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Research Article

Soybean growth and yield responses at third planting season to residual potassium fertilizer on a vertisol

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Abstract: Application of fertilizers on previous crops can leave a residue so that it can be used for the next crops. It is necessary to know the extent to which these residues can affect the growth and yield of soybean crops. The objective of this study was to explore the effect of potassium fertilizer residues on growth and yield of soybean crops at third planting season (PS-III) on a vertisol. The research was conducted at dry season using a vertisol from Nganjuk, East Java. The experiment was designed using a factorial randomized block design with two factors and three replications. The first factor was the dose of potassium fertilizer (KCl) in the first planting season (PS-I) of rice, i.e. 0, 500, 1500, and 2000 kg potassium fertilizer/ha. The second factor was the dose of potassium fertilizer in the second planting season (PS-II) of soybean, i.e. 0, 50, 100, 200, and 400 kg potassium fertilizer (KCl)/ha. The soybean variety used was Sinabung. The results showed that fertilizer residues of planting season I and planting season II affected the growth component and yield component of soybean, but did not affect seed yield of soybean. There was no consistent increase on growth component, yield component, or seed yield of soybean with an increasing residual dose of potassium fertilizer of planting season I or planting season II. The residual treatment of 1500 kg potassium/ha at planting season I gave the highest number of branches per plant (2 branches) and seed weight per plant (3.13 g) of soybean. The residual treatment of 50 kg potassium/ha at planting season II gave the highest root nodule weight per plant of 0.10 g and the highest seed weight per plant of 3.33 g.

Keywords: *potassium, residual fertilizer, soybean, vertisol*

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Introduction

Soybeans are the most widely used beans in the food industry and provide economic benefits to small-scale farmers (Zerihun et al., 2015). Soybean is one of the food crops that have the benefits as a source of vegetable protein. People in Indonesia generally use soybean as the main raw material in the manufacture of tempeh, tofu, soy sauce, and soybean sprouts (Kuntyastuti and Sutrisno, 2017a), but it can also be eaten directly after boiling. The extensive use of soybeans by the community has caused it needs to increase. It is not supported with sufficient available, one of the causes is the low productivity of soybean. According to Manshuri (2012), the low productivity of soybean in Indonesia is caused by the poor availability of nutrients in the soil so that plant growth becomes not optimal.

Soybean is widely grown in paddy fields, usually planted following the pattern of planting after rice. One of the most widely used rice fields is a vertisol. The existence of a program of intensification of rice crops that have lasted long, causing a decline in soil fertility level is quite severe. One of them is the occurrence of potassium potency that has been identified in vertisol rice fields (Adisarwanto, 2004). The way that can be done to improve the soil fertility level is by application of fertilization.

Fertilization is one of the cultivation technologies that can be done to increase the productivity of plants (Chakrabarty et al., 2014). Application of fertilizer in plants can have a positive effect on nutrient uptake, growth, and yield on plants. This is due to the availability of essential nutrients through improved soil capacity providing nutrients, as well as improved physical and biological properties of soil after fertilizer (Estiaty et al., 2006; Meena et al., 2015).

Potassium (K) is one element in the fertilizer. Potassium plays an important role such as regulating the availability of other nutrients, stimulating the process of photosynthesis and plant growth, assisting in the process of photosynthate distribution, becoming a catalyst in protein synthesis, and improving crop quality (Read et al., 2006). Potassium fertilizer is easy to decompose and very mobile in the ground. Most bean crops, one of which is soybean, require high amounts of potassium, so it will be greatly affected if there is a deficiency of potassium (Hendrival et al., 2014). The deficiency of K element can cause a decrease in the number of leaves and leaf size. This may lead to a reduction in photosynthetic rate which affects the reduced amount of assimilate produced, which may interfere with plant growth (Pettigrew, 2008).

Fertilization of previous crops may leave residues in the soil so that they can be used for the next crop and may affect crop yields (Yin and Vyn, 2004). Potassium fertilizer that has a degree of mobilization or solubility rate is lower than nitrogen the residual possibility can be utilized for minimum plant growth of up to six growing seasons (Kuntyastuti and Sutrisno, 2017b). The residue of potassium fertilizer has a significant effect on chemical properties such as soil pH, available P soil, exchangeable K, organic C, total N, and CEC in the lowland, but no effect on rice growth (Fitriadi et al., 2013). Fertilization of 200-500 kg potassium/ha on an entisol did not increase the yield of soybean varieties Sinabung. However, the accumulation of 100 kg potassium/ha on soil with residual of 200 kg potassium/ha can increase 39% soybean yield compared with no potassium fertilizer (Kuntyastuti et al., 2013). The increase of residual fertilizer doses did not give consistent effect to soil fertility, availability of K in the soil, or the increase of seed yield (Xing et al., 2007; Kuntyastuti and Sutrisno, 2017b). Residual of inorganic fertilizer affects the growth and nutrient uptake, but the effect is lower than the effect at the beginning of the application (Nurahmi, 2009). The objective of this study was to explore the effect of potassium fertilizer residues on growth and yield of soybean crops at third planting season on a vertisol.

Materials and Methods

The research was conducted at Kendalpayak Station Research, ILETRI, Malang, East Java using a vertisol from Nganjuk during the dry season (DS). The soybean seed used in this research was Sinabung variety. The design was a factorial randomized completely block design with three replications. The first factor was the dose of potassium fertilizer (KCl) at first planting season (PS-I) paddy, i.e. 0, 500, 1500, and 2000 kg potassium fertilizer/ha. The second factor was the dose of potassium fertilizer at second planting season (PS-II) soybean, i.e. 0, 50, 100, 200, and 400 kg potassium fertilizer/ha. The study used a concrete plot measuring 0.8 m long, 0.5 m wide, and 0.5 m high as 60 plots on concrete. The concrete plot was filled with soil (vertisol) collected from farmer's land in Ngujug village, Gondang district, Nganjuk regency at a depth of 0-20 cm. The soil used in this study has clay texture. At the beginning of the experiment, a composite soil sample was collected, at a depth of 0-20 cm. Soil sampling was done after PS-II soybean harvest, before PS-III soybean. The soil sample was analyzed for soil pH, and organic C, total N, P_2O_5, and exchangeable K, Na, Ca, and Mg. The soil analysis was performed on all treatment combinations of PS-I paddy and PS-II soybean. In PS-III, the soil was treated lightly. Soybean seeds of Sinabung variety were mixed with Marshall insecticide and planted without basic fertilizer with a planting space of 40 cm x 10 cm, two plants per hole. Soybean crops were harvested when 95% of the pods were brown and the leaves fell off, by being revoked. Observations of plant height, number of branches, number and weight of root nodule, root dry weight of soybean were made at the age of 45 days after sowing by removing two plants per concrete. Observations made during the harvest were number of filled pods, number of empty pods, weight of seeds per plant, weight of 100 seeds, and seed yield per concrete. Data were subjected to analysis of variance followed by the DMRT at 5% level.

Results and Discussion

Soil properties

There were changes in soil chemical properties after PS-II soybean harvest compared to after PS-I paddy harvest. Some soil chemical properties after PS-I paddy harvest (average) were pH H_2O 7.2; total N 0.07%; organic-C 1.1%; P_2O_5 41 ppm;

SO_4 16 ppm; exchangeable K 1.03 me/100 g; exchangeable Na 1.67 me/100 g; exchangeable Ca 6.30 me/100 g; exchangeable Mg 2.05 me/100 g; total P 45.4 mg/100 g; and total K 42.2 mg/100 g. After the PS-II soybean harvest, pH H_2O decreased to 6.5; levels of SO_4, exchangeable K, exchangeable Na, total P, and total K were decreased 37%, 15%, 11%, 63%, and 49%, respectively. In contrast, total N, organic C, P_2O_5, exchangeable Ca, and exchangeable Mg levels increased by 29%, 22%, 207%, 545%, and 248%, respectively. Drastic changes occurred at pH, P_2O_5, exchangeable Ca, exchangeable Mg, total P, and total K levels. In general, potassium fertilization on PS-II decreased soil pH, followed by the decrease in total P and total K, but increased levels of P_2O_5, exchangeable Ca, and exchangeable Mg (Table 1). Results of soil sample analysis after PS-I and PS-II, before planting PS-III showed that the soil was quite acid to neutral (Table 1). The soil belongs to the acid category if it has pH <6.0 and base saturation <50% (Mulyani, 2006). Soil nutrient status was very low to very high category. N content was very low and organic C was low. The levels of P_2O_5 and exchangeables K, Na, Ca, and Mg were very high (Table 1). The high level of K element needs to be watched because it can affect the absorption of calcium element that can prevent the formation of new roots and root elongation, so that nutrient uptake for plant growth can be hampered (Pracaya, 2009).

Table 1. Effect of potassium fertilizer on PS-I paddy and PS-II soybean on soil chemical properties after soybean harvest PS-II on a vertisol

Potassium (kg/ha)	pH H_2O	N (%)	Organic C (%)	P_2O_5 ppm	Exchangeable cations (me/100 g)			
					K	Na	Ca	Mg
Planting season I								
0	6.68	0.05	1.29	132.6	0.73	1.29	39.60	8.02
500	6.64	0.10	1.34	124.6	0.83	1.51	39.86	8.05
1500	6.34	0.10	1.41	117.6	1.05	1.68	41.44	8.18
2000	6.26	0.12	1.32	129.8	0.91	1.51	41.58	8.34
Planting season I								
0	6.50	0.09	1.36	113.0	0.89	1.33	40.13	8.09
50	6.38	0.09	1.29	169.3	0.88	1.37	39.73	8.09
100	6.58	0.09	1.37	114.5	0.87	1.51	40.58	8.10
200	6.55	0.09	1.39	116.8	0.82	1.58	40.95	8.32
400	6.40	0.09	1.31	117.3	0.96	1.70	41.73	8.15
Average	6.48	0.09	1.34	126.2	0.88	1.49	40.62	8.15

Soybean growth

The potassium fertilization residue in PS-I paddy had a significant effect on dry weight of canopy and number of branches per plant at PS-III soybean. Treatment of 2000 kg potassium/ha fertilizer residue showed the highest dry weight of the canopy although not statistically different compared to the residue of 1500 kg potassium/ha. The residual treatment of 1500 kg potassium/ha showed the highest number of branches compared with other treatments.

Fertilization residue on PS-II soybean significantly affected the dry weight variables of root nodule, root, and soybean plant canopy. Potassium fertilizer residue can improve root and canopy growth, as well as dry weight of soybean nodule on PS-III. Soybean plants can reach an average height of 72.5 cm with 1.7 branches/plants. The highest root and canopy drift on PS-II was obtained at an application residue of 200 kg potassium/ha (Table 2). The presence of residual potassium for up three planting seasons may be due to the soil in this study including heavy soils or clay so that potassium fertilizer is still available from previous crops and can be used for plant growth. According to Utomo (2016), vertisols are dominated by clay texture and clump structure at every depth. Rosolem et al. (2010) also mentioned that the soil structure affects the availability of potassium element in the soil. The heavier soil types, such as clay, can lead to the leaching of potassium so slowly that it will be stored longer in the soil.

Yield component and seed yield

Residual fertilizer on PS-I and PS-II only affected the weight of the seeds per plant but did not affect the number of filled pods, the number of empty pods, the weight of 100 seeds, and the yield of soybean seeds. There was no interaction between the treatment of residual fertilizer on PS-I and PS-

II (Table 3). Seed weight per plant with potassium fertilizer residues was higher than seed weight per plant without potassium fertilizer residue. Seed weight per plant reached the maximum point on fertilizer residue of 1500 kg potassium/ha in PS-I and on fertilizer residue of 50 kg potassium/ha in PS-II. Based on this, it can be seen that there was no consistency in the increase on seed weight per plant with increasing of fertilizer dosage at PS-I or PS-II. The higher dose of fertilizer application, the residue may also be more, but it may not be used entirely by the next plant. This is similar to the results of Berg et al. (2005) that no significant difference between the highest dose and other doses is likely because the high residue of fertilizers cannot be maximally utilized by the plants, so the crops yield does not increase with the increase of fertilizer residue.

Table 2. Effect of potassium fertilizer on PS-I paddy and PS-II soybean on the growth of Sinabung soybean variety on PS-III on a vertisol

Potassium (kg/ha)	Root nodule/plant		Dry weight (g/plant)		Plant height (cm)	Branch number /plant
	Number	Weight (g)	Root	Shoot		
Planting season I						
0	18.1 a	0.10 a	0.42 a	1.95 ab	70.6 a	1.6 b
500	17.9 a	0.08 a	0.39 a	1.64 b	72.9 a	1.9 ab
1500	18.5 a	0.09 a	0.42 a	2.05 a	72.2 a	2.0 a
2000	17.1 a	0.08 a	0.45 a	2.27 a	73.6 a	1.5 b
Planting season II						
0	16.7 a	0.06 b	0.37 b	1.57 b	71.0 a	1.7 a
50	17.8 a	0.10 a	0.36 ab	1.85 ab	74.1 a	2.0 a
100	17.7 a	0.09 a	0.41 ab	2.22 a	71.9 a	1.8 a
200	18.3 a	0.10 a	0.50 a	2.29 a	72.5 a	1.6 a
400	18.9 a	0.09 a	0.40 b	1.95 ab	72.2 a	1.7 a
Average	17.9	0.09	0.42	1.98	72.5	1.7
Interaction	**	ns	ns	**	ns	ns
CV (%)	15.78	16.83	10.04	13.26	6.75	12.88

Note: Numbers followed by different letters in a column were significantly different according to DMRT test ($P<0.05$); CV = coefficient of variation

Table 3. Effect of potassium fertilizer on PS-I paddy and PS-II soybean on seed yield and soybean yield component of Sinabung variety on PS-III on a vertisol

Potassium (kg/ha)	Pod number/plant		100 seeds weight (g)	Seed weight (g/plant)	Seed yield (g/0.4 m^2)
	Filled	Empty			
Planting season I					
0	16.7 a	3.3 a	6.79 a	2.65 b	62.88 a
500	18.1 a	2.9 a	6.86 a	3.05 a	68.88 a
1500	19.0 a	3.1 a	7.09 a	3.13 a	63.85 a
2000	17.0 a	2.5 a	7.01 a	2.81 ab	65.40 a
Planting season II					
0	16.7 a	3.3 a	7.00 a	2.49 c	62.04 a
50	18.8 a	2.7 a	7.23 a	3.33 a	67.56 a
100	18.1 a	2.8 a	6.89 a	2.91 abc	65.29 a
200	17.8 a	2.6 a	6.99 a	3.05 ab	66.41 a
400	17.5 a	3.5 a	6.57 a	2.75 bc	65.97 a
Average	17.8	3.0	6.94	2.91	65.25
Interaction	ns	ns	ns	ns	ns
CV (%)	15.44	19.27	9.96	16.93	13.3

Note: Numbers followed by different letters in a column were significantly different according to DMRT test ($P<0.05$); CV = coefficient of variation

Table 4. Correlation between potassium fertilizer dose on PS-I paddy and PS-II soybean with seed yield, growth component, and soybean yield components of Sinabung variety on PS-III on a vertisol

Variable	r P	Potassium PS-I	Potassium PS-II	Seed yield	Nodule number	Nodule weight	Root weight	Shoot weight	Plant height	Branch number	Filled pods	Empty pods	100 seeds weight
Seed yield	r	0.000	0.063										
	P	0.999	0.792										
Nodule number	r	-0.10	0.319	0.146									
	P	0.663	0.170	0.539									
Nodule weight	r	-0.24	0.175	0.134	0.737								
	P	0.306	0.461	0.573	0.000								
Root weight	r	0.164	-0.12	0.193	0.259	0.413							
	P	0.490	0.620	0.415	0.269	0.071							
Shoot weight	r	0.343	0.201	-0.21	0.232	0.317	0.689						
	P	0.139	0.395	0.364	0.324	0.173	0.001						
Plant height	r	0.354	0.000	0.588	0.359	0.175	0.398	0.222					
	P	0.125	0.999	0.006	0.120	0.461	0.082	0.346					
Branch number	R	0.071	-0.10	-0.05	0.179	0.150	-0.13	-0.19	0.015				
	P	0.768	0.690	0.826	0.451	0.528	0.598	0.432	0.950				
Filled pods	R	0.102	-0.03	0.332	0.369	0.379	0.134	-0.03	0.498	0.583			
	P	0.669	0.905	0.153	0.109	0.100	0.574	0.904	0.026	0.007			
Empty pods	R	-0.34	0.277	-0.36	0.253	0.083	-0.54	-0.28	-0.26	0.267	0.032		
	P	0.139	0.236	0.118	0.282	0.729	0.015	0.234	0.261	0.256	0.895		
100 seeds weight	R	0.276	-0.47	0.223	0.183	0.099	0.371	-0.05	0.471	0.193	0.597	-0.35	
	P	0.238	0.036	0.345	0.440	0.677	0.107	0.842	0.036	0.416	0.005	0.127	
Seed weight/plant	R	0.146	-0.04	0.620	0.356	0.428	0.333	-0.05	0.585	0.499	0.844	-0.18	0.561
	P	0.539	0.879	0.004	0.123	0.060	0.152	0.825	0.007	0.025	0.000	0.440	0.010

***Stepwise regression*: (R^2 = 55.8%, P = 0.001)**

Seed yield = 48.466 + 10.558 seed yield/plant – 7.985 branch number/plant

Note: Value of **r** = correlation coefficient value

Observations in the number of filled pods, the number of empty pods, the weight of 100 seeds, and the yield of soybean seeds did not show significantly different results. Although there was no consistency in the effect of higher fertilizer doses, it caused higher growth and yield, but all treatments with potassium fertilizer residue had higher values than without residue. The influence of potassium fertilizer residue might be caused by the soil used in this study that is recognized as a heavy soil (clay) so that the potassium fertilizer applied could still be used for plant growth. Rosolem et al. (2010) stated that the availability of abundant potassium in the soil was influenced by soil structure (the type of soil that is getting heavier will cause leaching of potassium slower so that K element will be stored longer in the soil) and will usually increase nutrient uptake of potassium. However, the research they have done did not improve the yield and quality of soybean seeds.

Before planting PS-II or PS-III soybean (after PS-I paddy harvest), the soil was a rich plant medium of K (exchangeable K > 0.7 me/100 g). Soybean crops grown on the soil were responsive to potassium fertilization when exchangeable K content was less than 0.3 me/100 g after the PS-II soybean harvest, The soil remained rich in K (exchangeable K >0.7 me/100g). These factors may be the cause of soybean crops unresponsive to K fertilizer residue.

The potassium fertilization on PS-I and PS-II soybean could increase the weight of PS-III soybean seeds, but the correlation analysis was not significant. Potassium fertilization in PS-II soybean was negatively correlated with the weight of 100 seeds at PS-III, although the result of variance was not significant. In addition, based on correlation analysis, the yield of PS-III soybean was positively correlated with plant height and seed per plant weight (Table 4).

Conclusion

The potassium fertilization residue in PS-I and PS-II affected the growth component and the soybean crop component on PS-III but did not affect seed yield. No consistent increase in growth components, yield components, or results with an increase in residual doses of potassium fertilizer on PS-I or PS-II. Treatment of 1500 kg potassium/ha fertilizer residue at PS-I gave the highest number of branches per plant and seed weight per plant, each of 2 branches and 3.13 g. The treatment of 50 kg potassium fertilizer residue/ha on PS-II gave the highest root weight of nodule per plant by 0.10 g and the highest seed weight per plant was 3.33 g.

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