JOURNAL OF DEGRADED AND MINING LANDS MANAGEMENT
ISSN: 2339-076X (p); 2502-2458 (e), Volume 5, Number 2 (January 2018): 1133-1139
DOI:10.15243/jdmlm.2018.052.1133

Research Article

Sweet potato response to biochar application on sub-optimal dry land

Edyson Indawan, Sri Umi Lestari*, Nurita Thiasari

Faculty of Agriculture, Tribhuwana Tunggadewi University, Jl. Telaga Warna, Tlogomas, Malang 65144, Indonesia

* corresponding author : sriumi.lestari@yahoo.com

Received 02 October 2017, Accepted 20 December 2017

Abstract: This trial was aimed to evaluate the performance of sweet potato cultivars on biochar application. The treatments were carried out using a Split-plot Design with three replications. The cultivars were placed on main plots and biochar doses were on sub-plots. The thirteen cultivars consisted of seven varieties and six accessions from Tribhuwana Tunggadewi University and Brawijaya University collections. The applied biochar doses were B_0 (0 t/ha) and B_1 (5 t/ha). The experimental unit measuring of 5 m x 0.6 m consisted of single row and planted with a spacing of 25 cm in row or 20 cuttings/row. The storage root weight, % dry matter, storage root dry weight, dry weight of biomass, harvest index and yield estimation were determined. The results showed that the sweet potato cultivars gave a significant response to the biochar application on fresh storage root weight, storage root dry weight, biomass dry weight, harvest index and storage root yields, but no interaction between cultivars and biochar doses. Storage root yield ranged from 8 to 21 t/ha without biochar and from 10 to 23 t/ha with 5 t biochar /ha, except for Beta 1 and Boko. The use of 5 t biochar /ha increased storage root yields that ranged from 8 to 45%.

Keywords: *biochar from tobacco industry waste, sweet potato, storage root fresh weight*

To cite this article: Indawan, E., Lestari, S.U. and Thiasari, N. 2018. Sweet potato response to biochar application on sub-optimal dry land. J. Degrade. Min. Land Manage. 5(2): 1133-1139, DOI: 10.15243/jdmlm.2018.052.1133.

Introduction

Agricultural land on the island of Java has been degraded, resulting in decreased soil fertility. Severe degraded land has become the main causes of low crop productivity. According to Sitorus et al. (2011), criteria of land that have been degraded are based on variations of parent material, silt percentages fraction on soil texture, type of land use, the slope conservation handling, and the chemical property variables (i.e. pH value, organic C, total N, available P, Ca, Mg, K, Na, CEC, base saturation, exchangeable Al and H). For example, the lands have been intensively cultivated for food crops with a percentage of silt fraction between 20-40% and have a very low available P (< 3 ppm) including the land that has been degraded very severe. Sweet potato [*Ipomoea batatas* (L.) Lam.] is highly efficient starchy food crops more efficient than rice, corn and potatoes (Kozai et al., 1999). This crop is suitable for subsistence farming in Indonesia (Zuraida and Supriyati, 2001). The crop is usually planted on marginal lands with erratic rainfall (Motza et al., 2015). Nevertheless, optimal fertilization is required to reach the output potential. Their potential yields harvested at 4 months after planting can produce 30-40 t/ha fresh storage root weight (Saleh and Hartojo, 2003) with a dose of 100-200 kg Urea+100 kg SP36+100 kg KCl/ha. The sweet potato will grow optimally if the crop is fertilized with organic fertilizer (ILETRI, 2010). The trial on a research station at North Carolina University could produce more than 65 t/ha (Ziska et al., 2009). On the contrary, the average yield of farmer's sweet potato in Indonesia is only 10 t / ha. Local varieties of sweet potatoes are cultivated by farmers that have low yields. Agricultural land that has been intensively cultivated for continuous cultivation of food crops causes severe degradation, and further decreases yields (Sitorus et al., 2011). Soils obtaining inorganic fertilizers continuously show a decrease in productivity and tend to suffer secondary nutrient deficiencies as well as micronutrients (Sheth et al., 2017). The addition of soil amendment is necessary to restore the fertility of the soil. Biochar is one of the soil amendments that can improve soil fertility (Ding et al., 2016; Hunt et al., 2010). Biochar can be produced by utilizing agricultural and industrial wastes. Tobacco industry waste is the remnants of cigarette industry production, which mostly comes from tobacco leaves and clove flowers that have been dumped into landfills. Production of tobacco industry waste is quite high, more than 20 tons every day, potentially as a source of environmental pollution (Talkah, 2010). Currently this tobacco industry waste has been produced into biochar, therefore this research was aimed to evaluate performance of sweet potato cultivars against biochar application on degraded agricultural land that has been used intensively for cultivation of crops.

Materials and Methods

This research was conducted at Brawijaya University research station located in Jatikerto Village, Kromengan District of Malang Regency, from March to July 2017. The research site has an altitude of 352 m above sea level and soil type of Inceptisol. The soil has the following characteristics: acid pH (pH H_2O 5.5), organic C, total N and level of P are very low (0.87%, 0.09% N, 0.76 P mg/kg respectively) (Table 1). The soil texture (17% sand, 35% silt and 48% clay) has a silt fraction in the range of 20-40%. The plant materials used in this study consisted of 13 cultivars of sweet potato, including seven varieties (Kuningan putih, Beta 1, Beta 2, Kuningan Merah, Sari, Boko and Jago) and six clones of Tribhuwana Tuggadewi University and Brawijaya University collection (BIS OP- 61-OP-22, 73-6/2, 73 OP-8, BIS OP-61, 73 OP-5, and BIS OP-61-♀-29). The cultivars characteristics are shown in Table 2.

Table 1. Soil properties at the experimental site

Soil Properties	Value	Criteria
pH H_2O	5.5	Acid
pH KCl	4.9	Acid
Organic C (%)	0.87	Very Low
Total N (%)	0.09	Very Low
C/N ratio	10	Low
Avaiable P (mg/kg)	0.76	Very Low
Exchangeable Cations		
– K (me/100g)	2.61	Very High
– Na (me/100g)	1.27	Very High
– Ca (me/100g)	6.57	Medium
– Mg (me/100g)	2.9	High
Cation Exchange Capacity (me/100g)	18.96	Medium
Base Saturation (%)	67	High
Sand (%)	17	
Silt (%)	35	Clay
Clay (%)	48	texture

Table 2. Cultivars of sweet potato used in this trial

No	Clone	Character	Pedigree
1	Kuningan Putih	High dry weight	Local varieties of Kuningan Regency (West Java)
2	BIS OP-61-OP-22$^{**)}$	High levels of Fe and Zn	Open pollination progeny of BIS OP-61 no 22
3	73-6/2$^{***)}$	High dry weight	Improved clone
4	Beta 1	High beta-carotene	Variety that has been released in 2009
5	Beta 2	High beta-carotene	Variety that has been released in 2009
6	Kuningan Merah	High beta-carotene	Local variety of Kuningan Regency (West Java)
7	73 OP-8$^{**)}$	High Protein	Open pollination progeny of 73-6/2 clone no 8
8	BIS OP-61$^{**)}$	High Protein	Open pollination progeny of BIS-214$^{*)}$ clone
9	73 OP-5$^{**)}$	High Protein	Open pollination progeny of 73-6/2 clone no 5
10	Sari	Control	Varietyhas been released in 2001
11	Boko	Control	Varietyhas been released in 2001
12	Jago	Control	Varietyhas been released in 2001
13	BIS OP-61-♀-29 $^{**)}$	High foliage yield	Progeny of BIS OP-61 clone as a female parent no 29

Note: $^{*)}$Introduction clone from Nigeria; $^{**)}$ Clones collection of Tribhuwana Tunggadewi University, $^{***)}$ Clone of Brawijaya University collection

Biochar of tobacco industry waste used in this study was obtained from PT Gudang Garam Kediri, has characteristics of pH 9.57, 1.85% N, 1.88% P_2O_5, 2.50% K_2O, C/N ratio of 21.34%, and organic-C amounted to 39.47%. The basic fertilizer for packet of sweet potato technology used was NPK Phonska fertilizer (15% N, 15 P_2O_5, 15% K_2O) with dose of 400 kg/ha to replace a standard dose of sweet potato with a dosage of 100-200 kg Urea+100 kg SP36+100 kg KCl/ha.
The split plot design was used with three replications. The thirteen sweet potato cultivars were placed as main plots and doses of biochar of 0 and 5 t/ha were placed as sub-plots. The plot size was 5 m x 0.6 m, as a plot of single row, planted cuttings of sweet potatoes with spacing in rows of 25 cm, so that there were 20 cuttings per plot. Biochar was applied one week before planting.

All experimental plots were given basic fertilizer of NPK Phonska (15% N, 15% P_2O_5, 15% K_2O) at a dosage of 400 kg/ha and applied twice, firstly 1/3 of the portion was given at plant age one week after planting and the remainder was given at plant age 1.5 months. Standard cultivation technology for sweet potato was applied. Plants were harvested at 4 months after planting. The storage root weight, % dry matter, storage root dry weight, biomass dry weight, harvest index and yield estimation were determined. Analysis of variance was done for all collected data. The mean value was presented descriptively, no difference test between mean, because the difference between cultivars was not important. The difference in the application of biochar used is clearly visible if there is a significant difference, so that the application of 5 t biochar / ha must be different againts to the control or without biochar.

Results and Discussion

Biochar effect

The performance of thirteen cultivars evaluated for dosage of tobacco biochar application at 5 t / ha on observation parameters (Tables 3 and 4) showed significant differences (Table 5), particularly for storage root weight, storage dry root weight, biomass dry weight, harvest index and estimated storage root yield. Tobacco biochar application increased storage root weight, storage root dry weight and storage root yield. According to Biederman and Harpole (2013) biochar application to soil increased plant productivity. Most of these effects are associated with properties of biochars, such as high surface area and porosity, water holding capacity, cation exchange capacity, that interact with soil biota and nutrient dynamics (Glaser et al., 2002; Lehmann et al., 2011). Biochar is a substance of charcoal that has a fine-grained and highly porous, increased surface area and porosity of soil. Biochar enables to adsorb or retains nutrients and water and also provides a habitat for beneficial microorganisms to multiply and flourish (Hunt et al., 2010).

Table 3. Storage root weight, storage root yield, % dry matter of storage root and storage root dry weight of 13 sweet potato cultivars with application of biochar (B_1 = 5 t/ha) and without biochar.

No	Cultivar	Storage root weight (kg/plant)		% Dry matter of storage root		Storage root dry weight (kg/plant)	
		B_0	**B_1**	**B_0**	**B_1**	**B_0**	**B_1**
1.	Kuningan Putih	0.31	0.45	31.43	32.48	0.10	0.15
2.	BIS OP-61-OP-22	0.53	0.57	27.94	29.58	0.15	0.17
3.	73-6/2	0.34	0.48	33.36	32.66	0.11	0.16
4.	Beta 1	0.33	0.31	21.77	22.45	0.07	0.07
5.	Beta 2	0.37	0.52	23.96	22.72	0.09	0.12
6.	Kuningan Merah	0.31	0.34	23.40	24.95	0.07	0.09
7.	73-OP-8	0.20	0.26	24.06	24.23	0.05	0.06
8.	BIS OP-61	0.23	0.28	33.34	34.95	0.08	0.10
9.	73 OP-5	0.46	0.54	28.02	27.51	0.13	0.15
10.	Sari	0.35	0.44	27.36	28.29	0.10	0.12
11.	Boko	0.29	0.28	31.10	31.58	0.09	0.09
12.	Jago	0.29	0.33	32.30	32.18	0.09	0.11
13.	BIS OP-61-♀-29	0.44	0.47	28.76	28.07	0.13	0.13

Storage root weight of each cultivar ranged from 0.20 to 0.53 kg per plant without biochar, but increased to between 0.25 and 0.57 kg/plant when treated with biochar as much as 5 t/ha. The average storage root weight per plant could be used to estimate fresh storage root yield with conversion based on population 40000 plants/ha, it is expected to obtain a sweet potato yield range of 8-21 t/ ha without biochar, whereas with biochar application 5 t/ha could produce 10-22.70 t/ha (Table 4). Tobacco biochar application could increase 8-45% of storage root yields compared without biochar (Table 4), except for Beta 1 and Boko which decreased when biochar was applied.

Table 4. Biommas dry weight, harvest index and storage root yield of 13 sweet potato cultivars with application of biochar (B_1 = 5 t/ha) and without biochar

No	Clone	Biomass dry weight (kg/plant)		Harvest index (%)		Storage root yield (t/ha)	
		B_0	B_1	B_0	B_1	B_0	B_1
1.	Kuningan Putih	0.17	0.22	56.60	65.17	12.33	17.95
2.	BIS OP-61-OP-22	0.19	0.21	76.64	80.31	21.00	22.70
3.	73-6/2	0.17	0.21	66.70	75.06	13.47	19.33
4.	Beta 1	0.18	0.18	40.91	38.44	13.12	12.50
5.	Beta 2	0.14	0.17	61.96	68.07	14.99	20.93
6.	Kuningan Merah	0.16	0.18	45.86	46.96	12.48	13.50
7.	73-OP-8	0.11	0.12	44.63	52.32	8.03	10.55
8.	BIS OP-61	0.20	0.23	43.34	45.26	9.25	11.16
9.	73 OP-5	0.20	0.21	64.97	69.59	18.60	21.75
10.	Sari	0.12	0.16	78.05	75.54	14.02	17.55
11.	Boko	0.17	0.17	53.09	52.52	11.46	11.36
12.	Jago	0.14	0.16	64.71	65.67	11.71	13.04
13.	BIS OP-61-♀-29	0.20	0.20	62.53	65.58	17.47	18.94

Table 5. Variance analysis of storage root weight, percentages dry matter, storage root dry weight, biomass dry weight, harvest index and storage root yield of 13 sweet potato cultivars with application of biochar (B_1 = 5 t/ha) and without biochar.

Source of variation	db	Mean Square: Storage root weight (kg/plant)		% Dry matter of storage root		Storage root dry weight (kg/plant)		Biomass dry weight (kg/plant)		Harvest Index (%)		Storage root yield (t/ha)	
Replication	2	0.059	**	2.36	ns	0.0058	**	0.0022	ns	1252.56	**	94.85	**
Cultivar (main plot)	12	0.056	**	96.20	**	0.0052	**	0.0052	**	946.57	**	89.76	**
Error (a)	24	0.006		5.05		0.0008		0.0010		202.79		10.15	
Biochar	1	0.080	**	2.69	ns	0.0075	**	0.0089	**	189.18	*	128.32	**
Cultivar x Biochar	12	0.004	ns	1.41	ns	0.0003	ns	0.0005	ns	22.03	ns	7.05	ns
Error (b)	26	0.005		1.42		0.0004		0.0007		29.12		8.39	

Tobacco biochar did not increase the percentage of storage root dry matter or sweet potato foliages (stover), conversely with storage root weight increased by application of biochar. Due to increasing the trait of storage root weight, so that it could improve the dry weight of storage root, dry weight of biomass and harvest index. The increasing of biomass dry weight and harvest index reached 0.07-34.46% and 1-17%, respectively (Table 6). The results of the tobacco biochar analysis showed that the biochar had a high pH value of 9.57 with N content of 1.85%, P_2O_5 1.88% and K_2O 2.5%, CEC 34.62 me/100g (PT Gudang Garam Kediri). Result of soil analysis in experimental plots planted with 13 cultivars of sweet potato after harvesting showed on plots given tobacco biochar 5 t/ha having a higher interchangeable potassium (Table 7). Biochar induced changes in soil properties such as cation exchange capacity and exchangeable cations (Kim et al., 2015). The condition of the soil where the research was conducted have some limiting factors, i.e. acid soil pH, very low organic C, total N, and available P contents (Table 1). The addition of biochar is expected to improve the availability of nutrients. Applivation of biochar 5 t/ha in this trial improved potassium exchangeable (Table 7).

Rainfall and sweet potato performance

The amount of rainfall and the number of rainy day distribution during the trial period was conducted, from March to July 2017 are presented in Figure 1. The rainfall was still relatively high at the beginning of the trial and very low at the end, this was quite beneficial for the sweet potato growth. The harvest index of all cultivars showed an increase when the biochar was applied. At the trial without biochar, their harvest indexes only ranged from 41.63 to 77.76% and increased to 43.85-81.01% when the biochar was added (Table 4), except for Beta 1, Sari and Boko (Table 4). Sweet potatoes are easy to produce with productivity between 20-40 t/ha of fresh storage root weight (Zuraida and Supriati, 2001; Saleh and Hartoyo, 2003), but in reality the productivity at the farmer level is still low, gaining only 10 t/ha (ILETRI, 2010). Likewise, the effects of this work showed that the likely output of all cultivars had not been reached until now. The sweet potato yield in this study reached in the range of 8 - 21 t / ha (Table 4). Application of biochar from tobacco industry waste with a dose of 5 t/ha could increase storage root yields ranging from 8-45%.

Table 6. Increasing of the storage root yield and harvest index of 13 sweet potato cultivars with the application of biochar (B_1 = 5 t/ha)

No	Clone	Percentage of increasing on biochar 5 t / ha (%)		
		Biomass dry weight	**Storage root yield**	**Harvest index**
1	Kuningan Putih	32.73	45.53	15.14
2	BIS OP-61-OP-22	8.43	8.08	4.79
3	73-6/2	27.39	43.56	12.53
4	Beta 1	-(0.26)	-(4.72)	-(6.04)
5	Beta 2	20.33	39.64	9.87
6	Kuningan Merah	10.15	8.19	2.40
7	73-OP-8	8.58	31.34	17.23
8	BIS OP-61	12.79	20.73	4.42
9	73 OP-5	7.29	16.98	7.10
10	Sari	34.46	25.19	-(3.22)
11	Boko	0.88	-0.92	-(1.07)
12	Jago	16.23	11.43	1.48
13	BIS OP-61-♀-29	0.07	8.41	4.88

Note: parentheses -(..) show a negative number (or decreasing)

Table 7. Exchangeable potassium measured on a plot after harvesting the sweet potato clone

No	Clone	Exchangeable potassium (me/100 g)	
		Without biochar (0 t/ha)	**With Biochar (5 t/ha)**
1	Kuningan Putih	2.249	2.401
2	BIS OP-61-OP-22	1.337	2.711
3	73-6/2	1.573	2.613
4	Beta 1	1.322	2.223
5	Beta 2	2.173	3.364
6	Kuningan Merah	1.623	4.108
7	73-OP-8	1.659	2.676
8	BIS OP-61	1.105	1.635
9	73 OP-5	1.690	2.280
10	Sari	1.882	2.216
11	Boko	2.351	2.972
12	Jago	1.110	1.182
13	BIS OP-61-♀-29	2.902	2.241

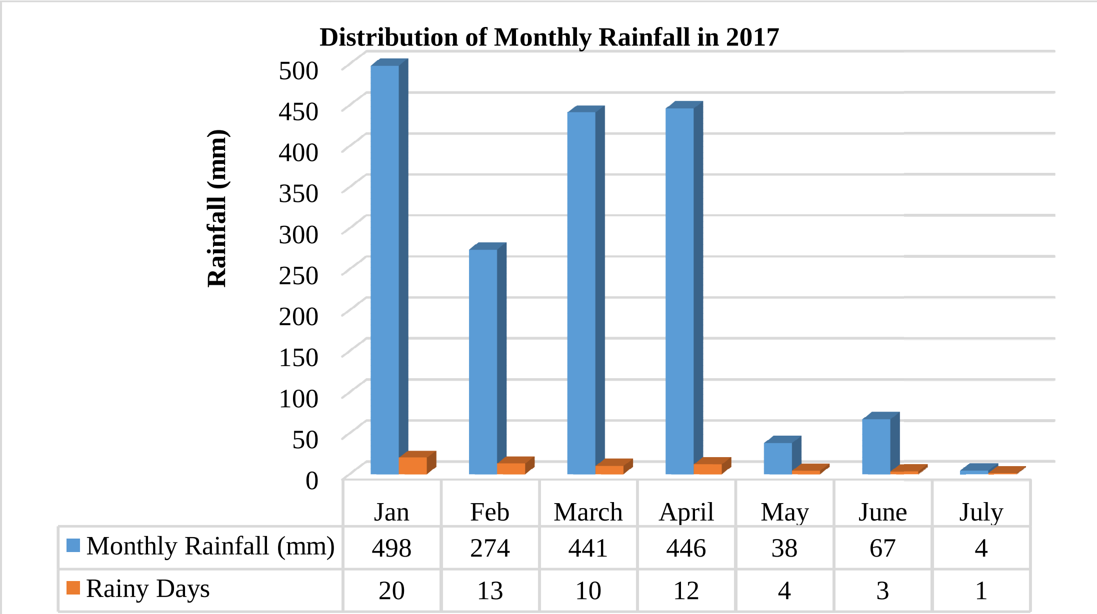

Figure 1. Distribution of rainfall and rainy days during the trial

The storage root yield had not been achieved as optimally due to the crop was harvested at the age of 3.5 months, should be a normal harvest age in the research area at least 4 months after planting. Besides that, it is suspected that there was another factor that limited the growth and yield of the sweet potato, namely the condition of soil fertility of the site where the research was done. Several plant growth limiting factors as seen from soil analysis (Table 1), the soil has a low pH (acid), very low levels of organic C, total N, and available P. Furthermore, there were possibly caused by the existing nutrient imbalances, namely K, Na and Mg were high, Ca was medium, while total N and available P were very low as shown in Table 1. The sweet potato takes up relatively large amounts of nutrients in the soil. According to Zhang et al. (2017) from 19 experiments, it is known that for every ton of sweet potato yield absorbs the amount of N, P_2O_5 and K_2O that each in the range of 2.30 - 7.58 kg N, 0.47 - 2.64 kg P_2O_5, and 1.59 - 11.47 kg K_2O. If it is assumed to produce 20 t/ha, the three nutrients must be available on the soil as much as 4.6-151 kg N, 9.4-52.00 kg P_2O_5 and 31.8- 229.40 kg K_2O per ha, respectively. The available nutrient elements come from fertilizers as well as those contained in the soil. The fertilizer given in this trial was Phonska (15 15 15) of 400 kg/ha, can provide as much as 60 kg N, 60 kg P_2O_5 and 60 kg K_2O. Therefore, from the applied fertilizer, the insufficient nutrients were N and K_2O, but since the K content in the soil was high, it is possible that the K element was not a limiting factor. The limiting factor at the experimental site was the N element, because the soil total N was very low. Calculating the availability of nutrients in the soil should take into account the factors that cause the nutrients to be unavailable, for example by the effect of soil pH and the adsorption of the P complex by Ca or Mg or Al-Fe in acid soil or its properties of antagonism between elements. The addition of 5 t biochar /ha had a positive effect on storage root weight or fresh storage root yield, storage root dry weight, biomass dry weight, and harvest index (Tables 3 and 4). Biochar is usually loaded with ammonium, nitrate, and phosphate content, so it can be a slow release fertilizer to improve soil fertility (Ding et al., 2016). Nitrogen content of tobacco biochar is 1.85% (results of laboratory analysis in this work), and then application of 5 t / ha provided 92.5 kg N for soil. The utilization of a dose of 5 t biochar /ha combined with 400 kg Phonska fertilizer (15 15 15) provided N amounts of 152.5 kg N / ha(= 92.5 kg N + 60 kg N) for soil. Nitrogen requirement for sweet potato to produce 20 ton storage root/ha is 4.6-151 kg N / ha. This computation is established on the trial of Zhang et al. (2017) which pointed out that to produce every ton of storage root yield requires nitrogen as much as 2.30 - 7.58 kg N. However, the calculation of nitrogen availability has not yet considered the nitrogen property which is volatile and leaching out. Long-term agricultural cultivation can lead to soil degradation, soil acidification, decline in soil organic matter, and severe soil erosion. Sitorus et al. (2011) mentioned that the soils with percentages silt fraction textures are in the range of 20-40% and the availability of P is very low, including under conditions of degraded soil. The soil of the experimental site has a silt fraction of 35%, very low organic C, total N, and available P contents (see Table 1), and the land has been used for intensive cultivation of plants, so that the degradation of the land has been already in the middle-heavy category. According to Ding et al. (2016), the decrease of the soil organic matter effect in decreasing soil aggregate stability, so that with very low levels of organic matter due to the soil becomes very vulnerable to erosion. Therefore, it is very important to improve soil degradation by a simple and sustainable method, by adding biochar as soil amendment. Biochar from tobacco industry waste gave a positive effect on fresh storage root yields of sweet potato cultivars.

Conclusion

Cultivars of sweet potatoes responded very significantly to 5 t/ha of tobacco biochar, especially with fresh storage root weight, storage root dry weight, biomass dry weight, harvest index and estimated fresh storage root yield per hectare. Increasing the storage root yield of sweet potato cultivars as a response of tobacco biochar application reached 8-45% compared without biochar.

Acknowledgements

The authors thank the Directorate General of Higher Education, the Ministry of Research, Technology and Higher Education of the Republic Indonesia for financially supporting through the PUPT Grant in 2017; as well as to Research Station of Brawijaya University and Indonesian Legumes and Tuber Crops Research Institute (ILETRI) that have been supported this research.

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