zea mays* L), and black gram were obtained by combined application of organic and inorganic fertilizers. In the long term, manure and inorganic fertilizer would also be able to improve the chemical and biological components of soils (Liu et al. 2010).

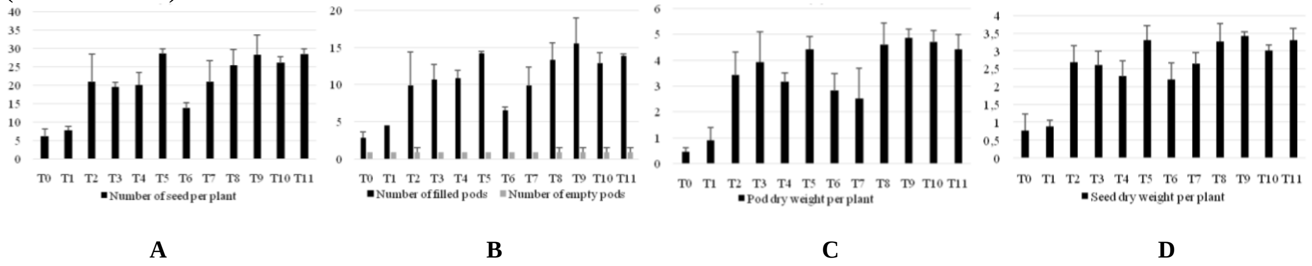


Figure 2. Character of soybean generative growth in the various combinations of manure, NPK chemical fertilizer and PSB, Malang 2014. Error bars represent standard deviation from measurements in triplicate. Note: T0-T11 can be seen in Table 1

It can be summarized from the present study results that treatment combinations of NPK chemical fertilizer, manure, and PSB were the best practices to maximize soybean productivity in acid soils. NPK chemical fertilizer provided nutrients that are quickly available to the plant while manure and PSB play important roles in improving soil fertility and soybean productivity. Single manure application in an adequate amount/dosage could also become an alternative way to produce high soybean yield since manure can provide more complex nutrient so that application of manure in higher dosage will provide enough nutrients to improve the soybean yield.

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