Research Findings

Sukadana site, East Lampung, Indonesia. Photo by A. Taufiq.

Response of Cassava (*Manihot esculenta* crantz.) to Potassium Application on Acidic Dryland in Indonesia

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Abstract

Lampung district is among the major cassava producers in Indonesia. The soils of the region are acidic, with very low cation exchange capacity and negligible organic matter content. Assuming that potassium (K) availability is a limiting factor for cassava cropping under the given conditions, the effects of K fertilizer at six seasonal doses (0, 30, 60, 90, 120, and 180 kg K_2O ha^{-1}) applied once (15 days after planting), and one treatment attributed to farmers' practice, were examined at two locations, Sukadana and Rumbia. All K fertilizer treatments were combined with 135 kg N ha^{-1} and 36 kg P_2O_5 ha^{-1}, except one treatment with 200 kg N ha^{-1} and 60 kg P_2O_5 ha^{-1}. Urea (46% N), SP36 (36 kg P_2O_5), and KCl (60% K_2O) were used as the source of N, P, and K fertilizer, respectively. While K doses hardly affected soil properties at harvest, they had obvious correlative influences

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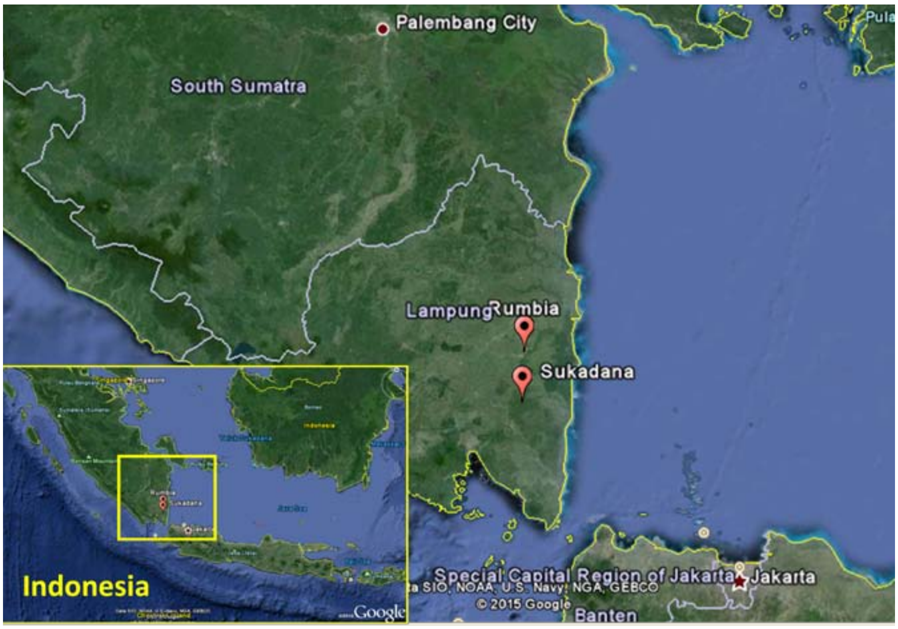
Note: IPI acknowledge Mr. Alexey Shcherbakov, former IPI Coordinator for Southeast Asia, for his contribution to this project.

on plant growth, organ K contents, and tuber yields. An optimum dose of 60-90 kg K_2O ha^{-1} seemed to satisfy cassava requirements in Sukadana, whereas the adequate dose in Rumbia was a bit higher. Nevertheless, some evidence indicates that the potential for K fertilization and other means to improve cassava production in this region is considerably higher. Measures, such as division of the seasonal K dose into many frequent applications, and supplementation of composted organic matter, in order to enhance soil fertility and cassava crop performance, are discussed.



Map 1. Map of Lampung, Indonesia, with the experimental sites Sukadana and Rumbia. Created using GoogleEarth™.

Introduction

Indonesia is the fourth cassava producer in the world after Nigeria, Brazil, and Thailand. BPS data (http://www.bps.go.id) showed that cassava harvested area during the last 10 years (2000-2011) decreased by 7.7%, from 1.28 to 1.18 million ha, but productivity increased by 62.4%, from 12.5 to 20.3 Mg ha^{-1}. Lampung, East Java, and Central Java Provinces are the main cassava producers, consecutively covering 26.3%, 17.7%, and 16.2% of the total area. Soil type in the main area is dominated by ultisol, alfisol, and inceptisol that are considered to be of marginal fertility (Suryana, 2007).

Cassava has multiple end-uses such as food, animal feed, and raw material for many industries hence the demand for this produce is likely to increase. In Indonesia, cassava has a strategic role for food security because 64% of total cassava consumption is for food. Recently, examinations have been carried out aiming to develop cassava as a raw material for biofuel.

In Lampung, cassava is mainly processed into flour. In 2013 the Ministry of Industry and Trade reported that there were 66 cassava flour producers in the region (contributing significant added-value and welfare impact in Lampung (Nugroho and Hanani, 2007)), with cassava production steadily increasing; Lampung Agricultural Office data showed that the cassava area in 2012 was 366,830 ha, 42.6% more than in 2011, and the production increased by 121%.

In Indonesia, cassava yield could attain 25-40 Mg ha^{-1} with good cultural practices (Wargiono *et al.*, 2006). Taufiq *et al.* (2009) reported that a cassava yield of 63 Mg ha^{-1} can be achieved by application of 70, 30, and 115 kg per ha of nitrogen (N), P_2O_5, and K_2O, respectively. The amount of nutrient uptake by cassava is high. Howeler (1981) found that with a fresh tuber yield of 21 Mg ha^{-1}, cassava absorbed 87, 37.6, and 117 kg ha^{-1} of nitrogen (N), phosphorus (P), and potassium (K), respectively. Wargiono *et al.* (2006) reported that at a yield level of 30 Mg ha^{-1}, cassava absorbed 147.6, 20.7, and 148.8 kg ha^{-1} of N, P and K, respectively. Amanullah *et al.* (2007) showed that fresh tuber yields ranging from 20-35 Mg ha^{-1} required quite stable nutrient rates of about 6, 0.75, and 6 kg of N, P, and K, respectively, per Mg ha^{-1}. These data revealed that K uptake was as high as that of N. Putthacharoen *et al.* (1998) showed that K removed by cassava in the harvested product was as high as K removal by maize and peanut.

The positive response of cassava yields to K application, particularly on poor soils, below the critical threshold of exchangeable K^+, 0.15 meq per 100 g soil (Howeler, 1981), has been well documented (Maduakor, 1997; Suyamto, 1998; Nguyen *et al.*, 2002; Ispandi and Munip, 2005). Also, the significant reduction in cassava yield in the absence of K fertilization during five consecutive cropping years was clearly demonstrated (El-Sharkawy and Cadavid, 2000). Furthermore, this yield reduction was considerably restrained by K application. Nevertheless, cassava response to fertilizer application may largely depend on the local soil properties and on farmers' practices. In the past, the majority of the Indonesian cassava growers did not apply any fertilizer (FAO, 2005). Those who did, used to apply high levels of N, less P, and no K fertilizer. Almost all cassava biomass is taken away from the field at harvest, thus soil fertility, especially K, is rapidly degraded. Therefore, it is important to optimize K dose to the local soil properties and cassava plant requirements.

The objectives of the present study are:

1. to examine cassava response to elevated K dose on two typical soils of Lampung, the main cassava growing region in Indonesia;
2. to demonstrate the contribution of K application to the cassava yield, as compared to the common K-deficient practices; and
3. to create awareness among farmers and extension workers on balanced nutrient management and cost and benefit ratio analysis.

Materials and methods

Location and planting date

Field experiments were conducted in farmers' fields in two locations (Map 1):

Sukadana Ilir Village, Sukadana Subdistrict, East Lampung District (5°2'38.63"S; 105°32'27.98"E) 46 m above sea level, Lampung Province. The crop was planted on 22 Nov 2012, and harvested on 20 Jun 2013.

Restubaru Village, Rumbia Subdistrict, Central Lampung District (4°46'15.30"S; 105°34'12.40"E) 47 m above sea level, Lampung Province. The crop was planted on 16 Nov 2012, and harvested on 14 Jun 2013.

Experimental set up

The trial consisted of seven treatments arranged in a randomized complete block design, and replicated three times. The treatment consisted of six doses of K fertilizer (0, 30, 60, 90, 120, and 180 kg K_2O ha^{-1}), and one treatment attributed as farmers' practice, with ten replicates per treatment. All K fertilizer treatments were combined with 135 kg N ha^{-1} and 36 kg P_2O_5 ha^{-1}, except one treatment with 200 kg N ha^{-1} and 60 kg P_2O_5 ha^{-1}. Urea (46% N), SP36 (36 kg P_2O_5), and KCl (60% K_2O) were used as the source of N, P, and K fertilizer, respectively. Nitrogen fertilizer was applied three times during the cropping season: 25, 50, and 25% of the annual dose, applied on 30, 90, and 120 days after planting (DAP). Phosphorus was applied on planting (50%), and once again on 90 DAP. Potassium was applied once, 15 DAP, dibbled in the soil at both sides of the plant and covered.

The farmer at Sukadana site applied 300 kg ha^{-1} Phonska (15-15-15-10, N-P-K-S, respectively) and 300 kg ha^{-1} urea (46% N). The farmer at Rumbia site applied 200 kg ha^{-1} Phonska (15-15-15-10) and 200 kg ha^{-1} SP36 (36% P_2O_5). All fertilizers were applied 30 DAP.

Implementation

The soil was cultivated twice without ridging. Stem cuttings of cassava of the in-situ variety were planted at distances according to the common local farmers' practice (farmers prefer short maturing cultivars that can be harvested within 6-7 months after planting). In Sukadana, the UJ3 cassava variety was planted at distance of 60 cm between rows and 50 cm within a row (plant density 33,333 plants ha^{-1}). In Rumbia, the UJ5 cassava variety was planted at a distance of 70 cm between rows and 50 cm within a row (plant density 28,570 plants ha^{-1}). Farmers in all locations usually plant cassava twice a year as a monocrop. The crops were harvested at seven months after planting (about 210 DAP). The dimension of the experimental plots were 7.2 x 8 m, and 7 x 8 m, in Sukadana and Rumbia, respectively.

Performance of Cassava of c.v UJ3 five months after planting, grown on acidic dryland at Sukadana site, East Lampung, without K fertilization (treatment no. 2=135 kg N ha^{-1} + 36 kg P_2O_5 ha^{-1} + 0 kg K_2O ha^{-1}). Photo by A. Taufiq.

Performance of Cassava of c.v UJ3 five months after planting grown on acidic dryland at Sukadana site, East Lampung, with K fertilization (treatment no. 4=135 kg N ha^{-1} + 36 kg P_2O_5 ha^{-1} + 60 kg K_2O ha^{-1}). Photo by A. Taufiq.

Bud reduction, to maintain two buds per plant, was executed at 30 DAP. Hand weeding was performed according to requirements 30, 60, and 90 DAP. Insect and disease control included the use of chemical pesticides as required.

Data collection

Initial analysis of soil properties at 0-20 cm and 20-40 cm soil depth included soil texture, pH, available P, exchangeable K, Ca, and Mg, and organic C. Nine soil sub-samples were collected systematically from the experiment site using a soil auger. The sub-samples from each depth were mixed together for the laboratory analysis.

Plant height was measured on five plants per plot at 30, 60, 90, 120, 150, 180 DAP, and at harvest. Dry weight of leaves, stems, and tubers were determined at harvest, taking three plants per plot. The samples were oven-dried at 105°C for at least 48 hours (until constant weight).

Potassium concentration in the leaf (including petiole), stem and tuber were determined at harvest. Also, the soil was randomly sampled from the root (tuber) zone at harvest at each plot for soil K analysis. Potassium in plant and in soil was determined using methods as described by Eviati dan Sulaeman (2009).

Fresh tuber yield was determined in each experimental plot using crops harvested from the six rows from the middle of the plot. Tubers were sampled and starch content was determined using acid hydrolysis methods (Nelson-Somogyi *et al.*, 1997).

Analysis of variance and mean comparison of collected data were processed using Statistix 3.0 statistical software (N.H. Statistical Software).

Results and discussion

Soil properties

Soil texture in topsoil (0-20 cm) and in subsoil (20-40 cm) layers at two sites was dominated by sand but a considerable fraction of clay was also present (Table 1). Soil pH at all sites was acidic to very acidic. Soil organic matter, as indicated by organic carbon (C) content, was very poor at all sites, even in the topsoil layer. Phosphorus availability in the topsoil was high above the critical threshold of 18 ppm P_2O_5 (Howeler, 1981), but lower than the threshold in the subsoil. Potassium availability (exchangeable K rate) at all sites was very low (Table 1), below the critical threshold of 0.15 meq 100 g^{-1} (Howeler 1981). In both sites, exchangeable Ca was above the 0.25 meq 100 g^{-1} critical level (Howeler, 1981).

Soil K status in the top layer at harvest (210 DAP) remained consistently very low, with a very slight response to the increasing K fertilizer doses (Table 2). This response was statistically significant only in Rumbia, where exch-K positively correlated (r=0.79*) with K fertilizer rate. Also, exch-K slightly increased from planting to harvest in Sukadana, but decreased in Rumbia (Tables 1 and 2). Interestingly, farmers' practices in both experimental sites gave rise to exch-K values equivalent to those of the moderate to high K doses (Table 2).

Crop growth and development

Cassava growth responded significantly to fertilization treatments at both sites as indicated by stem growth (Fig. 1), and by the above ground biomass accumulation (Table 3). While stem length gradually increased along with increased K rate, significant differences occurred quite late, when the largest K doses, 120 and 180 kg K_2O, gave rise to the highest stem length values. Accordingly, at the absence of any K fertilization, stem

Table 1. Soil properties of the experimental sites at Sukadana and Rumbia.

	Sukadana - East Lampung		Rumbia - Central Lampung	
	0-20 cm	20-40 cm	0-20 cm	20-40 cm
Sand (%)	40	61	81	79
Silt (%)	26	39	8	3
Clay (%)	34	0	11	18
Texture class	Clay loam	Silty loam	Loamy sand	Sandy loam
pH-H_2O (1:2.5)	4.5	4.7	5.1	4.9
pH-KCl (1:2.5)	3.9	4.1	4.2	4.2
C-organic (%)	0.95	0.72	1.18	0.79
P (Bray 1) (ppm P_2O_5)	27.8	8.45	49.2	11.4
Exch-K (meq 100 g^{-1})	0.05	0.09	0.07	0.12
Exch-Ca (meq 100 g^{-1})	0.36	0.54	0.75	0.48
Exch-Mg (meq 100 g^{-1})	0.20	0.30	0.28	0.20

Table 2. Effect of K fertilization on K availability in the top soil layer (0-20 cm) at harvest. Lampung, 2012-2013.

Treatment	Fertilizer treatment			Exchangeable K	
	N	P_2O_5	K_2O	Sukadana	Rumbia
	-------------------------*kg ha*$^{-1}$-------------------------			--------------*meq 100 g*$^{-1}$--------------	
T_1	Farmer(1)	Farmer	Farmer	0.07	0.06
T_2	135	36	0	0.06	0.04
T_3	135	36	30	0.06	0.04
T_4	135	36	60	0.08	0.06
T_5	135	36	90	0.07	0.05
T_6	135	36	120	0.08	0.06
T_7	200	60	180	0.08	0.07

Note: (1)Farmers' fertilization practices are detailed in the Materials and methods section.

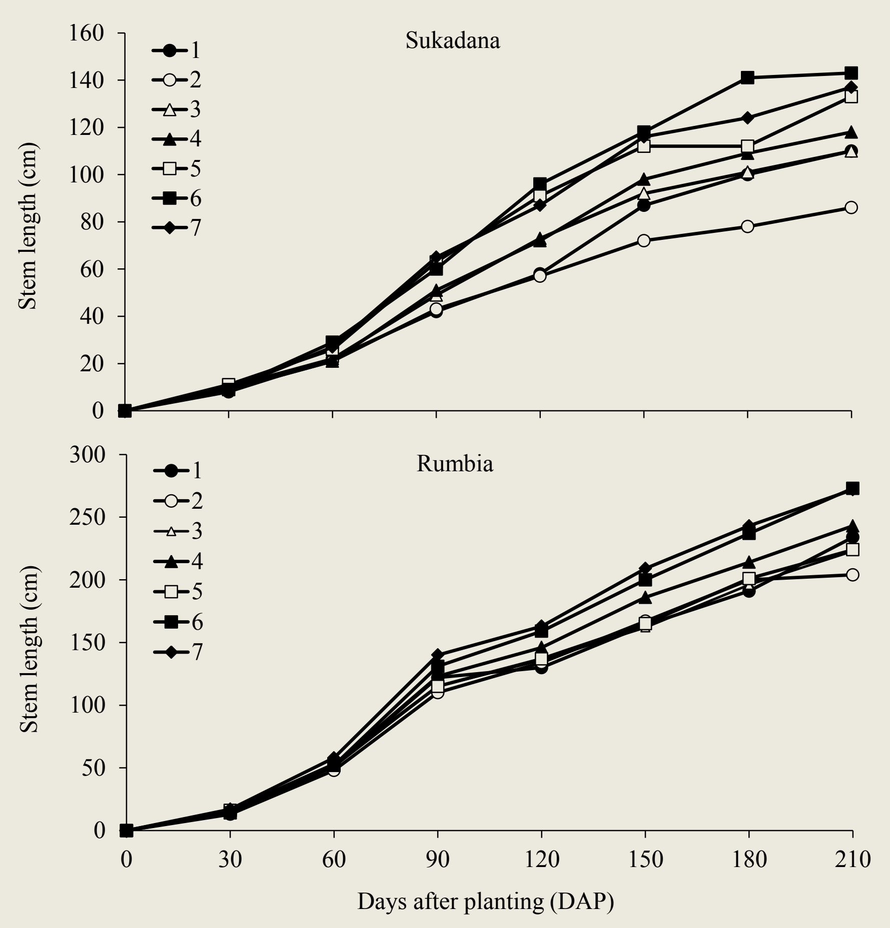


Fig. 1. Effect of K fertilization on cassava stem growth at Sukadana (cv. UJ3), and at Rumbia (cv. UJ5) during 2012-2013 cropping season (treatment codes as in Table 2).

Table 3. Effects of K fertilization on above ground dry biomass of cassava at Sukadana and Rumbia. Lampung, 2012-2013.

Treatment	Fertilizer treatment			Dry weight			
				Sukadana East Lampung		Rumbia Central Lampung	
	N	P_2O_5	K_2O	Stem	Shoot	Stem	Shoot
	----------------*kg ha^{-1}*----------------			-------------------------*Mg ha^{-1}*-------------------------			
T_1	Farmer[(1)]	Farmer	Farmer	1.7 bc[(2)]	2.1 bc	5.5 bc	6.1 bc
T_2	135	36	0	1.3 c	1.7 c	4.2 c	4.8 c
T_3	135	36	30	1.6 bc	2.1 bc	5.2 bc	5.8 bc
T_4	135	36	60	2.1 ab	2.5 ab	6.6 ab	7.2 ab
T_5	135	36	90	2.7 a	3.2 a	5.4 bc	6.1 bc
T_6	135	36	120	2.8 a	3.2 a	6.7 ab	7.4 ab
T_7	200	60	180	2.5 a	2.9 a	8.2 a	8.9 a

Notes: [(1)]Farmers' fertilization practices are detailed in the Materials and methods section.
[(2)]Different letters in a column indicate significant differences at $P < 0.05$.

length was significantly the least among treatments, particularly towards the end of the cropping season. Plant heights at farmers' practices did not significantly differ from those of the intermediate K treatments.

The dynamic of stem growth indicated that significant response of cassava to K fertilizer started quite late during the season and differed between the two sites or cultivars; in Sukadana, significant response to K fertilization could be observed not earlier than 90 DAP, while at Rumbia the response was delayed until 180 DAP.

Shoot dry weight of cassava significantly increased due to K fertilizer application (Table 3). At both sites, shoot dry weight significantly increased by 21-23% due to application of 30 kg K_2O ha^{-1}, and further increased by 47-50% where 60 kg K_2O ha^{-1} were applied, as compared to shoot dry weight in the absence of K fertilizer. The tendency of shoot dry weight to increase continued with K doses higher than 60 kg K_2O ha^{-1}, but it was not statistically significant. Farmers' practices gave rise to shoot dry matter similar to those obtained with the application of 30 kg K_2O ha^{-1} in both sites, somewhat higher than with the absence of K fertilization.

At harvest, stem dry weight was the dominant component determining shoot dry weight, both displaying similar patterns (Table 3). Leaves remaining on the plants at harvest assembled about 15% of the total foliage produced during the cropping season. Therefore, foliar biomass at harvest could not serve as an indicator for K influence of dry weight accumulation. Anyway, dry weight of leaves at harvest was 0.4-0.5 Mg ha^{-1} at Sukadana site and 0.6-0.8 Mg ha^{-1} at Rumbia site, showing no significant differences between the fertilization treatments.

No deficiency symptoms could be observed in the leaves at 30 DAP in all treatments at both sites. These began to occur at 60 DAP, when plants grown in the absence of K fertilizer had smaller leaves compared to fertilized plants, with no further symptoms. From 90 DAP until harvest, plants grown without K fertilizer were shorter, had smaller leaves (data not shown), and exhibited typical chlorosis symptom on leaf margins.

Fertilization effects on organ K and starch contents

Leaf K content at harvest was significantly correlated with the seasonal K doses applied, in both experimental sites (Fig. 2; Table 4). Under zero or low K dose, leaf K content was about 1% of leaf dry matter, while it reached 2.4% under the highest K dose. Stem K content also corresponded with the applied K dose, but to a lesser significance, displaying much smaller values that ranged between 0.4 and 0.9% (Table 4; Fig. 2). Tuber K content at harvest was even smaller, ranging between 0.2 and 0.4%, and it was correlated with a K dose up to 90-120 kg K_2O ha^{-1}, above which it decreased (Fig. 2). Farmers' fertilization practices gave rise to leaf, stem, and tuber K content values equivalent to those of the intermediate-to-high K doses (Fig. 2). Some correlation occurred between leaf and stem, and between leaf and tuber K contents (Table 4).

Tuber starch content at harvest did not show any significant response to the K doses applied (Fig. 2; Table 4). In Sukadana, it ranged between 25 and 28% of fresh tuber weight, and 31-34% in Rumbia, irrespective of K dose. No significant correlations were observed between K contents in above ground organs and tuber starch (Table 4).

Tuber (storage roots) yield

In the absence of any K fertilization, tuber fresh and dry matter yield were significantly low at both experimental

Table 4. Coefficients of linear correlations between seasonal K dose and cassava leaf, stem, and tuber K contents, and tuber starch content at harvest, in Sukadana and Rumbia, 2012-2013.

Experiment site	Variables	K_2O dose	K leaf	K stem	K tuber	Starch
Sukadana	K_2O dose (kg ha^{-1})	1.00	-	-	-	-
	K leaf (%)	0.95**	1.00	-	-	-
	K stem (%)	0.67*	0.60*	1.00	-	-
	K tuber (%)	0.74*	0.65*	0.23	1.00	-
	Starch (%)	0.53	0.61	0.09	0.38	1.00
Rumbia	K_2O dose (kg ha^{-1})	1.00	-	-	-	-
	K leaf (%)	0.71*	1.00	-	-	-
	K stem (%)	0.85*	0.84**	1.00	-	-
	K tuber (%)	0.86**	0.68*	0.78**	1.00	-
	Starch (%)	-0.01	0.40	0.32	0.04	1.00

Note: n=10; * and ** indicate statistical significance at 5% and 1% levels.

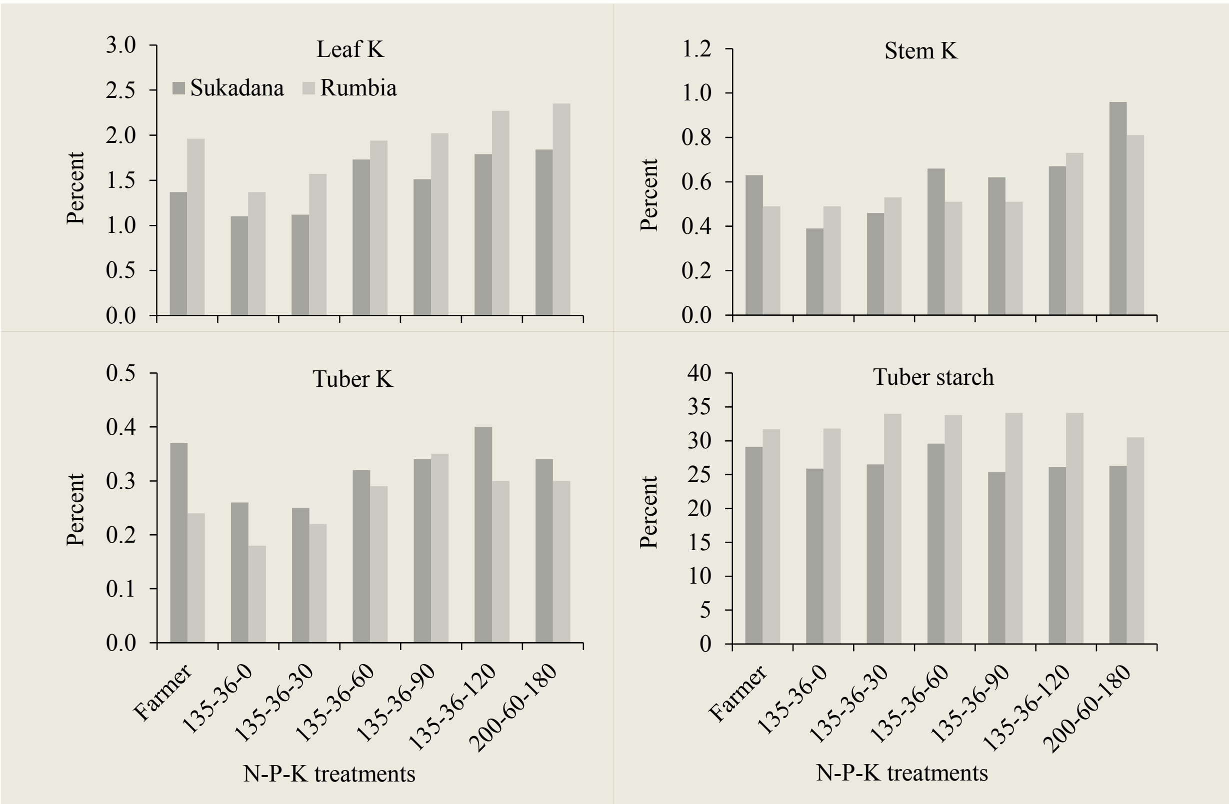


Fig. 2. Fertilization effect on cassava leaf, stem, and tuber K content (% of dry matter), and tuber starch content (% of fresh weight) at harvest, in Sukadana and Rumbia, 2012-2013.

sites (Table 5). At Sukadana, the highest tuber yield, 47% more than at zero K, was obtained where 60 kg K_2O ha^{-1} was applied. Any further increase in K dose failed to produce significantly higher yields. At Rumbia, the highest yield was as a result of higher doses, 90 kg K_2O ha^{-1} for fresh tuber yield, and 120 kg K_2O ha^{-1} for dry matter yield, only about 15 and 25% more than at zero K, respectively. Further increases in K dose did not bring about any benefit. At both sites, tuber yields of farmers' practices were equivalent to those of the intermediate K applications, 30 and 30-60 kg K_2O ha^{-1}, giving rise to about 25% and 19% more dry matter yield than at zero K, in Sukadana and Rumbia, respectively (Table 5). The harvest indices were unaffected by K fertilization, being 0.8 and 0.7, at Sukadana and Rumbia, respectively.

Agronomic and economic efficiency

Agronomic efficiency of K fertilization at the Sukadana site reached its maximum at a dose of 60 kg K_2O ha^{-1}, 207 kg FTY per kg K_2O, and slowly declined at the higher K doses. At the Rumbia site, the peak of agronomic efficiency was much smaller, 83 kg FTY per kg K_2O and was reached already at 30 kg K_2O ha^{-1}, and declined with increasing K dose. At the Sukadana site, net return showed an optimum curve with a maximum of about $33 \cdot 10^6$ Indonesian rupee (IDR) ha^{-1} at a K dose between 60 to 90 kg K_2O ha^{-1}, and then declined steeply at further increasing K dosage (Fig. 3). In Rumbia, the initial (without K fertilizer) net return was higher, but increased very slowly in response to K dose up to about $28 \cdot 10^6$ IDR ha^{-1} at a K dose of 120 kg K_2O ha^{-1}.

Table 5. Effects of K fertilization on fresh tuber yield (FTY) and dry tube yield (DTY) of cassava crop at Sukadana and Rumbia sites, Lampung, 2012-2013.

Treatment	Fertilizer treatment			Tuber yield			
				Sukadana (cv. UJ3)		Rumbia (cv. UJ5)	
	N	P_2O_5	K_2O	FTY	DTY	FTY	DTY
	kg ha⁻¹			*Mg ha⁻¹*			
T_1	Farmer[(1)]	Farmer	Farmer	31.3 b[(2)]	9.4 abc	30.9 a	13.9 ab
T_2	135	36	0	26.1 c	7.5 c	27.9 b	11.7 c
T_3	135	36	30	31.4 bc	8.6 bc	30.4 ab	13.3 b
T_4	135	36	60	38.5 a	11.1 a	30.3 ab	13.5 ab
T_5	135	36	90	37.8 a	10.4 ab	31.6 a	14.0 ab
T_6	135	36	120	35.0 ab	10.6 ab	32.1 a	14.6 a
T_7	200	60	180	36.5 ab	9.5 abc	32.7 b	14.7 a

Notes: [(1)]Farmers' fertilization practices are detailed in the Materials and methods section.
[(2)]Different letters in a column indicate significant differences at $P < 0.05$.

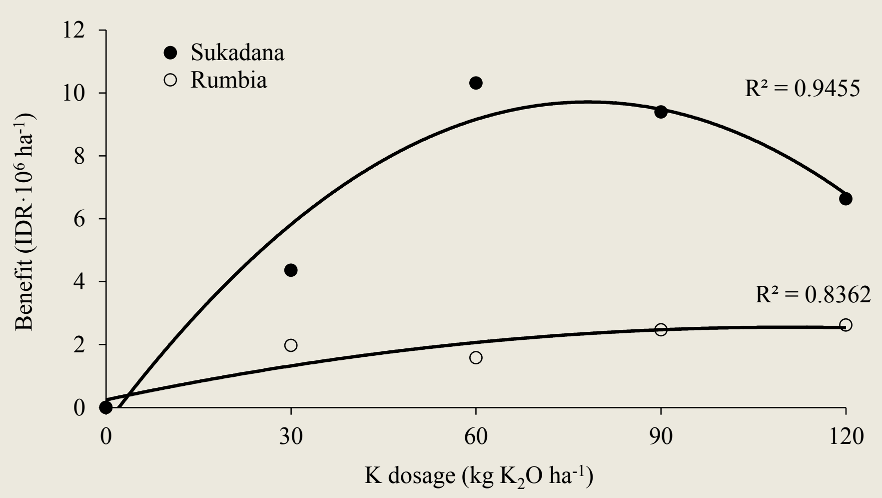


Fig. 3. Effect of K fertilization dose on the net return from cassava at Sukadana and Rumbia, Lampung, Indonesia, 2012-2013.

Discussion

Sandy soils, such as those that characterize the two experimental sites of the present study, usually favor the cultivation of tuber crops like cassava. When soils also comprise a considerable fraction of clay (Table 1), cation exchange capacity (CEC) is not expected to significantly restrict cropping. However, in both sites, soils were very acidic, and furthermore, were incredibly poor with organic matter (OM). The combination of high sand fraction, low soil pH, poor OM content, intensive rainfall (about 1800 mm during the growing season), and repeated land exploitation has brought about extremely low values of CEC, particularly of exch-K (Table 1), far below Howeler's thresholds (Howeler, 2002). Therefore, it has been postulated that K availability might be a major limiting factor for cassava cultivation in the region. Where most cassava growers use very little K fertilizers, an in-situ demonstration for the beneficial effects of K fertilization on cassava yield was required.

Some differences that occurred in plant performance and FTY between the two sites could be attributed to significant cultivar-dependent differences rather than to slight differences in soil properties. Farmers in Sukadana preferred cv. UJ3 variety (named also 'Thailand'), while cv. UJ5 ('Kasetsart') was preferred in Rumbia. UJ3 grows faster, produces higher FTY and obtains a higher harvest index than UJ5 (0.8 vs. 0.7, respectively).

In contrast, UJ5 tubers display significantly higher dry matter content (starch), 44 vs. 36%, and consequently, it redeems a higher price than UJ3 (in the 2013 season, 910 vs. 880 IDR, respectively). Therefore, in light of these embedded differences, the discussion here will be focused on some principal aspects of K fertilization as they relate to environmental conditions.

Indeed, K fertilization contributed significantly to plant growth (Fig. 1; Table 3) and FTY (Table 5). Soil K availability at both sites was originally very low, leaving no doubt that the application of K fertilizer at almost any dose was responsible for improved cassava growth, as indicated by plant height, and by stem and shoot dry weight. Apparently, a response curve could be illustrated, determining a seasonal dose ranging from 60-90 kg K_2O ha^{-1} as the optimum level (Table 5; Fig. 3) for K fertilization of cassava in Lampung district. Nevertheless, some evidence indicates that the potential of K fertilization and other means to improve cassava production in this region is considerably higher.

The maximum cassava yields obtained in the present study ranged from 30-40 Mg ha^{-1}. These are generally within the upper range of yields reported for cassava in various conditions of soil and fertilization regimes (Wargiono *et al.*, 2006). Nevertheless, reports of much higher yields (Taufiq *et al.*, 2009) may point to reasonably higher potential. What practical means can be taken in order to realize this potential?

In the present study, soil K status at harvest was hardly changed in comparison to initial values, even under the highest K doses (Table 2), indicating short-term effect of the fertilizer. Fertilizer application took place once and very early at 15 DAP. It's obvious influence on plant growth and on organs' K contents (Fig. 2), even at harvest, show that some of the applied nutrients were absorbed by the plant. Potassium is very mobile in the plant, redistributed among organs according to sugar translocation requirements and starch accumulation (Marschner, 1995). It may be postulated, however, that much of the K dose was leached away from the reach of plant roots quite early after application, as frequently happens in soils with poor CEC and high precipitation rates (Lambin and Meyfroidt, 2010). According to farmers' practices in the region, fertilizer application took place later, at 30 DAP, when the new fibrous roots penetrate into the soil and begin functioning (Alves, 2002). These practices gave rise to yield levels equivalent to those of the intermediate K doses. It may be concluded that K application should be carried out later than 15 DAP, and moreover, a division of the seasonal dose into frequently applied sub-doses throughout the season should be considered.

Lack of organic material is often associated with loosening of soil particles and consequent soil erosion and poor CEC (Don *et al.*, 2010; Prabowo and Nelson, 2015). The common practice to remove all above ground residues from cassava fields after harvest, although done for phytosanitary reasons, accelerates processes of soil degradation. In cassava, organic manurial treatments were shown to result in higher nutrient uptake by plants, higher tuber yields, and the least depletion of soil nutrients (Amanullah *et al.*, 2007). Embedding composted organic matter in ridges along the rows and application of supplemental fertilizers and soil amendments (e.g. gypsum to reduce soil acidity) directly to that strip would enhance root expansion into the new fertile soil space, thus improving nutrient uptake and crop performance. In the long-term, reiteration of such practices is expected to restore soil properties.

In conclusion, K application to cassava crop grown on acidic soils with very low CEC was shown to have obvious beneficial effects. Yet, there is considerable potential for further yield enhancement. Improving practical approaches to problems of soil fertility will pave the way to realize this potential.

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The paper "Response of Cassava (*Manihot esculenta* crantz.) to Potassium Application on Acidic Dryland in Indonesia" also appears on the IPI website at:

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