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Research Article

Improvement of soybean productivity through the application of organic, inorganic, and biological fertilizers in acid soils

Henny Kuntyastuti, Sri Ayu Dwi Lestari*, Didik Sucahyono, Sutrisno

Indonesian Legume and Tuber Crops Research Institute, JL Raya Kendalpayak KM 8 Po Box 66, Malang 65101, Indonesia

*corresponding author: estawinasa@gmail.com

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Abstract

Acid dry land can become a centre for soybean production through improved cultivation techniques and the use of improved varieties that are acid-tolerant. In connection with this problem, research has been carried out to evaluate the effect of the application of organic fertilizers, inorganic fertilizers, and biological fertilizers on soybean productivity in acid soils. The experiment was conducted in a screen house at Iletri, Malang, East Java, using acid dry soil from Banten, West Java. The soybean seed used in this research was Wilis variety. The evaluated treatments were a combination of types and quantities of nutrient-rich organic fertilizer with acid formula (Santap-M), NPKS Phonska inorganic fertilizer, and biological fertilizer (Iletrisoy Rhizobium and *Pseudomonas* sp. P-solubilizing bacteria, both were Iletri collections). The results showed that the addition of organic and inorganic NPKS fertilizers on acid soils could increase soybean productivity and the population of P-solubilizing bacteria *Pseudomonas* sp. The recommended alternative technology component for improving soybean productivity and Banten acid soil is a combination of 1500 kg Santap-M nutrient-rich organic fertilizer + 150 kg Phonska ha^{-1}. The results of this study add to the positive list that the use of organic fertilizers and inorganic fertilizers NPKS is an alternative option that needs to be considered for sustainable soybean cultivation in an acid dry land.

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Introduction

Domestic soybean production is not sufficient for food and raw materials for various industries. The increase in soybean production is facing constraints on the planting area and the harvesting area, which is decreasing, and the productivity is low. Extensification (increase in planting area) and intensification (increased productivity) of soybeans can be carried out on dry land. Dry land includes acid dry land (pH <6.0), neutral dry land (pH 6.0-7.0), and basic dry land (pH >7.0).

In terms of land area, acid dry land is more potential than non-acid dry land (neutral + basis). However, in terms of physical, chemical, and biological soil fertility, non-acid dry land is better than acid dry land. Acid dry land suitable for the developing food crop commodities is available in an area of 18.5 million hectares (Mulyani, 2006).

Acid dry land can become a soybean production centre with proper land management and the application of effective techniques such as the use of improved varieties that are tolerant of acid soils. Land rehabilitation technology through land management is available, namely conservation, enhancement of chemical, physical, and biological fertility, as well as management of organic matter and water. The application of land rehabilitation technology on acid soil adaptive soybean new high-yielding varieties can preserve the biophysical quality of the soil and its environment so that soybean plant productivity can be sustainable. However, it does not leave the socio-economic aspects of developing land rehabilitation technology for soybean crops (Barus, 2013; Erfandi, 2013).

Soybean plants on acid dry land slightly retain N from the air because the rhizobium population is very low, namely 5.8 x 10^4 CFU g^{-1} soil in Ultisol Central Lampung (Soedarjo et al., 2007) and 6.5 x 10^1 CFU g^{-1} soil in Ultisol East Lampung (Harsono et al., 2009). Inoculation of soybean seeds with Iletrisoy Rhizobium (isolate collection of Iletri) on acid dry land can increase the number of root nodules, leaf chlorophyll index, number of pods, and soybean yield from 1.43 to 1.73 t ha^{-1} (Harsono et al., 2008; Harsono et al., 2010). Ca and P were essential nutrients for root growth, nodule formation, growth of soybean and the most limiting nutrients for BNF (biological nitrogen fixation) of soybean in the acid soils (Waluyo et al., 2004). The application of biological fertilizers without or in combination with inorganic fertilizers can increase the growth and yield, and quality of soybean seeds (Suryantini, 2011; Purba, 2016; Idaryani and Rauf, 2017).

Indonesian Legume and Tuber Crops Research Institute (ILETRI) has released soybean varieties with a potential yield of 2.5-4.0 t ha^{-1} and some are suitable for acid dry land through improved seed size (Kuswantoro et al., 2013; ILETRI, 2016). However, the provincial mean yield is still low, namely between 1.44-1.56 t ha^{-1} (BPS, 2020). On acid dry land, improved soybean cultivation techniques combined with the use of acid-tolerant varieties such as Wilis, Argomulyo, and Anjasmoro in South Kalimantan (Sumanto, 2016) or the Tanggamus, Nanti, Ratai, and Seulawah in West Sumatera (Atman, 2011) can produce grain >2 t ha^{-1}. The Tanggamus variety is more suitable than the Anjasmoro variety for acid sulfate soils in South Sumatera (Noya et al., 2014).

On the other hand, the application of lime with a fineness level of 100 mesh on slightly acid soils (pH 5.60) can increase soybean plant productivity (Rosmaiti et al., 2017). The increase in productivity was caused by the addition of Ca elements increasing the activity of the plasma membrane H^+-ATPase enzyme, thereby increasing nutrient uptake (Liang and Zhang, 2018).

Cultivation of food crops is one of the causes of decreased levels of soil organic matter. Excessive use of chemicals also reduces soil quality, while intensive cultivation and erosion reduce the carbon content of microorganisms (Susilawati et al., 2013). Furthermore, Kusumastuti et al. (2018) explained that the 29th year long-term conservation tillage system affected the chemical properties of the soil, especially the availability of P and K nutrients.

An environmentally friendly land management action is needed. The use of organic matter needs to be reconsidered. Cow, chicken, and goat manure; and rice straw are relatively widely used by farmers and can be produced by farmers. In order to increase the productivity of soybean plants, organic fertilizers are needed in large quantities, namely 5000-45000 kg ha^{-1}. In addition to increasing soybean yields, the use of organic fertilizers and their residues can also improve soil physical and chemical properties (Hartatik and Widowati, 2006; Kuntyastuti et al., 2012). Application of 1500-2000 kg manure ha^{-1} + 200-250 kg Phonska ha^{-1} can obtain soybean yields >2 t ha^{-1} in acid soils in South Kalimantan (Sumanto, 2016). Meanwhile, in the acid soils of West Sumatera, soybean yields of 1.6-2.7 t ha^{-1} were obtained by using 3000 kg of manure + 2000 kg of dolomite + 50 kg of Urea + 100 kg SP36 + 75 kg KCl ha^{-1} (Atman, 2011). The dose of organic fertilizers is reduced, but inorganic fertilizers are added to enrich the nutrients in order to fulfil the needs of plants. Liquid organic fertilizer can also increase soybean yield (Widiastuti and Latifah, 2016). Even on peatlands, a combination of NPK inorganic fertilizer with manure is the best alternative to increase the CEC, K-dd, total N, and available P of the soil (Fitra et al., 2019). Integrated application of organic and inorganic fertilizer is the best option to improve soil chemical properties and nutrient uptake of maize and soybean (Almaz et al., 2017).

The use of large amounts of organic fertilizers makes it difficult for farmers to supply, transport, and cost. The use of nutrient-rich organic fertilizers can be an alternative choice because it is more efficient while preserving the environment. The use of nutrient-rich organic fertilizers of Santap-M formulated by Iletri can increase soybean yields on acid dry land in Lampung (Harsono et al., 2010; Wijanarko and Subandi, 2010; Harsono et al., 2012). Improvement of soil fertility due to the use of manure increases the activity of dehydrogenase enzymes, acid and alkaline phosphatase, cellulose and protease activity, which ultimately improves nutrient transformation (Saha et al., 2008).

Continuous use of soil without the addition of organic fertilizers reduced soil organic C content by 39-43%. The addition of organic C is only 26, 18, and 6% of the total organic C added when using manure, rice straw, and green manure (Ghosha et al., 2012). The addition of green manure for legumes can increase the level of N in the soil by providing N as much as 136-180 ppm (Winarni et al., 2015). Amelioration using 2.5 t manure ha^{-1}, liming with dolomite equivalent to 20% of Al saturation, and NPK fertilizer improved soil properties and soybean growth and increased productivity to 2.4 t ha^{-1} (Wijanarko et al., 2016). In a soybean-wheat system under an acidic soil environment, balanced fertilizer management with suitable amendment (organic manure/lime) is compulsorily required for optimum nutrient supply without affecting soil health for sustainable production (Vishwanath et al., 2020).

In connection with the information that has been conveyed, research has been carried out with the aim of evaluating the effect of using organic, inorganic, and biological fertilizers on soybean plants in acid soils.

Materials and Methods

The study was conducted on Iletri screen house, Malang, East Java that was arranged in a randomized block design with twelve replications. Four replications were arranged for destructive samples at 45 DAP (days after planting), and eight replications were arranged for component yield and yield observations. The treatments evaluated were a combination of organic fertilizer (Santap-M) and inorganic compound fertilizer (Phonska, containing 15% N, 15% P_2O_5, 15% K_2O, and 10% S), as well as rhizobium biological fertilizer (Iletrisoy) and *Pseudomonas* sp. P-solubilizing bacteria (both collections of Iletri) (Table 1). Santap-M organic fertilizer is a nutrient-rich organic fertilizer formulation suitable for acid dry lands that has been developed by ILETRI. Santap-M organic fertilizer is made from cow dung (48%), chicken manure (20%), rock phosphate (15%), sugar factory boiler ash (15%), and Urea (2%). The chemical properties of Santap-M fertilizer are presented in Table 2. Boiler ash is a waste of the sugar industry and contains 3.07% K_2O, 2.33% CaO, 1.07% MgO, 0.04% S, and 68 ppm Zn. The addition of rock phosphate and sugar factory boiler ash aims to increase the P_2O_5 and K_2O content (Subandi et al., 2011). The indicator plant used was Wilis soybean variety which is adaptive in acidic soils with a yield of >2 t ha^{-1} (Atman, 2011; Sumanto, 2016). The soybean seeds of the Wilis variety were planted in a 12 kg polybag containing 10 kg of air dry soil. The top 20 cm layer of acid dry land soil samples were taken from Pejagan Village, Sajira District, Lebak Regency, Banten (6,4 SL, 106.313 EL, 110 m asl). Soil samples were drained, and chunks of soil were crushed to homogenize the soil samples. The soil was watered to reach field capacity conditions. The day after the soil was watered, four soybean seeds were planted in the middle of the polybag. Iletrisoy Rhizobium biofertilizer and *Pseudomonas* sp. P-solubilizing bacteria were applied to the soybean seeds before planting. The seeds were moistened with water and then mixed with Iletrisoy Rhizobium biofertilizer and *Pseudomonas* sp. P-solubilizing bacteria. At the age of 10 days after planting (DAP), the plants were sparse, keeping the two plants relatively uniform. The Santap-M fertilizer is applied by means of a hole beside the seed hole during planting. Phonska was poured next to the plant when the plants are 10 DAP. Observations were made on: (1) pH, organic C content, macro and micro nutrients and CEC in the soil and ferilizers of Santap-M, (2) plant height, number and weight of root nodules at 45 DAP, leaf chlorophyll index, number of filled pods, weight of 100 seeds, and seeds yield, (3) NPK nutrient content in the shoot (above-ground plant parts) at the age of 45 DAP, and (4) *Pseudomonas* sp. P-solubilizing bacteria population after soybean harvest. The total nutrient uptake (mg polybag^{-1}) was calculated by multiplying the nutrient content (%) by the shoot dry weight at 45 DAP (g polybag^{-1}). Analysis of variance (F test) was carried out on the observational data, and if it was significantly different, it was continued with the 5% BNT test. Banten acid soils have a pH of 5.3, poor in macro nutrients, but rich in micro nutrients (Table 2). Aluminium saturation is only 10.39% (below the tolerance limit for soybean plants), so it does not require the addition of lime.

Table 1. Fertilization treatment on Wilis soybean variety in Banten acid soils.

Treatments	Type and dosage fertilizer (kg ha^{-1})
A	Control (without fertilizer)
B	150 Phonska
C	300 Phonska
D	1500 Santap-M
E	1500 Santap-M + 150 Phonska
F	1500 Santap-M + 150 Phonska + 0.2 Iletrisoy Rhizobium
G	1500 Santap-M + 150 Phonska + 0.2 *Pseudomonas* sp. P-solubilizing bacteria
H	1500 Santap-M + 150 Phonska + 0.2 Iletrisoy Rhizobium + 0.2 *Pseudomonas* sp. P-solubilizing bacteria

Table 2. Chemical properties of Santap-M fertilizer.

Chemical properties	Value	Chemical properties	Value
pH H_2O (1:5)	5.03	Total-P HNO_3 + $HClO_4$ (%)	4.64
Organic C (%)	8.25	Total-S HNO_3 + $HClO_4$ (%)	7.16
Organic N (%)	0.56	Total-K HNO_3 + $HClO_4$ (%)	0.74
N-NH_4 (%)	0.64	Total-Ca HNO_3 + $HClO_4$ (%)	1.16
N-NO_3 (%)	0.03	Total-Mg HNO_3 + $HClO_4$ (%)	0.63
N-total (%)	1.23		

Table 3. Chemical properties of Banten acid soils.

Chemical properties	Value / criteria	Chemical properties	Value / criteria
pH H_2O	5.3	CEC (cmol(+) kg^{-1})	9.83
pH KCl	4.5	Al-dd (cmol(+) kg^{-1})	0.43
Total-N (%)	0.16	H-dd (cmol(+) kg^{-1})	0.32
P_2O_5 Bray-1 (ppm)	9.67	Fe (ppm)	448
K (cmol(+) kg^{-1})	0.15	Zn (ppm)	53.4
Na (cmol(+) kg^{-1})	0.19	Cu (ppm)	2.7
Ca (cmol(+) kg^{-1})	1.95	Mn (ppm)	74.1
Mg (cmol(+) kg^{-1})	1.10		

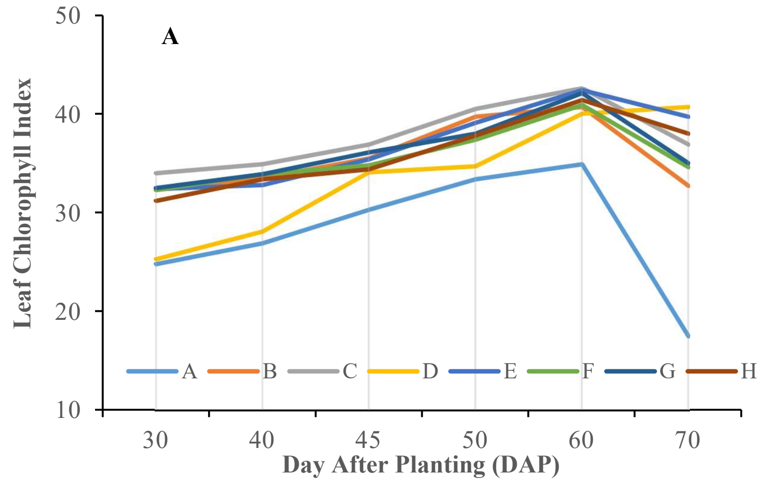
Results and Discussion

Wilis soybean varieties grew well on the acid soils of Banten. Soybean leaves showed symptoms of Fe toxicity, namely rusty leaf spots and stained leaf edges (Sahrawat, 2010). Banten acid soil is very rich in iron, the level is 448 ppm Fe (Table 2), and has the potential to poison the plants. In these conditions, the additions of nutrient-rich organic fertilizer (Santap-M), compound inorganic fertilizer (Phonska), Iletrisoy Rhizobium biofertilizer, and *Pseudomonas* sp. P-solubilizing bacteria affected the growth and yield of soybean. The leaf chlorophyll index of Wilis soybean variety increased with plant growth and decreased after 60 DAP until harvest when the leaves began to turn yellow. Application of 300 kg Phonska ha^{-1} (45 kg N + 45 kg P_2O_5 + 45 kg K_2O + 30 kg S ha^{-1}) produced the highest leaf chlorophyll index, reaching 43 at 60 DAP and only 35 in the treatment without fertilizer (Figure 1A).

The NPKS nutrients contained in Phonska NPKS inorganic fertilizer are more easily decomposed so that soybean plants can immediately use them. The addition of Phonska NPKS inorganic fertilizer on nutrient-poor acid soils such as Banten soil can more quickly have a positive effect on soybean plant growth. As it has been reported that the application of 300 kg Phonska ha^{-1} also increased the chlorophyll index of soybean leaves at 60 DAP from 40 to 46 on paddy field Vertisol, Ngawi and from 43 to 49 on dry land Vertisol, Nganjuk (Subandi et al., 2013; Muzaiyanah et al., 2015). The application of 150-300 kg Phonska ha^{-1} with or without Santap-M organic fertilizer, Iletrisoy rhizobium biological fertilizer, and P-solubilizing bacteria increased the height of soybean plants. In contrast, the application of 1500 kg Santap-M ha^{-1} without other fertilizer did not increase plant height; the effect was the same as the treatment without fertilizer (Figure 1B). The decomposition of nutrients contained in organic fertilizers is slower than inorganic fertilizers, so the addition of Santap-M organic fertilizers is slower to have a positive effect on soybean plant growth. Wilis soybean variety at 45 DAP without fertilization only formed 1 nodule $polybag^{-1}$ with a weight of 0.3 mg $polybag^{-1}$. Application of 300 kg Phonska ha^{-1} or 1500 kg Santap-M + 150 kg Phonska ha^{-1} increased the number and dry weight of root nodules to 9 nodules $polybag^{-1}$ and 7 nodules $polybag^{-1}$ weighing 11.2 mg $polybag^{-1}$ and 13.9 mg $polybag^{-1}$ (Table 4). The addition of 0.2 kg *Pseudomonas* sp. P-solubilizing bacteria ha^{-1} to the combination of 1500 kg Santap M + 150 kg Phonska ha^{-1} resulted in the highest number of nodules, namely 13 nodules $polybag^{-1}$ with a nodule weight of 15.4 mg $polybag^{-1}$. Soybean plants actively form root nodules in sufficiently P nutrient soil conditions.

If the combination of 1500 kg Santap-M + 150 kg Phonska ha^{-1} plus 0.2 kg Iletrisoy Rhizobium + 0.2 kg *Pseudomonas* sp. P-solubilizing bacteria ha^{-1}, the number of root nodules is reduced to 7 nodules $polybag^{-1}$, but the weight remains high, namely 15.7 mg $polybag^{-1}$. Soybean shoot dry weight at 45 DAP only 1.35 g $polybag^{-1}$ with root dry weight 0.30 g $polybag^{-1}$ in the treatment without fertilizer. The addition of organic, inorganic, and biological fertilizers could improve the growth of the Wilis soybean variety plant. The addition of 150 kg Phonska ha^{-1} increased shoot dry weight to 6.68 g $polybag^{-1}$ (increased by 5.33 g $polybag^{-1}$, 395%) and root dry weight to 1.16 g $polybag^{-1}$ (increased by 0.86 g $polybag^{-1}$, 287%) compared without fertilizer. The best growth was obtained by applying 300 kg Phonska ha^{-1}, namely increasing shoot dry weight to 9.13 g $polybag^{-1}$ (an increase of 557%) and root dry weight to 1.63 g $polybag^{-1}$ (an increase of 447%) compared without fertilizer. On the other hand, the addition of 1500 kg Santap-M ha^{-1} did not increase the shoot and root dry weight of soybean plants (Table 4). The application of 1500 kg Santap-M +150 kg Phonska ha^{-1} with or without 0.2 kg ha^{-1} Iletrisoy Rhizobium *or* *Pseudomonas* sp. P- solubilizing bacteria can improve the growth of soybean plants, especially shoot dry weight to 7.03-8.08 g $polybag^{-1}$ and root dry weight to 1.25-1.69 g $polybag^{-1}$,

The addition of 1500 kg Santap-M ha^{-1} increased the leaf area index of Wilis soybean variety from 2.7 in the treatment without fertilizer to 9.2 (Table 4). Leaf area index increases to 25.2-34.9 when fertilized with 150-300 kg Phonska and 1500 kg Santap-M + 150 kg Phonska ha^{-1} with or without 0.2 kg Iletrisoy Rhizobium ha^{-1} or 0.2 kg *Pseudomonas* sp. P-solubilizing bacteria ha^{-1}.



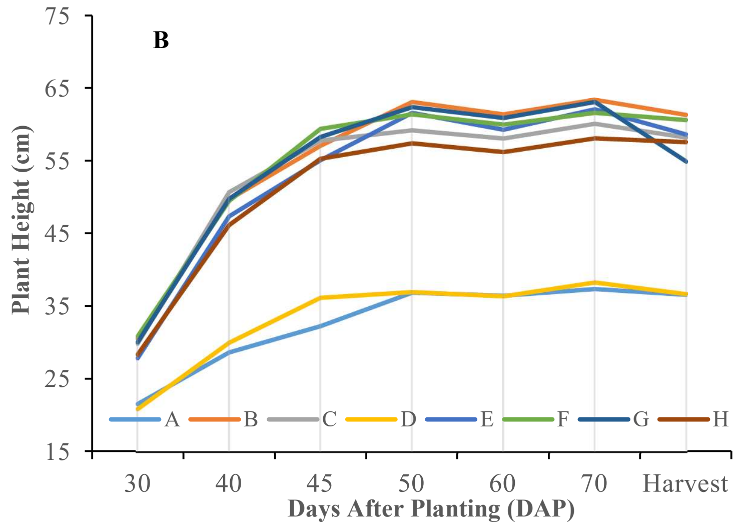


Figure 1. Effect of fertilizer on Wilis variety leaf chlorophyll index (A) and plant height (B) at various stages in Banten acid soils.
Notes: A= Control (without fertilizer), B= 150 kg Phonska ha^{-1}, C= 300 kg Phonska ha^{-1}, D= 1500 kg Santap-M ha^{-1}, E= 1500 kg Santap-M + 150 kg Phonska ha^{-1}, F= 1500 kg Santap-M + 150 kg Phonska + 0.2 kg Iletrisoy Rhizobium ha^{-1}, G= 1500 kg Santap-M + 150 kg Phonska + 0.2 kg *Pseudomonas* sp. P-solubilizing bacteria ha^{-1}, and H= 1500 kg Santap-M + 150 kg Phonska + 0.2 kg Iletrisoy Rhizobium + 0.2 kg *Pseudomonas* sp. P-solubilizing bacteria ha^{-1}.

The levels of N and P elements in soybean plants at 45 DAP in all fertilizer treatments were classified as deficient to low, while the levels of element K were in the sufficient category (Table 5). Although the nutrient levels in the soybean tissue were not different in various fertilizer, the total absorption could be different if there were differences in growth measured by biomass weight. Various combinations of organic, inorganic, and biological fertilizer did not increase the NPK nutrient content in the soybean plant tissue compared to the treatment without fertilizer. However, this fertilization increased NPK nutrient content uptake (Tables 4 and 5). Soybean plants took up 57.6 mg N $polybag^{-1}$, 2.7 mg P $polybag^{-1}$, and 34.4 mg K $polybag^{-1}$ in the treatment without fertilizer (Table 5). The addition of 300 kg Phonska ha^{-1} increased the highest N and K uptake to 386.0 mg N $polybag^{-1}$ and 171.6 mg K $polybag^{-1}$ compared without fertilizer. Fertilization of 300 kg Phonska ha^{-1}, 1500 kg Santap-M ha^{-1}, and 1500 kg Santap-M + 150 kg Phonska ha^{-1} increased the P nutrient uptake of soybean plants from 2.7 mg P $polybag^{-1}$ to 4.9-6.8 mg P $polybag^{-1}$. If Iletrisoy Rhizobium or 0.2 kg *Pseudomonas* sp. P-solubilizing bacteria ha^{-1} were added to the combination of 1500 kg Santap-M + 150 kg Phonska ha^{-1}, and the P nutrient uptake increased to 14.9-15.3 mg P polybag^{-1}, which means an increase of 9.4 mg P polybag^{-1}, almost double compared to the 1500 kg Santap-M + 150 kg Phonska ha^{-1}. So, the addition of Iletrisoy Rhizobium or *Pseudomonas* sp. P-solubilizing bacteria to the combination of Santap-M + Phonska fertilizer could improve the availability of P nutrients in acidic soils, thereby increasing the uptake of P nutrients by soybean plants, thereby improving and increasing the growth and development and yield of soybean seeds (Figure 1, Table 4, dan Table 6). Similar results were also conveyed by Sabilu et al. (2015). On the other hand, according to Setiawati et al. (2017), the application of organic, inorganic, and biological fertilizer does not increase the level of N element because the fertilizer dose given may not meet the plant needs for NPK nutrients (Juarsah, 2016).

The yield of Wilis soybean is only 1.46 g polybag^{-1} without the addition of fertilizer. The use of 150 kg Phonska ha^{-1} increased soybean yields of 5.23 g polybag^{-1} (up 359%) with 36 filled pods polybag^{-1}. The yield increased by 7.83 g polybag^{-1} (538%) with 48 filled pods polybag^{-1} compared without fertilizer when soybean was fertilized by 300 kg Phonska ha^{-1}. On the other hand, the application of 1500 kg Santap-M ha^{-1} only increased the yield of 2.15 g polybag^{-1} (148%), the lowest increase in yield compared to other fertilizer treatments (Table 6). If the soybean was fertilized by 1500 kg Santap-M + 150 kg Phonska ha^{-1}, it produced 52 filled pods polybag^{-1} (highest) with a yield of 9.58 g polybag^{-1} (highest).

Table 4. Effect of fertilizer on nodule number, nodule weight, shoot dry weight, root dry weight, and leaves area index of Wilis soybean variety at 45 DAP in Banten acid soils.

Type and dosage fertilizer (kg ha^{-1})	**Nodule number polybag^{-1}**	**Nodule weight (mg polybag^{-1})**	**Shoot dry weight (g polybag^{-1})**	**Root dry weight (g poybag^{-1})**	**Leaves area index**
Without fertilizer	1 d	0.3 c	1.35 c	0.30 d	2.7 c
150 Phonska	5 b	4.6 bc	6.68 b	1.16 bc	31.0 a
300 Phonska	9 ab	11.2 ab	9.13 a	1.63 ab	27.0 a
1500 Santap-M	2 c	4.4 bc	2.82 c	0.75 cd	9.2 b
1500 Santap-M + 150 Phonska	7 b	13.9 a	7.03 ab	1.25 abc	25.9 a
1500 Santap-M + 150 Phonska + 0.2 Iletrisoy Rhizobium	9 ab	11.9 ab	8.08 ab	1.60 ab	25.2 a
1500 Santap-M + 150 Phonska + 0.2 *Pseudomonas* sp. P-solubilizing bacteria	13 a	15.4 a	7.85 ab	1.25 abc	34.9 a
1500 Santap-M + 150 Phonska + 0.2 Iletrisoy Rhizobium + 0.2 *Pseudomonas* sp. P-solubilizing bacteria	7 b	15.7 a	7.15 ab	1.69 a	33.4 a
Means	7	10.0	6.26	0.60	23.7
LSD 5%	0.21	0.005	2.184	0.509	0.16

Table 5. Effect of fertilizer on NPK nutrient content and NPK nutrient uptake of Wilis soybean variety at 45 DAP in Banten acid soils.

Type and dosage fertilizer (kg ha^{-1})	**NPK nutrients content (%)**			**NPK nutrients uptake (mg pot^{-1})**		
	N	**P**	**K**	**N**	**P**	**K**
Without fertilizer	4.27	0.19	2.55	57.6	2.7	34.4
150 Phonska	3.83	0.19	1.82	255.7	12.7	121.5
300 Phonska	4.23	0.06	1.88	386.0	5.5	171.6
1500 Santap-M	3.87	0.24	2.21	109.3	6.8	62.4
1500 Santap-M + 150 Phonska	3.54	0.07	1.79	248.7	4.9	125.7
1500 Santap-M + 150 Phonska + 0.2 Iletrisoy Rhizobium	3.45	0.19	1.81	278.6	15.3	146.2
1500 Santap-M + 150 Phonska + 0.2 *Pseudomonas* sp. P-solubilizing bacteria	3.41	0.19	2.12	267.7	14.9	166.4
1500 Santap-M + 150 Phonska + 0.2 Iletrisoy Rhizobium + 0.2 *Pseudomonas* sp. P-solubilizing bacteria	3.95	0.19	1.75	282.4	13.6	125.1
Means	3.82	0.17	1.99	235.7	9.5	119.2
Sufficient category	4.51-5.5	0.26–0.50	1.71-2.50			

The addition of 0.2 kg Iletrisoy Rhizobium + 0.2 kg *Pseudomonas* sp. P-solubilizing bacteria ha^{-1} in the combination of 1500 kg Santap-M + 150 kg Phonska ha^{-1} could reduce soybean yields by 1.19 g $polybag^{-1}$ (12%) and decrease *Pseudomonas* sp. P-solubilizing bacteria population (Table 6) compared to 1500 kg Santap-M + 150 kg Phonska ha^{-1}. In the end, the decrease in the population of *Pseudomonas* sp. P-solubilizing bacteria contributed to lower soybean yields. The role of multiple P-solubilizing bacteria isolates *Pseudomonas* sp. of Iletri collection to increase soybean yield in acid soils can be increased by the addition of dolomite (Suryantini, 2012). The benefits of multiple isolates of Iletrisoy Rhizobium and *Pseudomonas* sp. solubilizing-P Iletri collection combined with Santap-M organic fertilizer and NPKS inorganic fertilizer on increasing soybean yield in acid soils still require further study. On acid soils in Lampung, application of Santap-M + Iletrisoy Rhizobium from Iletri collection fertilizer without or with inorganic NPK fertilizer could increase soybean yield (Harsono et al., 2010; 2012). Similar results were also conveyed by Astari et al. (2016) and Setiawati et al. (2017) that the addition of biological fertilizers, organic fertilizers, and inorganic fertilizers could increase soybean yields.

The effect of application of 1500 kg Santap-M + 150 kg Phonska ha^{-1} on increasing soybean yield is the same as the effect of application of 300 kg Phonska or 1500 kg Santap-M + 150 kg Phonska + 0.2 Iletrisoy Rhizobium and/or 0.2 *Pseudomonas* sp. P-solubilizing bacteria ha^{-1}. This means that the combination of fertilization can be a component of an alternative technology to reduce the dosage of 300 kg Phonska/ha as a general recommendation for fertilization in acid soils. According to Bandyopadhyay et al. (2010), the application of 4000 kg manure + 30 kg N + 26 kg P + 25 kg K ha^{-1} significantly improved the allocation of dry matter to pods compared to only application NPK or without fertilizer, thus increasing soybean yield.

The use of 1500 kg Santap-M produced the highest seed weight of 100 seeds, namely 10.57 g 100 $seeds^{-1}$ because the number of filled pods was lower compared to other fertilizer treatments (Table 6). As a result, the accumulation of assimilates is maximized and produces larger seeds compared to other fertilizes treatments. The weight of 100 seeds is in accordance with the description of Wilis soybean varieties (Iletri, 2016), namely medium seeds weighing 10 g 100 $seeds^{-1}$.

Soybean cultivation without the addition of fertilizers increased the *Pseudomonas* sp. P-solubilizing bacteria population from 2.1 x 10^6 CFU g^{-1} soil at the start of the study before planting to 4.8 x 10^6 CFU g^{-1} soil at harvest (increase >100%). The population of *Pseudomonas* sp. P-solubilizing bacteria increased 379% to 23.0 x 10^6 CFU g^{-1} of soil when fertilized with 150 kg Phonska ha^{-1} (Table 6).

Table 6. Effect of fertilizer on yield component, seeds yield of Wilis soybean variety, and *Pseudomonas* sp. P-solubilizing bacteria population after harvesting in Banten acid soils.

Type and dosage fertilizer (kg ha^{-1})	Filled pods number $polybag^{-1}$	100 seeds weight (g)	Seeds yield (g $polybag^{-1}$)	*Pseudomonas* sp. P-solubilizing bacteria population (CFU g^{-1} soil)
Before planting				2.1 x 10^6
After soybean harvesting				
Without fertilizer	10 c	7.38 c	1.46 e	4.8 x 10^6
150 Phonska	36 b	8.99 b	6.68 c	23.0 x 10^6
300 Phonska	48 a	9.72 ab	9.29 ab	12.9 x 10^6
1500 Santap-M	18 c	10.57 a	3.61 d	4.7 x 10^6
1500 Santap-M + 150 Phonska	52 a	9.03 b	9.58 a	24.9 x 10^6
1500 Santap-M + 150 Phonska + 0.2 Iletrisoy Rhizobium	46 a	9.54 ab	8.89 ab	8.6 x 10^6
1500 Santap-M + 150 Phonska + 0.2 *Pseudomonas* sp. P-solubilizing bacteria	44 ab	9.56 ab	8.76 ab	14.0 x 10^6
1500 Santap-M + 150 Phonska + 0.2 Iletrisoy Rhizobium + 0.2 *Pseudomonas* sp. P-solubilizing bacteria	47 a	8.60 b	8.39 b	16.0 x 10^6
Means	38	9.18	7.08	13.6 x 10^6
LSD 5%	9.186	1.159	1.154	

However, increasing the dose of 300 kg Phonska ha^{-1} reduced the *Pseudomonas* sp. P-solubilizing bacteria population to 12.9 x 10^6 CFU g^{-1} soil. Application of 1500 kg Santap-M + 150 kg Phonska ha^{-1} also increased the population of *Pseudomonas* sp. P-solubilizing bacteria to 24.9 x 10^6 CFU g^{-1} soil. The addition of 0.2 kg Iletrisoy Rhizobium ha^{-1} to the combination of 1500 kg Santap-M + 150 kg Phonska ha^{-1} suppressed the development of *Pseudomonas* sp. P-solubilizing bacteria compared to the application of 1500 kg Santap-M + 150 kg Phonska.

The population of *Pseudomonas* sp. P-solubilizing bacteria increased again when 0.2 kg Iletrisoy Rhizobium ha^{-1} in the combination of 1500 kg Santap-M + 150 kg Phonska + 0.2 kg Iletrisoy ha^{-1} was replaced by 0.2 kg *Pseudomonas* sp. P-solubilizing bacteria ha^{-1}. However, the population is still lower than the application of 150 kg Phonska ha^{-1}. So, fertilization of 150 kg Phonska ha^{-1} can increase the population of *Pseudomonas* sp. P-solubilizing bacteria on acidic soil in Banten. On the other hand, 300 kg Phonska ha^{-1} or 1500 kg Santap-M ha^{-1} suppressed the development of *Pseudomonas* sp. P-solubilizing bacteria (Table 6). In edamame soybean plants, the addition of biological fertilizer containing *Azotobacter sp.*, vermicompost, and NPK inorganic fertilizer increased the population of *Azotobacter* sp. and pod weight (Setiawati et al., 2017).

Fertilization of 1500 kg Santap-M + 150 kg Phonska ha^{-1} increased the highest soybean yield in the acid soils Banten, although the effect on increased yield is not different from the application of 1500 kg Santap-M + 150 kg Phonska + 0.2 kg Iletrisoy Rhizobium ha^{-1}, 1500 kg Santap-M + 150 kg Phonska + 0.2 kg *Pseudomonas* sp. P-solubilizing bacteria ha^{-1}, or 300 kg Phonska ha^{-1}. This means that the three combinations of organic, inorganic, and biological fertilizer can be a component of alternative technology to reduce the dosage of 300 kg Phonska ha^{-1} as a general recommendation for fertilization in acid soils. In addition, the 1500 kg Santap-M + 150 kg Phonska ha^{-1} also had the best and positive effect on the development of *Pseudomonas* sp. P-solubilizing bacteria after soybean harvest. If the assessment of the feasibility of the fertilizer technology component is based on its effect on increasing yields and improving or preserving the quality of soil resources, then fertilization technology component of 1500 kg Santap-M + 150 kg Phonska ha^{-1} can be the best alternative choice for soybean fertilization in Banten acid soils.

The results of this study add to the information on the effect of adding organic, inorganic, and biological fertilizers on improving soil and plant productivity as presented by Hanum (2013), Naini et al. (2015), Wijanarko et al. (2016), Almaz et al. (2017), Fahrizal et al. (2017), Sari et al. (2017), Hasibuan et al. (2018), Utami et al. (2018), Kristiono et al. (2020), Sitawati et al. (2020), and Vishwanath et al. (2020). The positive impact is caused by the addition of organic, inorganic, and biological fertilizers that can increase the levels of organic matter, nutrients, and soil exchange capacity (Shiddieq and Partoyo, 2000; Bandyopadhyay et al., 2010; Verde et al., 2013; Syahputra et al. 2015; and Hasibuan et al., 2018). The addition of Ca increases the activity of the plasma membrane H^+-ATPase enzyme, thereby increasing nutrient uptake (Liang and Zhang, 2018). In addition, rhizobium inoculation and the addition of S fertilizer were reported to improve growth, increase NPKS element uptake, yield, and quality of soybean seeds (Getachew, 2017).

The addition of organic matter is needed to improve, increase and maintain acid soil fertility in order to support optimal plant growth. Improving soil fertility is the main key to increasing land productivity through fertilization, liming and/or application of organic matter. Raising awareness of government program to increase the use of organic fertilizers will reduce the use of inorganic fertilizers, and improve the quality of agricultural land that has been degraded due to its very low organic C content, less than 2% (Shiddieq and Partoyo, 2000) with a low soil microbial population. In the long term, cultivation of plants without tillage on acid soils with liming without or with phosphogypsum can also increase soil organic C content (da Costa and Crusciol, 2016).

The addition of organic fertilizers and liming can increase soil pH, nutrient uptake, nodule formation, and soybean productivity on acid soils (Otieno et al., 2018). The most relevant soil chemical properties influencing N fixation were soil pH and Al saturation (Alves et al., 2021). The addition of a combination of organic and inorganic fertilizers is needed to increase and maintain soil microbial populations (Ding et al., 2015). In addition, increasing the efficiency of fertilizer input is carried out by fertilizing based on soil nutrient status (Kasno, 2019). Results of this study add to the list of positive impacts of managing organic and inorganic fertilizers for sustainable agriculture. The use of organic and NPK inorganic fertilizer are alternative options that need to be considered for sustainable soybean cultivation on acid dry land.

Conclusion

The following conclusions can be drawn from the study results on Banten dry land acid soils: 1) application of 150 kg Phonska ha^{-1} and 300 kg Phonska ha^{-1}, 1500 kg Santap-M ha^{-1}, and 1500 kg Santap-M ha^{-1} + 150 kg Phonska ha^{-1} with or without 0.2 kg Iletrisoy Rhizobium ha^{-1} with or without 0.2 kg *Pseudomonas* sp. P-solubilizing bacteria increased 143-528% soybean yield than without fertilizer; 2) Application of 1500 kg Santap-M ha^{-1} + 150 kg Phonska ha^{-1} increased soybean yield with highest population of *Pseudomonas* sp. P-solubilizing bacteria; 3) alternative components of fertilization technology that could increase soybean yield and improve the quality of acid soils Banten was a combination of 1500 kg Santap-M ha^{-1} + 150 kg Phonska ha^{-1}. The application of organic fertilizer and NPK inorganic fertilizer was a choice that needs to be considered for sustainable soybean cultivation in acid dry land.

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