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Optimizing Crop Nutrition

Editorial

Dear readers,

It is quite plausible that urban consumers do not consider that the coffee they sip first thing in the morning, and later during the day, starts its growth on a bush requiring large amounts of fertilizer. In fact, efficient use of fertilizer applied to Robusta coffee (*Coffea robusta*), grown in the highland region of Vietnam, produces significantly better coffee bean yield and quality - and therefore a better cup of coffee as well as better income for farmers. You can find out more about how this is achieved in a paper included in this issue.

Cassava (*Manihot esculenta*) is the star crop of this edition of *e-ifc*. This versatile, multi-purpose root crop can be used for food and various starch industries and can provide yields in excess of 50 tonnes per ha. Although cassava plants are able to grow on marginal, infertile soils with proper fertilization practices, its yield can rise dramatically. Cassava is particularly important in Indonesia, and in this edition you can read details of our IPI potash experiment there.

It is not every day that a mineral is mined from deep within the earth's crust and used as a plant nutrient; yet this has been done by potash producers in Europe since the second half of the 19th century. Recently, in the UK, a new (if a natural mineral can be called 'new') potash mineral has been mined and used as a fertilizer. Polyhalite is a potash fertilizer containing almost one quarter of the potassium in comparison to potassium chloride (KCl), but it also contains sulfur, magnesium and calcium. In this edition, we bring you the very first report on the use of Polyhalite on mustard and sesame in India. It is fascinating to learn about the behavior of a new fertilizer, and we look forward to bringing you many more interesting reports from other countries and crops around the world in future issues of *e-ifc*.

In the meantime, happy reading.

Hillel Magen
Director

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A pomegranate fertilizer experiment in soilless culture. Photo taken at the Center for Fertilization and Plant Nutrition (CFPN), Gilat, ARO, Israel.

Research Findings

Fertilization at Cu Mgar, Dac Lak, Vietnam. Photo by Tran Minh Tien.

Potassium Application and Uptake in Coffee (*Coffea robusta*) plantations in Vietnam

Tran Minh Tien(1), Ho Cong Truc(2), and Nguyen Van Bo(3)

Abstract

Coffee (*Coffea robusta*) is an important crop for Vietnam. Vietnam obtains the second highest yield of coffee in the world, just after Brazil, with around 1.2 million Mg per year. Exported coffee products contribute significant income to the Vietnamese economy, about US$3.62 billion in 2014 alone. Most coffee plantations in Vietnam are located in the Central Highland region on two main soil types: (i) Reddish brown soil derived from basic and intermediate magmatic rocks (basaltic soil); and (ii) Reddish yellow soil derived from acid magmatic rocks (granite soil). The poor nature of both soil types, but particularly that of the granite soils, poses significant challenges when considering plant nutrition strategies and practices. Therefore, special concern has been devoted to nutrient requirements and fertilization dosage and regime. In a previous study, an annual dose of 600 kg

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potassium chloride (KCl) was suggested as an optimum suitable for coffee plantations in the region, yielding 3.5-4 Mg ha^{-1} coffee beans. However, this amount is twice the theoretical K required to obtain a similar yield range. The objectives of the present follow-up study were: 1) to elucidate whether the excess K quantities enriched the orchards' soils, were absorbed and accumulated in the trees, or were lost to the environment; 2) to suggest ideas for testing and improving fertilization efficacy under these particular environmental conditions. The results demonstrate that the soils of the Central Highlands of Vietnam are rather poor, undergo active erosion processes and possess very low cation exchange capacity (CEC), with restricted ability to store and provide nutrients. Extensive nutrient leaching takes place during the rainy season. Nutrient uptake by trees is very limited to brief occasions, whereas large portions of the nutrients applied are leached away and lost. We suggest that a substantial reduction in fertilizer applications is considered during the rainy season. Most nutrition requirements should be supplied during the dry season, along with frequently scheduled irrigation. Such a regime, if implemented, may improve fertilization efficacy, reduce K inputs, and bring about a further increase in coffee yield.

Introduction

In the Central Highland region in Vietnam, an area of about 500,000 ha is under coffee plantations. Coffee is a major economic engine for the local developing agricultural sector. Therefore, much effort is made to improve the region's coffee yield and quality. Vietnam has unique achievements in developing robusta coffee (*Coffea robusta* or *canephora*) as a high yielding cash crop, which has been made possible by intensification methods, including irrigation during the dry season (Marsh, 2007).

The nature of the soil may be crucial to the quality and productivity. Soils in Vietnam were developed from many different parental rocks including basalt, gneiss, granite, shale, limestone, lava and volcanic ashes. Soil texture may vary from heavy loam to sandy soils with no obvious effects on coffee production as long as the soil layer is deep (at least 0.7 m), easily drained (belowground water deeper than 1 m) but porous enough (64%, bulk density 0.9-1.0 g cm^{-3}, and particle density about 2.54 g cm^{-3}) to hold considerable levels of water, air, and nutrients (Hoang Thanh Tiem 1999). Studying suitable soil properties for coffee, Nguyen Tri Chiem and Doan Trieu Nhan (1974) showed that coffee yields are strongly affected by the content of organic matter, total nitrogen (N), total potassium (K) and available phosphorus (P).

In general, there are two main soil types for coffee production in the Central Highlands of Vietnam: reddish brown soil derived from basic and intermediate magmatic rocks, as a weathering material of basaltic rocks (basaltic soils); and reddish yellow soil derived from acid magmatic rocks (granite soils).

The basaltic soils are distributed from north to south and occupy 27.8% of the total Highland area (about 1.53 million ha). Basaltic soils are relatively rich with organic matter, which holds about 95% of the total N content. The residual inorganic N is vital for the crop and requires careful replenishment. Basaltic soils are quite rich with total P content, which is evenly distributed among layers. However, available P is lower than required due to rapid precipitation of aluminum (Al) and iron (Fe) phosphates. Potassium, calcium (Ca), and magnesium (Mg) contents are poor, mainly due to the original bedrock composition. In spite of their high clay content (50-60%), these basaltic soils have a low dispersion degree, low cation exchange capacity (CEC), and low K, Ca, Mg and boron (B) content (Nguyen Vi and Tran Khai, 1978). Furthermore, these cations are rapidly leached. The rigid acidic nature of the basaltic soil largely restricts attempts to enrich this soil with cations, hence frequent applications are required. The high porosity of the basaltic soils provides relatively high maximum field moisture capacity, on the one hand, but the moisture fades away quite rapidly, on the other hand. Irrigation requirements and frequency are, therefore, higher than might be expected.

The granite soils occupy the largest area, more than 60% of the Highlands (3.62 million ha). These soils possess light texture, loose structure, low clay and high sand contents, and are poorly aggregated. The retaining capacity of water and nutrients is low, thus nutrient loss is high. Similarly, these soils are highly susceptible to drought during the dry season. Soil acidity is high throughout its profile, pH_{KCl} ranges from 3.5 to 4.5. Consequently, these soils are very poor with organic matter and nutrients, including N, P, K, Ca, Mg, and microelements.

The nature of both soil types, but particularly that of the granite soils, poses significant challenges when considering plant nutrition strategies and practices. Therefore, special concern has been devoted to nutrition requirements and fertilization dosage and regime (Ton Nu Tuan Nam and Truong Hong, 1993; Truong Hong, 1997; Nguyen Van Sanh, 2009). In a previous article (Tran Minh Tien, 2015), optimizing K application in the Central Highland region of Vietnam was addressed. Six annual doses of K (MOP) application (0, 400, 500, 600, 700 and 800 kg KCl ha^{-1}) were tested on a uniform background of annual N and P doses. Coffee tree growth was sufficient and the yield was highest at 600 kg KCl ha^{-1}, with 3.99 and 3.55 Mg beans ha^{-1}, in basaltic and granite soil, which was 47.3% and 49.7% higher than with zero K application, respectively. Further increased K dosage failed to add any extra value. Potassium application improved vegetative growth, reduced fruit abortion, increased fruit and bean size, and reduced mealybug damage. Economic analysis also showed that profit was maximized at an annual K dosage of 600 kg KCl ha^{-1}.

Coffee harvesting at Dak Ha, Kom Tum, Vietnam.
Photo by Tran Minh Tien.

Water supply for coffee at Dak Ha, Kom Tum, Vietnam.
Photo by Tran Minh Tien.

Apparently, this K dose should be recommended to the region's farmers. Nevertheless, to obtain one Mg (tone) of coffee beans, Robusta coffee trees would require 30-35 kg N; 5.2-6.0 kg P_2O_5; 36.5-50.0 kg K_2O; and 4 kg CaO; 4 kg MgO depending on tree age and soil type (Jessy, 2011). Theoretically, a coffee bean yield of about 4 Mg ha^{-1} would require up to 320 kg KCl per hectare, about half the optimum annual dose determined by Tran Minh Tien (2015). What then happens to the surplus K?

The objectives of the present study were: 1) to elucidate, using data from our previously reported experiment (Tran Minh Tien, 2015), whether the excess K quantities enriched the orchards' soils, were absorbed and accumulated in the trees, or were lost to the environment; 2) If necessary, to suggest ideas for testing and improving fertilization efficacy in the particular environmental conditions prevailing at the coffee plantations in the Central Highlands of Vietnam.

Materials and methods

Experiments were carried out during three consecutive years (2012-2014) in two sites: Quang Phu town, Cu'Mgar district, Dak Lak province (12°49.5N; 108°5.3E, elevation: 480 m); and Dak Ha town, Dak Ha district, Kom Tum province (14°30.3N; 107°54.9E, elevation: 600 m). The two experimental sites are located in the Central Highlands of Vietnam and differ in their soil type. The soil in the Dak Lac province is a reddish-brown, derived from basic and intermediate magmatic rocks (basaltic soil), whereas the Kom Tum province is typified by a reddish-yellow soil derived from acid magmatic rocks (granite soil).

In each study site, a commercial phase plantation of Robusta coffee was used. Each experiment included six treatments with four replications, designed following the random completed block design (RCBD) method with 24 slots (180 m^2 or 20 coffee trees slot^{-1}). The total area of each experimental site was 4,320 m^2. The treatments included six levels of annual K (MOP) application: 0, 400, 500, 600, 700, and 800 kg ha^{-1}, on a uniform background of 652 and 667 kg ha^{-1} year^{-1} of N (urea) and P (fused-magnesium phosphate, FMP), respectively. MOP and urea were embedded at 5-10 cm below soil surface, while FMP was spread onto the soil surface under the tree canopy. The distribution of the fertilizer doses during the year is shown in Table 1.

Irrigation took place during the dry season from February to May, divided into four to five intervals with a total amount of 50-60 mm. Pruning was carried out twice a year in July, and in late December after harvest.

Soil samples were taken before and after each crop season to provide 96 samples each year. In the laboratory, the following parameters were determined (Nguyen Vy and Tran Khai, 1978): soil particle size; pH_{KCl}; organic matter (OM) content; total and available N, P, and K; exchange cations (Ca, Mg and K); and soil CEC.

Table 1. The distribution of fertilizer application during the year.

Fertilizer type	Time and amount of application (% of total)			
	Feb	May - Jun	Jul - Aug	Sep - Oct
MOP	15	25	25	35
Urea	15	25	35	25
FMP	0	50	0	50

Leaf samples were taken 30 days before and after K fertilizer application. In each plot, 10 leaves per tree were sampled from five trees. Indicative leaves were defined as the fourth couple, counting down from the top of the branch. In the laboratory, N, P, and K were determined by digesting samples with H_2SO_4 and HCl, then N content in samples was determined by Kjeldahl, K by Flame photometer and P by Spectrophotometer; Ca and Mg contents were determined by digested samples with HNO_2 and HCl, then determined by Atomic Absorption Spectroscopy.

Results and discussion

Analyses of the major soil properties before and after the crop season indicate that soil erosion processes are actually active, particularly in the granite soils, where the clay fraction declined significantly (Table 2). Furthermore, soil acidity increased during the season indicating that chemical degradation continued to take place. The organic matter content decreased in both types of soil, as well as N, P, and CEC, signifying the steady loss of soil fertility throughout successive crop seasons. These results support previous studies that document the problem of soil erosion in the coffee plantations of the Central Highlands in Vietnam (D'haeze *et al.*, 2005; Ha and Shively, 2005; Giungato *et al.*, 2008).

Evaluating the specific influences of K dosage on the relevant soil properties may suggest that, with the appropriate amounts, K availability in the basaltic soils can be maintained throughout the season. At the end of the season, after applying annual doses above 500 kg KCl, the total and available K_2O were equal to those at the beginning, and even slightly increased (Table 3). However, this phenomenon failed to occur with the most relevant parameter - the exchangeable cations - which significantly dropped during the season. Interestingly, the levels of exchangeable Ca and Mg, very important nutrients, declined even further. In the granite soils, any indications for positive effects of K application on its availability failed to show up (Table 3). Nevertheless, the major conclusion emerging from this data set refers to the basal levels of K availability in the two soil types, levels that are by far below any fertility measure. Thus, all plant requirements for K are supposed to be met by transitory deposits of fertilizer supplies, when they exist, due to the lack of any nutrient reserves, even temporarily, in the soil.

Nutrient uptake by the coffee trees was determined in the leaves, indicated by the differences in nutrient contents before and 30 days after application (Table 4). The effect of fertilization was clearly observed, as all nutrient levels increased significantly. The effect of fertilizer application on K content in the leaves

Table 2. Soil properties of coffee plantations in basaltic vs. granite regions before and after crop season.

Soil property		Basalt			Granite		
		Before	After		Before	After	
Clay	(%)	54.7	54.6	NS	14.4	13.6	*
Silt	(%)	36.7	36.5	NS	32.6	32.5	NS
Sand	(%)	8.6	8.7	NS	52.9	53.9	*
pH_{KCl}		4.24	4.24	NS	3.62	3.57	*
Organic content	(%)	4.86	4.64	*	3.07	2.93	*
N content	(%)	0.236	0.217	*	0.146	0.136	*
P_2O_5 content	(%)	0.24	0.23	NS	0.095	0.085	NS
Available P_2O_5	mg 100 g^{-1}	8.35	7.60	*	3.18	2.55	**
CEC	meq 100 g^{-1}	11.3	10.1	*	8.6	7.1	**

Note: * and ** indicate significant differences (at P=0.05, and P=0.01, respectively) before and after crop season within a soil type; NS indicates non-significant differences.

Table 3. Effects of annual K dose on soil properties of coffee plantations in the basaltic and granite soils, as measured before and after crop season.

	Annual KCl dose	K_2O				K		Ca		Mg	
		Before	After	Before	After	Before	After	Before	After	Before	After
	kg ha^{-1}	---------*Total %*---------		*Available mg 100 g^{-1}*		-----------------------*Exchangeable cations (meq 100 g^{-1})*	-----------------------				
Basaltic soil	0	0.10	0.06	15.0	10.1	0.09	0.05	0.8	0.5	0.6	0.4
	400	0.09	0.07	14.7	14.1	0.08	0.07	0.8	0.5	0.5	0.3
	500	0.08	0.08	14.8	14.3	0.09	0.07	0.9	0.5	0.6	0.3
	600	0.09	0.10	14.8	14.6	0.08	0.07	0.7	0.6	0.6	0.3
	700	0.09	0.09	14.9	15.1	0.09	0.08	0.8	0.6	0.5	0.4
	800	0.10	0.10	14.5	15.6	0.08	0.08	0.8	0.6	0.6	0.3
Granite soil	0	0.11	0.08	12.5	9.9	0.07	0.04	0.5	0.3	0.5	0.4
	400	0.10	0.08	12.8	11.1	0.07	0.04	0.5	0.4	0.5	0.3
	500	0.10	0.09	12.3	11.2	0.08	0.05	0.6	0.5	0.5	0.3
	600	0.11	0.10	12.7	12.0	0.08	0.06	0.6	0.3	0.4	0.3
	700	0.11	0.11	12.6	12.1	0.08	0.06	0.6	0.4	0.4	0.3
	800	0.10	0.10	12.8	12.2	0.07	0.05	0.6	0.4	0.5	0.3

Table 4. Leaf concentrations of N, P, Ca, and Mg prior to and 30 days after fertilizer application to coffee trees.

	Nutrient concentration in leaves (%)							
	N		P		Ca		Mg	
	Before	After	Before	After	Before	After	Before	After
Basaltic soil	2.74	2.87	0.10	0.12	0.93	1.06	0.21	0.28
Granite soil	2.64	2.77	0.09	0.11	0.91	1.03	0.21	0.27

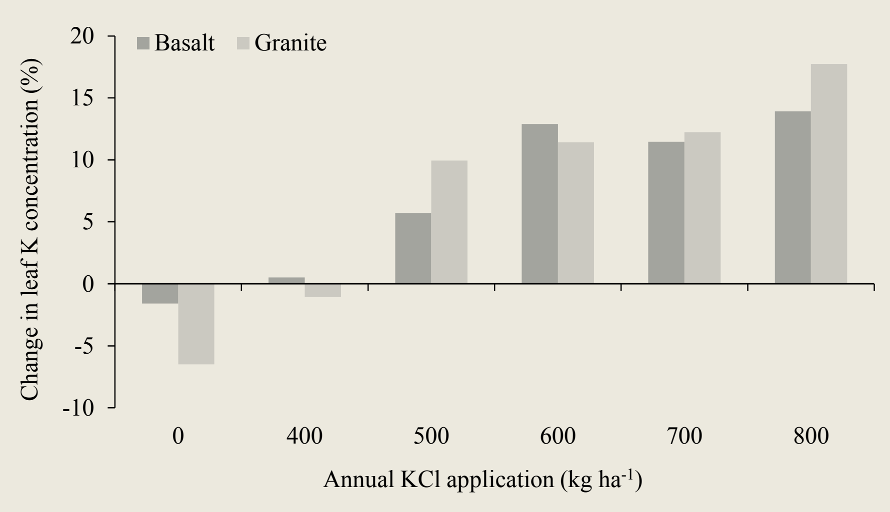

Fig. 1. The difference (%) between K leaf content in coffee trees prior to and 30 days after K application at six annual doses on basaltic and granite soils..

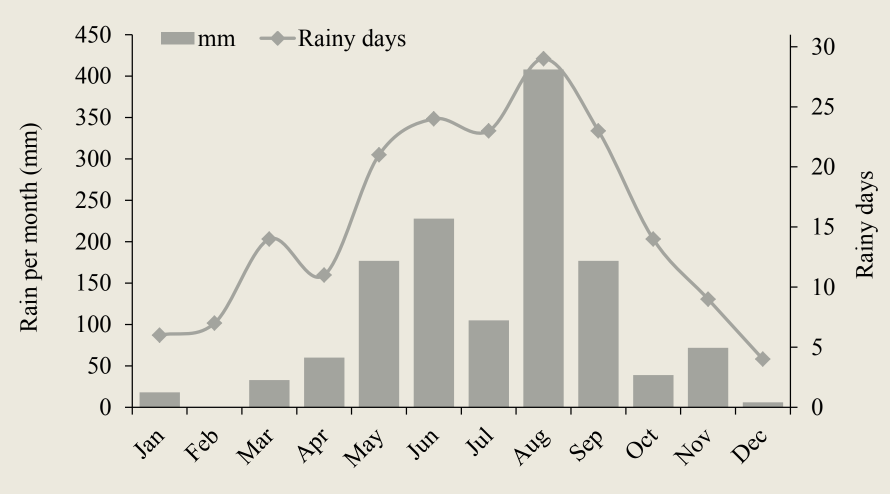

Fig. 2. Average monthly distribution of annual precipitation in Kon Tum, Central Highlands, Vietnam. *Source:* http://www.worldweatheronline.com/Kon-Tum-Ko-Nam-weather-averages/VN.aspx.

was obvious mainly at the lower doses (Fig. 1). At zero supply, K content declined by 2 or 7%, in trees grown on basaltic or granite soils, respectively. At an annual supply of 400 kg KCl, K content in leaves remained unchanged, but increased by 5 and 10% at 500 kg KCl, in basaltic and granite soils, respectively. A further increase in KCl dose brought about a much smaller response in leaf K content (Fig. 1). No interactions between K and the other minerals could be observed.

The response of nutrient contents in the leaves to fertilization is quite interesting as it provides direct evidence that mineral uptake by the trees did occur, at least in the short-term. The difference between the two soil types is demonstrated at the lower K doses: the response of K content in the leaves, either to shortage or to supply, is sharper in the granite soil due to its lower CEC and buffering ability. These differences vanish at the higher K doses, as does any further response to K content, which indicates a restricted ability of the trees to fully exploit nutrients above certain quantities.

Using leaf nutrient content as a reliable measure for the tree nutrient status requires a lot of calibration work, which has not been accomplished in coffee (Wairegi and van Asten, 2012). Thus, being quite clear on the short-term, the effectiveness of fertilizer application, as carried out in the present study, in the long-term is obscure. The bloom, and the developing and ripening fruit, have often been mentioned as major K sink organs (Mitchell, 1988; Jessy, 2011). Hence, further research is still required to quantify uptake and accumulation of nutrients in other organs of the coffee tree during the season and under various fertilization regimes.

Any conclusive remarks would be inconsequential, unless the effects of the climatic conditions in the region are considered where the precipitation regime (Fig. 2) plays a particular role. There are two distinct seasons: dry (October-April), and wet (May-September). A range of 1,200-1,500 mm, more than 80% of the annual rainfall, is expected during the five months of the wet season, falling almost daily. These quantities are far beyond the water requirements of coffee trees and the soil capacity to retain it. The consequences are intense soil erosion and rapid depletion of nutrients that are leached away. In contrast, plant water requirements during the dry season (80-150 mm month^{-1}) are far beyond rainfall (FAO, 2012; Amarasinghe *et al.*, 2015), and are hardly met through irrigation. In fact, the efforts made to irrigate the coffee plantations during the dry season already threaten the water resources of the region (D'haeze *et al.*, 2003).


Field meeting with farmers at Cu Mgar, Dac Lak, Vietnam. Photo by Tran Minh Tien.

When designing efficient fertilization regimes, rain intensity, leaching rates, and tree contemporary nutrient requirements and uptake must be taken into account (Amarasinghe *et al.*, 2015). Thus, any fertilizer application during the rainy season might be rather worthless, since most of the soluble nutrients are prone to be leached away soon after being applied. Preferably, most of the annual fertilizer dose should be applied during the dry season, simultaneously with irrigation; frequent applications of water and fertilizers during this season may significantly extend opportunities for nutrient uptake by the coffee trees, enhancing fertilization efficacy. Furthermore, two of the largest K consuming phases, fruit ripening and bloom (Forestier, 1969; Mitchell, 1988), occur in November and April, respectively, at both edges of the dry season. Targeting most of the fertilizer supply to the period between October and April is expected to support the most critical stage of fruit ripening, and also replenish the tree K reservoirs towards blooming.

In respect to the progressing soil erosion and the depletion of soil organic material, the recycling of postharvest waste material (mainly husks) should be considered. This material contains large amounts of nutrients, especially K (Dzung *et al.*, 2013). When done properly, composted postharvest waste may enrich the soil with organic material and improve its structure, as well as water and nutrient capacity. In addition, the use of slow-release fertilizer types should be considered, at least partially, in order to extend the period of nutrient availability, thus increasing the chances for their uptake by the tree.

Conclusions

The poor soils of the Central Highlands of Vietnam, basaltic as well as granite soils, undergo active erosion processes and possess very low CEC. Thus, their ability to store and provide nutrients is very much restricted. Additionally, an extensive nutrient leaching process occurs during the rainy season. Therefore, any amount of nutrient above the ability of a tree for immediate uptake is likely to be lost. The limited response of K leaf content to fertilization events and dose also indicate very short opportunities for K exploitation by the tree. Therefore, it may be concluded that almost half of the apparent optimum annual K dose for the region (Tran Minh Tien, 2015), 600 kg KCl ha^{-1} - twice the actual tree K requirements to obtain the highest yield in the present experiment - was leached away and lost to the environment. We suggest that a substantial reduction in fertilizer applications is considered during the rainy season. Most nutrition requirements should be supplied throughout the dry season, along with frequently scheduled irrigation. This regime may improve fertilization efficacy, reduce K inputs, and bring about a further increase in coffee yield.

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The paper "Potassium Application and Uptake in Coffee (*Coffea robusta*) plantations in Vietnam" also appears on the IPI website at:

Regional activities/Southeast Asia

Research Findings

Mustard field. Photo by IPI.

Effects of Polyhalite as a Fertilizer on Yield and Quality of the Oilseed Crops Mustard and Sesame

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Abstract

Mustard (*Brassica juncea)* and sesame (*Sesamum indicum* L.) are important oilseed crops in India. Both crops may benefit from sulfur (S) application. Polysulphate™ is the trade mark of the natural mineral 'polyhalite', which consists of four key plant nutrients - sulfur (S), potassium (K), magnesium (Mg), and calcium (Ca). In the present study, the effects of basal application of Polysulphate on the performance of mustard and sesame crops were examined in two distinct experiments. Each experiment included six fertilization treatments: T_1 - recommended doses of nitrogen (N) and phosphorus (P) (K omitted); T_2 - recommended NPK dose as control; T_3-T_5 - recommended NP + Polysulphate application at 20, 30, and 40 kg ha^{-1}, respectively, with compensation to the recommended K level; and, T_6 - recommended NPK + gypsum (with S dose equivalent to T_5). Potassium shortage reduced mustard and sesame grain yield by 12 and 17%, respectively, as compared to the control. In both crops, basal S application

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through Polysulphate brought about significant gains in grain yields with a linear response to the S dose, up to about 33% more at 40 kg S ha^{-1}, as compared to the control. Sulfur application appeared to increase the whole plant biomass, affecting most yield parameters, including oil concentration. Thus, mustard and sesame oil yields increased to 1,095 and 505 kg ha^{-1}, 39% and 43% more than the control, respectively. Sulfur application significantly increased K uptake by the plants, indicating a synergistic relationship between the two elements. Furthermore, S and K are translocated to the grains and are possibly involved in oil biosynthesis. It is concluded that S application at a macro-element dosage level significantly increases yields of oilseed species, such as mustard and sesame. The advantages of Polysulphate over gypsum as a basal fertilizer are discussed.

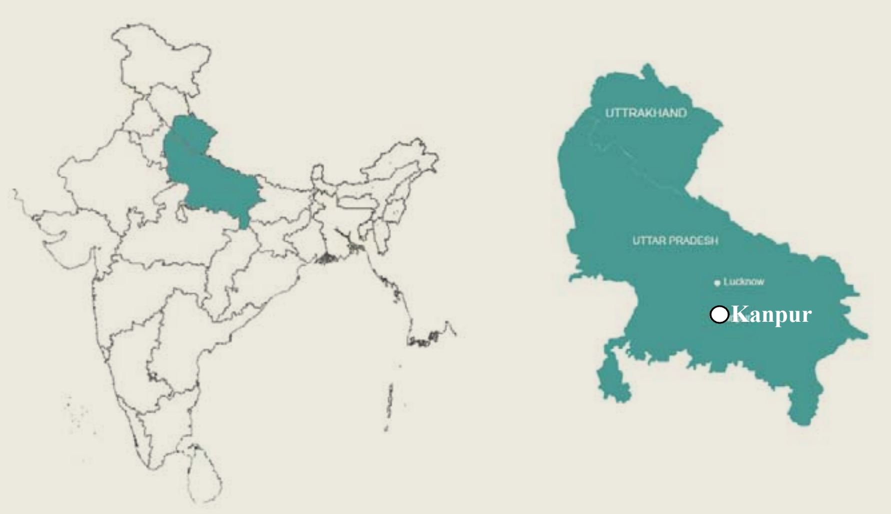
Photo 1. Polyhalite crystals. Photo by ICL Fertilizers.

Introduction

Human diets are changing and are becoming more reliant of vegetable oils. India is one of the major producers of many oilseed crops including groundnut, mustard, rapeseed, sesame seed, etc. Traditionally, Indians consume substantial quantities of edible oils that are mainly used for cooking. Among the oilseed crops in India, sesame (*Sesamum* indicum L.) is one of the earliest known crop based oils.. It contains 50% oil and 25% protein, as well as vitamins, minerals and antioxidants, and is grown across 1.74 million ha with a productivity of 421 kg ha^{-1} (OAS, 2009). The proteins in sesame seeds are remarkable for being rich in methionine, lysine, and tryptophan (Anilakumar *et al.*, 2010). These amino acids are essential for human nutrition, but are missing from a number of other vegetable protein sources, such as soy or cereals (Brosnan and Brosnan, 2006; Fukagawa, 2006). While significant efforts are being made to enrich various staple food crops with essential amino acids (Ufaz and Galili, 2008), sesame meal or flour can be used to enrich and provide a better nutritional balance to health food products (Prakash, 1985; El-Adawy, 1997; El-Adawy and Mansour, 2000; Quasem *et al.*, 2009). Methionine, a fundamental brick in protein biosynthesis, and cysteine, are both sulfur-containing amino acids, hence the availability of S is essential for normal growth and development of sesame plants. Furthermore, S-containing compounds contribute significantly to the aroma in heat-treated sesame seed oil and sesame butter (tahine) (Park *et al.*, 1995). Indeed, many studies have demonstrated the beneficial effects of supplemental S fertilization on crop growth and yield attributes in sesame (Rahul and Paliwal, 1987; Ghosh *et al.*, 1997; Tiwari *et al.*, 2000; Saren *et al.*, 2005; Puste *et al.*, 2015).

Sulfur is often associated with crops belonging to the Brassicaceae family that may possess significant amounts of S-containing secondary metabolites with various beneficiaries to plant protection, as well as to human health and diet (Stoewsand, 1995; Björkman *et al.*, 2011). The Brassicaceae include several oilseed crops, among which canola (rapeseed, *Brassica napus*) and mustard (*Brassica juncea*) are the most important ones economically. Mustard oil was once popular as cooking oil in northern India and Pakistan and is still the chief ingredient used in Bengali cuisine in Eastern India and Bangladesh. In the second half of the 20th century, the popularity of mustard oil declined in northern India and Pakistan due to the availability of mass-produced vegetable oils, but is still intricately embedded in the culture of the region. Sulfur and nitrogen (N) fertilization, and the balance between them, have a prominent effect on glucosinolate concentration in brassicaceous plants and an increased S supply has been shown to result in higher levels of total glucosinolates (Li *et al.*, 2007). Sulfur deficiency was shown to increase the disease susceptibility of canola to various fungal pathogens (Dubuis *et al.*, 2005) and this loss of antifungal activity was strongly correlated with the reduction of various glucosinolates, suggesting that they could have antimicrobial potential. An increase in S fertilization has also been shown to affect the content of polyphenols, such as flavonoids and phenolic acids (De Pascale *et al.*, 2007).

According to Khan *et al.* (2005), S is increasingly being recognized as the fourth major plant nutrient after N, P, and K. It is a constituent of amino acids cysteine and methionine, which act as a precursor for the synthesis of all other compounds containing reduced S (Marschner, 1995). Mustard (*Brassica juncea* L.) has the highest S requirement among various oilseed crops (McGrath and Zhao, 1996), but the amount required is not met due to the predominant use of N-based fertilizers (Zhao *et al.*, 1993). Thus, the shortage in S supplied to the crop lowers the use of other nutrients, particularly N. Several studies have established regulatory interactions between N and S assimilation in plants (Kopriva *et al.*, 2002). Sulfur availability regulates N utilization efficiency in plants, and thus affects photosynthesis, growth, and dry mass accumulation of crops.



Map 1. Map of Uttar Pradesh State in India (left), and the location of Kanpur city (right), where the experimental work took place. *Source*: http://office.incometaxindia.gov.in/kanpur/Pages/default.aspx.

Sulfur is readily available to plants only in sulfate (SO_4^{2-}), its inorganic form. Organic and elemental S must be converted to the inorganic form through microbial activity, a process depending on soil C:S ratio, temperature, and moisture (Boswell and Friesen, 1993). Sulfate may be applied as a fluid fertilizer (e.g. ammonium thiosulfate, 12-0-0+26S) through fertigation, although equipment and infrastructure required for this mode of application is seldom accessible or cost-effective. Calcium sulfate (gypsum) is an effective sulfur source, but not popular as a sulfur fertilizer because of its low sulfur content (15-18%). Other sulfur sources include fertilizers listed in combination with N, P, or K. Nitrogen-S materials include ammonium sulfate (21-0-0+24S), ammonium nitrate sulfate (30-0-0+15S), ammonium phosphate sulfate (13-39-0+7S), and ammonium phosphate nitrate (27-12-0+4.5S). Potassium-sulfur fertilizers include potassium sulfate (0-0-50+18S) and potassium magnesium sulfate (0-0-22+22S). Sulfate, as a negatively charged ion, is extremely mobile in the soil and is often leached from the root zone. Therefore, significant efforts are made to slow the release rate of sulfate to the soil (e.g. granulation), thus increasing energy inputs and product costs.

Polysulphate (Cleveland Potash Ltd., UK) is the trade mark of the natural mineral 'polyhalite' (Photo 1). Polyhalite occurs in sedimentary marine evaporates, consisting of a hydrated sulfate of K, Ca and Mg with the formula: $K_2Ca_2Mg(SO_4)_4{\cdot}2(H_2O)$. The deposits found in Yorkshire in the UK typically consist of K_2O: 14%, SO_3: 48%, MgO: 6%, CaO: 17%. As a fertilizer providing four key plant nutrients - S, K, Mg, and Ca - Polyhalite may offer attractive solutions to crop nutrition.

The objective of the present study was to evaluate effects and benefits of Polysulphate application in mustard and sesame crops under field conditions in Uttar Pradesh, India.

Two field experiments (mustard and sesame) were carried out on sandy loam soil at Oil Seed Farm Kalyanpur, C.S. Azad University of Agriculture and Technology Kanpur, Uttar Pradesh (India) during 2013-2014. Sub-surface (0-15 cm) soil samples were randomly collected before launching the experiment, and analyzed for their physico-chemical properties (Table 1).

Table 1. Major physico-chemical soil properties of the mustard and sesame experimental fields near Kanpur, Uttar Pradesh, India.

Properties	Mustard	Sesame
pH (1:2.5)	7.4	7.69
EC (1:2.5)	0.44	0.44
Available N (kg ha^{-1})	180	181
Available P (P_2O_5) (kg ha^{-1})	27.5	14.22
Available K (K_2O) (kg ha^{-1})	204	198
$CaCO_3$ (%)	1.2	1.21
Available S (kg ha^{-1})	16.8	16.6
Sand (%)	53.5	53.6
Silt (%)	22.5	22.2
Clay (%)	24	24.2

Mustard (var. Varuna) was sown on 11 November 2013, and harvested on 22 March 2014. Sesame (var. T-78) was sown on 20 July 2014, and harvested on 19 October 2014.

A similar experimental set was employed in both experiments: six treatments (T_1-T_6) were replicated three times in a randomized block design using 50 m^2 plots. Recommended doses of NPK and S were applied as per treatments. Full dose of P, K, S and half dose of N were applied at the time of sowing as a basal application. The remaining half dose of N was applied in two equal splits, at the stages of maximum tillering and flowering initiation. In treatments T_3-T_5, S and K were supplied through Polysulphate, and the required K dose was compensated with MOP. All agronomic practices and irrigation were carried out uniformly from time to time in each treatment. Further details are given in Table 2.

Table 2. Fertilization treatments included in the mustard and sesame experiments.

Treatment		N	P	K	S	Source of fertilizer
		-------------*kg ha^{-1}*-------------				
T_1	NP 100%	120	60	0	0	Urea and DAP
T_2	NPK 100% (control)	120	60	60	0	Urea, DAP, and MOP
T_3	NPK 100% + S 50%	120	60	60	20	Urea, DAP, MOP, and Polysulphate
T_4	NPK 100% + S 75%	120	60	60	30	Urea, DAP, MOP, and Polysulphate
T_5	NPK 100% + S 100%	120	60	60	40	Urea, DAP, MOP, and Polysulphate
T_6	NPK 100% + S 100%	120	60	60	40	Urea, DAP, MOP, and gypsum

Table 3. Effects of K deficiency (T_1) and of an increasing S dose through Polysulphate (T_3-T_5), or through gypsum (T_6), on the grain and stover yields of mustard and sesame. The harvest index (HI) presents the calculated ratio between the grain and the whole above ground plant biomasses.

Treatment	Mustard			Sesame		
	Yield		HI	Yield		HI
	Grains	Stover		Grains	Stover	
	----------*Mg ha^{-1}*----------			----------*Mg ha^{-1}*----------		
T_1	1.65	4.455	0.27	0.695	1.350	0.34
T_2	1.87	4.940	0.27	0.835	1.575	0.35
T_3	2.19	5.896	0.27	0.890	1.755	0.34
T_4	2.38	6.188	0.28	1.050	2.040	0.34
T_5	2.52	6.804	0.27	1.110	2.250	0.33
T_6	2.47	6.670	0.27	1.075	2.050	0.34
CD (P=0.05)	0.019	0.018		0.045	0.140	

Close to harvest, five plants of each plot were sampled, and yield properties (pods per plant, pod length, grains per pod, and weight of 1,000 grains) were determined. At harvest, grain and stover yield were determined for each plot, and the harvest index (grains to above-ground biomass ratio) was calculated. Oil was extracted by Soxhlet's method using petroleum ether as an extractant (Sawicka-Kapuskta, 1975) to determine oil concentration and yield. In mustard, S and K concentrations in the grains were determined on a fresh weight basis by digesting the samples in di-acid mixture of HNO_3 and $HClO_4$ (3:1). The digested samples were analyzed for K using a flame photometer (Jackson, 1967). S concentration was determined in the same extract by the turbidity method, as described by Chesnin and Yien (1951).

Results and discussion

In both mustard and sesame, grain and stover yields significantly declined by 12% and 17%, respectively, in the absence of K fertilization, compared to the control treatment (T_2) with the full NPK dose (Table 3; Fig. 1). The value of K fertilization in mustard has been recently demonstrated (Mozaffari *et al.*, 2012) and confirmed in the present study. However, the contribution of K fertilization to sesame cropping has been found insignificant in some previous studies (El-Aman *et al.*, 1998; Shehu, 2014). The results of the present study indicate an opposite situation or at least suggest considerable dependence on local edaphic conditions.

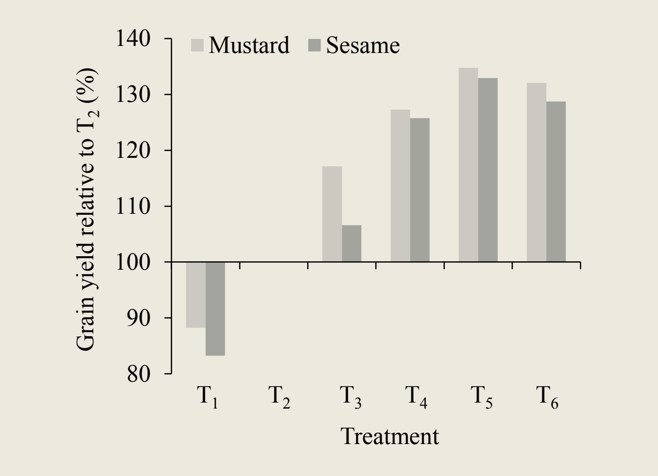


Fig. 1. Effects of K deficiency (T_1), S supplemented at 20, 30, and 40 kg ha^{-1} through Polysulphate application (T_3-T_5, respectively) or through gypsum (40 kg S ha^{-1}, T_6) on the grain yields of mustard and sesame relative to fertilization with the recommended doses of NPK (T_2). For further details, see the materials and method section and Table 2.

Yields of both crops rose significantly and steadily in response to the increasing S dose applied through Polysulphate in treatments T_3-T_5 (Table 3; Fig. 1). Mustard grain yield increased by 35%, from 1.87 Mg ha^{-1} at zero S application (T_2) to 2.52 Mg ha^{-1} at the maximum S dose, 40 kg ha^{-1} (T_5), applied with Polysulphate. A similar response was observed with sesame; grain yield increased by 33% at the maximum S level,

Photos 2. Polysulphate fertilizer in granular (left) and standard (right) grades. Photos by ICL Fertilizers.

1.11 Mg ha^{-1}, as compared to 0.835 in the control. The same S dose, when applied through gypsum (T$_6$), yielded slightly fewer grains, significantly at least for mustard (Table 3; Fig. 1).

These results are in agreement with an expanding list of evidence demonstrating the crucial role of S in oilseed crops (Boswell *et al.*, 1993; Zhao *et al.*, 1993; McGrath and Zhao, 1996; Ghosh *et al.*, 1997; Tiwari *et al.*, 2000; Saren *et al.*, 2005; Puste *et al.*, 2015), leading to the statement by Khan *et al.*, (2005) that S should be considered as the fourth macro-element required for plant growth and development.

The different fertilization treatments did not affect the harvest index (HI, Table 3); it was very stable at 0.27 and 0.34, for mustard and sesame, respectively. In other words, the remarkable effect on the yields was not an outcome of any shift in dry matter allocation between vegetative and reproductive organs. Instead, the whole plant biomass responded by further growth and development, manifested in pod number and size, as well as grain number and weight (Table 4). Oil concentration in mustard grains increased from 41.85% to 43.45%, and in sesame from 42.2% to 45.5%. In both cases, however, oil concentration was significantly lower with K and S deficiency (Table 4). Under the recommended NPK fertilization practice (T$_2$), oil yields were 786 and 352 kg ha^{-1}, for mustard and sesame, respectively. When K was not applied (T$_1$), oil yields declined by 12% in mustard and 22% in sesame crops (Fig. 2). The response of oil yields to Polysulphate application was dramatic (Fig. 2) providing 39% and 43% increases (T$_5$ vs. T$_2$) to more than 1,095 and 505 kg oil ha^{-1} for mustard and sesame, respectively. Sulfur applied through gypsum (T$_6$) also gave rise to a significant increase in oil yields, although to a lesser extent than with Polysulphate.

Mustard grains accumulate significant amounts of S and K, 10 kg ha^{-1} and 13.5 kg ha^{-1}, respectively, even when the application of these two nutrients is actually suspended (Fig. 3, T$_1$). Potassium applied at the recommended dose (T$_2$) drew 4 kg K ha^{-1} more into the mustard grains, as well as additional S, although the latter was not applied here.

The special interaction between K and S with regard to their accumulation in mustard grains became obvious when S was applied. Unsurprisingly, S increased in grains proportionately to the applied doses, up to about 20 kg ha^{-1}. Unexpectedly, K - the

Table 4. Effects of K deficiency (T$_1$), S supplemented at 20, 30, and 40 kg ha^{-1} through Polysulphate application (T$_3$-T$_5$, respectively), or through gypsum (40 kg S ha^{-1}, T$_6$), on major yield properties in mustard and sesame.

Treatment	Mustard					Sesame				
	Pods plant^{-1}	Pod length *(cm)*	Grains pod^{-1}	Grain wt *(g K^{-1})*	Oil *(%)*	Pods plant^{-1}	Pod length *(cm)*	Grains pod^{-1}	Grain wt *(g K^{-1})*	Oil *(%)*
T$_1$	195	4.4	9.8	4.85	41.85	97	2.8	43	3.1	39.5
T$_2$	197	5.1	9.9	5.05	42.02	105	2.9	47	3.4	42.2
T$_3$	202	5.8	10.2	5.35	42.45	115	3.0	48	3.6	43.5
T$_4$	204	6.2	11.8	5.36	42.22	125	3.1	58	3.8	44.2
T$_5$	204	6.2	11.8	5.36	43.45	130	3.2	60	4.0	45.5
T$_6$	201	6.0	11.7	5.35	42.14	120	3.1	50	3.7	43.9
CD (P=0.05)	1.84	0.26	0.36	0.04	0.51	4.7	-	3.2	0.12	1.1

Note: g K^{-1} = weight of 1,000 grains in grams.

Fig. 2. Effects of K deficiency (T_1), S supplemented at 20, 30, and 40 kg ha^{-1} through Polysulphate application (T_3-T_5, respectively), or through gypsum (40 kg S ha^{-1}, T_6), on the absolute oil yields of mustard (A) and sesame (B), and on their relative oil yields (C), as compared to T_2.

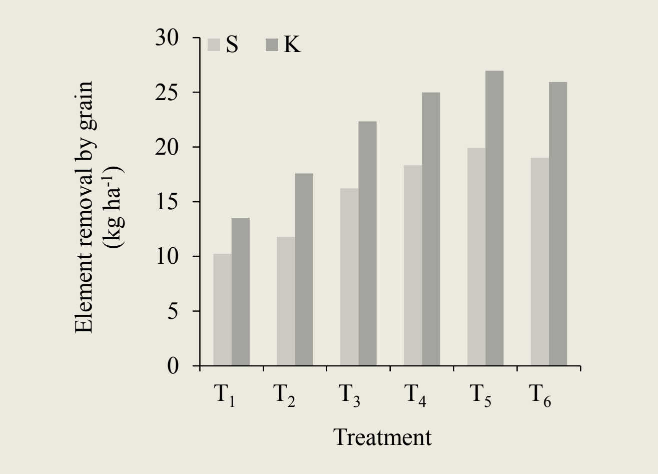


Fig. 3. Sulfur and K removal by mustard grains under K deficiency (T_1), recommended NPK dose (T_2), S supplemented at 20, 30, and 40 kg ha^{-1} through Polysulphate application (T_3-T_5, respectively), or through gypsum (40 kg S ha^{-1}, T_6). For further details, see materials and method section and Table 2.

dosage of which remained fixed in T_2-T_6 - continued to accumulate in the grains at a constant K:S ratio of 1.37 (Fig. 3). This pattern could not be attributed, for instance, to better K availability from Polysulphate, as a similar phenomenon was observed when gypsum was the S source.

Under K deficiency and no S supplement (T_1), the reduction rate in K content in the grains was significantly greater than the reduction in S content in the grains and in the grain and oil yields. Compared to the control, K content in the grains declined by 24%, whereas S content, oil yield, and grain yield declined by 14%, 12%, and 11.5%, respectively (Fig. 4). Nevertheless, when S was applied, grain and oil yields increased proportionately at similar rates, whereas S content in the grains grew at twice the rate. Also, K accumulation in the grains grew 50% more than the increases in grains and oil yields. These results show that in mustard, S is translocated to the seeds together with significant amounts of K. In addition to their demonstrated contribution to yield increases, these two elements may have significant roles in the production of secondary metabolites (Stoewsand, 1995; Fukagawa, 2006; Li *et al.*, 2007; De Pascale *et al.*, 2007). N and S interactions have been demonstrated contributing to growth, yield, and quality of oilseed crops (Zhau *et al.*, 1993; McGrath *et al.*, 1996; Tiawri *et al.*, 2000; Kopriva *et al.*, 2002; Li *et al.*, 2007). The results of the present study strongly indicate the existence of a synergistic relationship between K and S that leads to improved yields and quality in mustard and sesame.

The present study demonstrates the worth of Polyhalite as an effective S source for plants. Its compactness, relative to gypsum, together with the considerable content of other significant

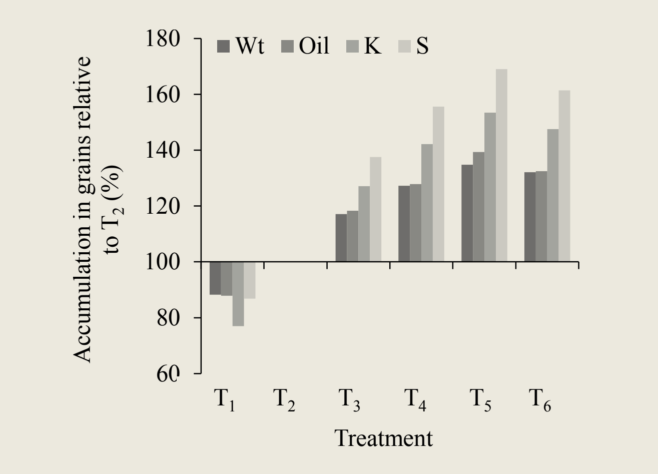


Fig. 4. Effects of K deficiency (T_1), S supplemented at 20, 30, and 40 kg ha^{-1} through Polysulphate application (T_3-T_5, respectively), or through gypsum (40 kg S ha^{-1}, T_6), on the accumulation of fresh weight, oil, K, and S in mustard grains, relative to fertilization with the recommended doses of NPK (T_2). For further details, see materials and method section and Table 2.

nutrients (K, Ca, and Mg) and the lack of Chloride, offer new solutions whenever basal S fertilization is taken into account.

Conclusions

- Potassium application is essential for obtaining reasonable grain and oil yields in mustard and sesame.
- Sulfur application at a macro-element dosage level significantly increases yields of oilseed species such as mustard and sesame.
- Sulfur and K seem to have a synergistic effect in oilseed species.
- Polysulphate is a considerable fertilizer for basal enrichment of soils with S, and also K.

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The paper "Effects of Polyhalite as a Fertilizer on Yield and Quality of the Oilseed Crops Mustard and Sesame" also appears on the IPI website at:

Regional activities/India

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

Taufiq, A.(1)(1a)**, Subandi**(1)**, and H. Suyamto**(1)

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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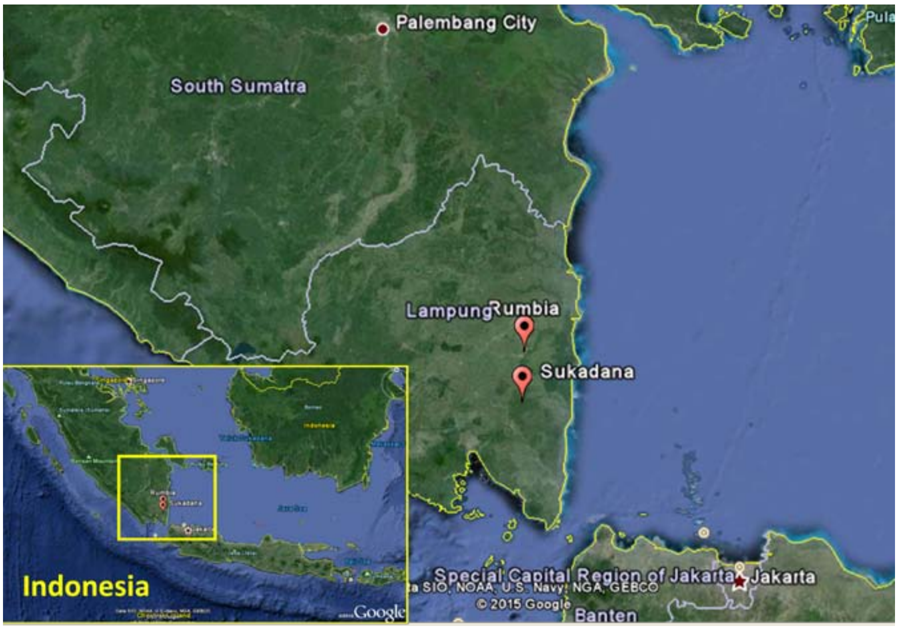
on plant growth, organ K contents, and tuber yields. An optimum dose of 60-90 kg K_2O ha^{-1} seemed to satisfy cassava requirements in Sukadana, whereas the adequate dose in Rumbia was a bit higher. Nevertheless, some evidence indicates that the potential for K fertilization and other means to improve 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.

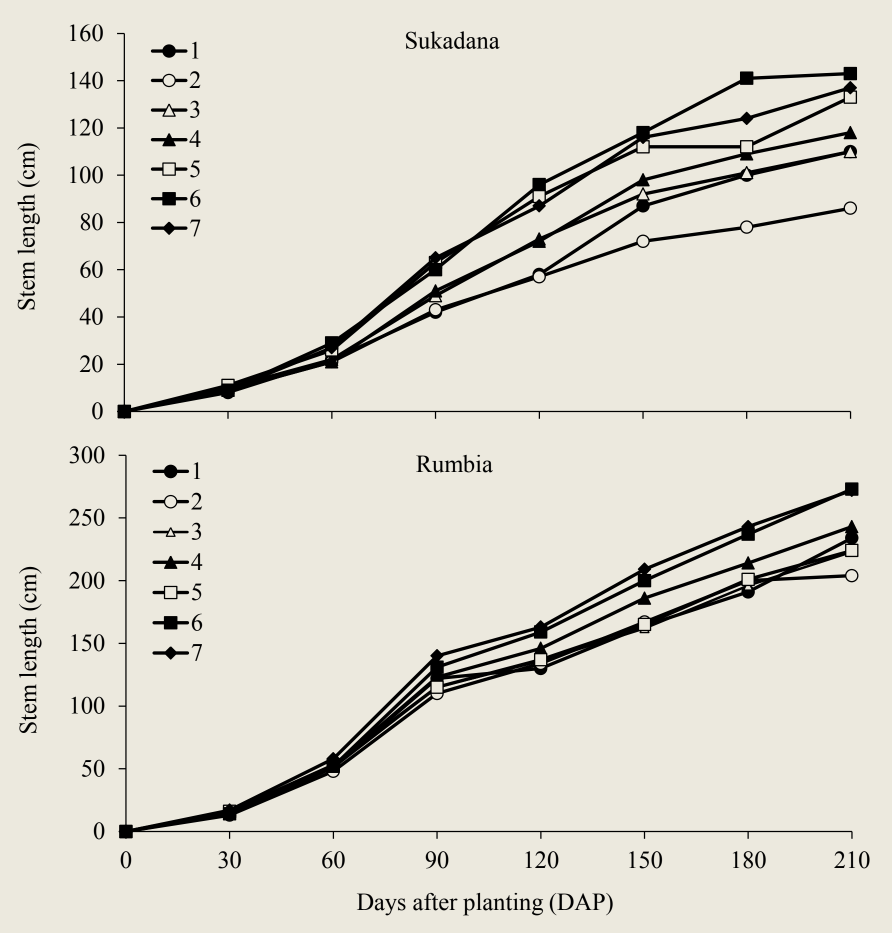


Fig. 1. Effect of K fertilization on cassava stem growth at Sukadana (cv. UJ3), and at Rumbia (cv. UJ5) during 2012-2013 cropping season (treatment codes as in Table 2).

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.

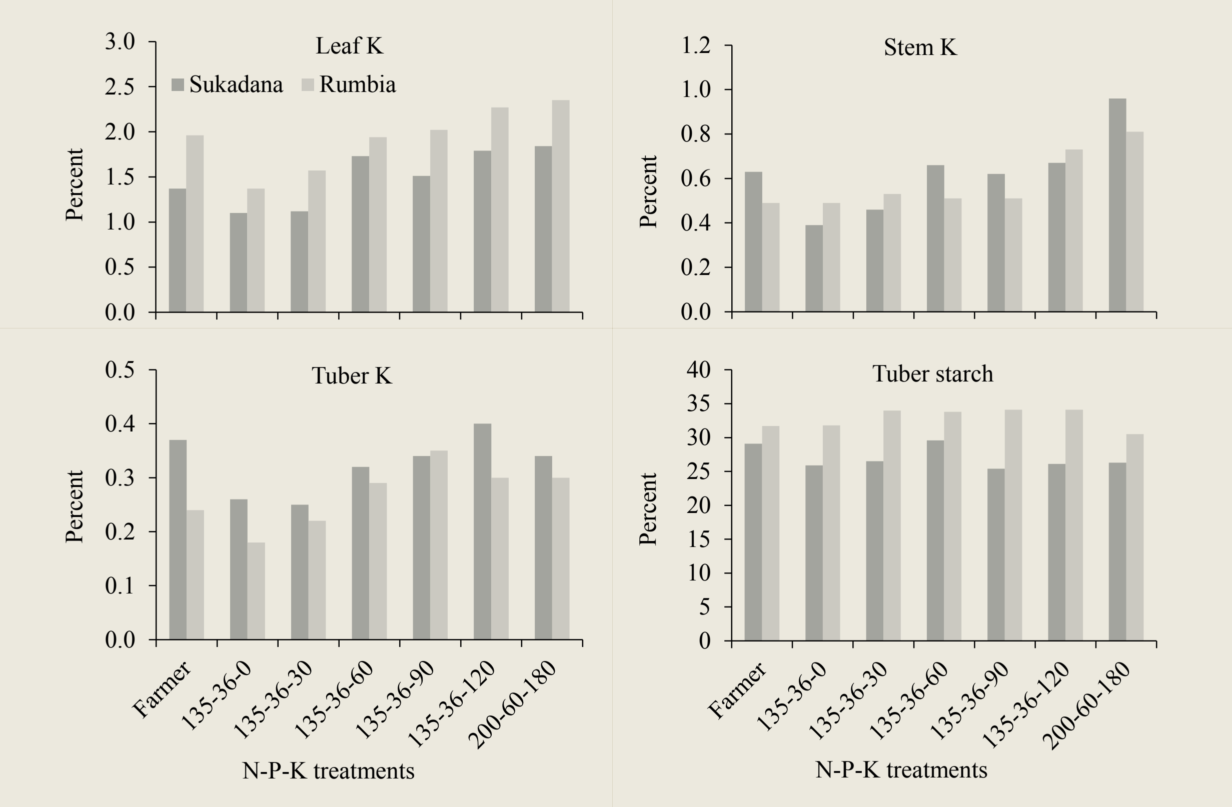


Fig. 2. Fertilization effect on cassava leaf, stem, and tuber K content (% of dry matter), and tuber starch content (% of fresh weight) at harvest, in Sukadana and Rumbia, 2012-2013.

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 $P < 0.05$.

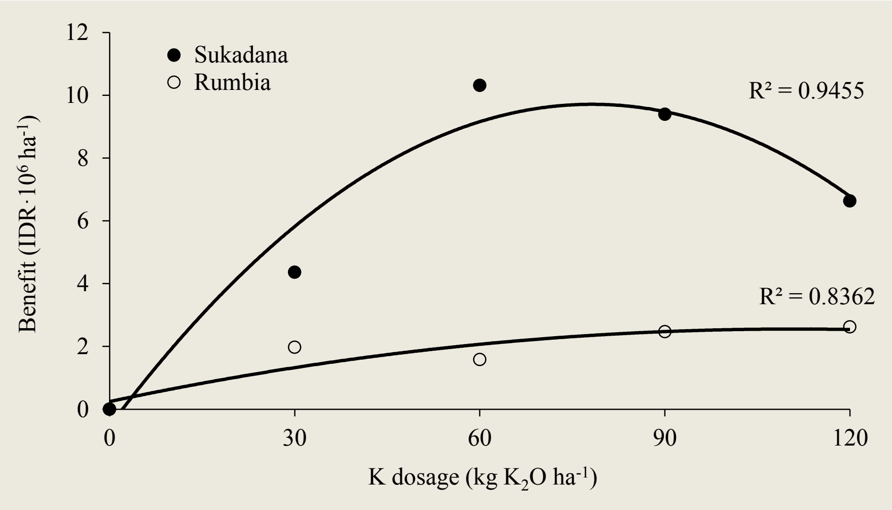


Fig. 3. Effect of K fertilization dose on the net return from cassava at Sukadana and Rumbia, Lampung, Indonesia, 2012-2013.

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:

Regional activities/Southeast Asia

Events

IPI Events

July 2015

First National Potash Symposium in Tanzania entitled "Potassium for Sustainable Crop Production and Food Security", 28-29 July 2015, Dar es Salaam, the United Republic of Tanzania

The 1st Potash Symposium in Tanzania was held in Dar es Salaam between 28-29 July 2015. Over 60 scientists, extension officers, officials, and fertilizer industry and farm technicians attended along with chief guest, Mr. Peniel Lyimo, Deputy Chief Executive from the President's Office - President's Delivery Bureau, the United Republic of Tanzania.

The event was organized by the African Fertilizer and Agribusiness Partnership (AFAP) in collaboration with the International Potash Institute (IPI, Switzerland) and Mlingano Agricultural Research Institute.

Over five decades, potassium has been regarded as sufficient in most of Tanzania's soils. This generalization has led to little research work regarding soil potassium status, plant nutrition and fertilizer recommendations, which include potassium in fertilizer formulations. Tanzania has potassium-blended fertilizer recommendations for a few crops like tobacco, sisal and tea. Other crops depend on the inherent potassium supply in the soil, which is gradually declining due to inadequate supplies.

In recent years, it has been recognized that levels of potassium in some soils are lower than normally anticipated, and that deficiency symptoms are common in some major crops like maize, cassava, and rice. With such observed deficiencies, there is an urgent need to provide updated fertilizer recommendations to include potassium.

This Symposium aimed to support the sustainable increase in agricultural productivity by including potassium in fertilizer recommendations for various crops. This is envisaged by the following steps:

1. Obtaining baseline information of potassium research in Tanzania
2. Synthesizing the available information
3. Identifying research gaps to establish a potassium research agenda for Tanzania.

Three key-note papers and 13 papers were presented by experienced scientists around the following sub-themes:

1. Potassium distribution in the soils of Tanzania
2. Role of potassium for sustainable crop productivity in Tanzania
3. Trends of potassium levels in the soils of Tanzania
4. Formulation and packaging of potassium based fertilizers
5. Economics of potassium based fertilizers for sustainable crop production.

Chief guest: Mr. Peniel Lyimo, Deputy Chief Executive, President's Office, President's Delivery Bureau, the United Republic of Tanzania. Photo by IPI.

Outcome and recommendations

The major outcome of the Symposium was a road map to promote the use of potassium through research, extension, policy and public-private partnerships.

To see the presentations, please go to the IPI website/Papers and Presentations.

This report also appears on the IPI website at:

Regional activities/sub-Saharan Africa

Events (cont.)

July 2015

FAI-IPI Roundtable on “Potassium in Balanced Fertilization in Rajasthan”, 9 July 2015, Jaipur, Rajasthan, jointly organized by The Fertiliser Association of India (FAI) and the International Potash Institute (IPI).

Shri Satish Chander, Director General, FAI delivered the opening address. Dr. Patricia Imas, IPI Coordinator for India delivered keynote address. Fifty delegates representing Rajasthan Agricultural Research Institute (Sri Karan Narendra Agriculture University, Jobner) Durgapura, Jaipur; State Institute of Agriculture Management; State Department of Agriculture; KVKs; and representatives of the Fertiliser Industry participated in the roundtable.

See the report from Indian Journal of Fertiliser, August 2015 on this Roundtable on the IPI website/Regional activities/India.

August 2015

National Workshop on “Sustainable Production of Pulses - Situation Analysis”, 11 August 2015, Bahauddin Zakariya University, Bahadur Sub-Campus, Layyah, Pakistan.

Pulses are the most important source of vegetable protein in Pakistan. Their use ranges from baby food to delicacies of the rich and the poor. Because of the population growth, demand for pulses is increasing day by day. However, during the last decade Pakistan has had to import 35-65% of pulses consumed to meet the domestic demand. Nonetheless, the area and production of pulses is further declining owing to frequent drought episodes, temperature extremes, and incidence of diseases. Moreover, use of “weedicides” is low, which make the situation worse.

This one day National workshop on Sustainable Production of Pulses will help analyse the situation, and will explore the potential strategies for enhancing pulse production in the country.

See more details on the IPI website/Events.

November 2015

2nd IPI-Ministry of Agriculture-Hawassa University-Ethiopian Agricultural Transformation Agency (ATA) joint Symposium on “The Role of Potassium in Balanced Fertilization”, 24-26 November 2015, at the Hawassa University, Hawassa, Ethiopia.

Background

The role of potassium in balanced fertilization and its impact on crop productivity and quality is gaining increasing attention from agronomists and plant nutritionists. This is particularly relevant to sub-Saharan Africa (SSA) where soils are nutrient depleted, fertilizer use is low and agricultural productivity remains the lowest in the world.

The Second Potash Symposium aims to maintain the momentum created by the previous symposium (which was held on 4-5 September 2014 in Addis Ababa) by bringing together key researchers and senior soil fertility experts with rich experience in potassium research, technology innovation and dissemination globally. Leading professionals from Africa, Asia and Europe will participate in this Second Symposium to share their experiences. Ethiopian researchers from higher learning institutions and the agricultural development sector will also present their recent findings from national digital soil fertility mapping, extensive potash fertilizer demonstrations, and potassium fertilizer research conducted by research staff and graduate students.

The Symposium has identified five timely and relevant thematic areas indicated below:

Main Themes:

- Soil Potassium Status
- Potassium and Balanced Fertilization
- Potassium for Sustainable Cropping Systems
- Potassium Dynamics in Shrink-Swell Soils
- Potassium Impact on Crop Quality

Please see the announcement and further updates on the IPI website/Events. For more details contact Mr. Eldad Sokolowski, IPI Coordinator sub-Saharan Africa.

International Symposia and Conferences

October 2015

9th Symposium for the International Society of Root Research "Roots Down Under", 6-9 October 2015, Hotel Realm Canberra, Australia. See more on the symposium website.

4th Commercial Farm Africa, 7-9 October 2015, Radisson Blu Hotel, Lusaka, Zambia.
Agriculture - the engine of growth in Africa! From Cote d'Ivoire to Tanzania, agriculture is propelling strong economic growth. Investments are pouring into Africa from farmland investment to agro-processing value chain. However, where are the hotspots for agri-investment and what are the challenges in these countries? How to develop a responsible and sustainable agriculture model? What are the prospects & challenges to develop the agro-processing value chain? How will these investments benefit small-holder farms and the community? See more details on the conference website.

3rd Africa Palm Oil (Rubber & Cocoa), 13-15 October 2015, Labadi Beach Hotel, Accra, Ghana.
CMT's 3rd AFRICA Palm Oil conference includes Rubber & Cocoa investments have been carefully put together and draws international stakeholders to take part and share latest developments in Africa's potential in the 3 major crops. See more details on the event website.

7th Palm Oil & Rubber Summit, 19-21 October 2015, Beyond Resort Krabi, Thailand.
See more details on the summit website.

November 2015

International Conference on "Soil Sustainability for Food Security", 15-17 November 2015, University of Agriculture, Faisalabad, Pakistan.
The Institute of Soil and Environmental Sciences, University of Agriculture Faisalabad, is organizing the International Conference in collaboration with public and private organizations to celebrate the 2015 International Year of Soils and raise awareness to promote the sustainability of our limited soil resources. We all have responsibility to communicate vital information on soil, a life sustaining natural resource. For further details contact Prof. Dr. Ghulam Murtaza, Institute of Soil and Environmental Sciences, University of Agriculture Faisalabad, Pakistan at isscpk2015@gmail.com.

The 2nd World Congress on the Use of Biostimulants in Agriculture, 16-19 November 2015, Florence Convention Centre, Italy.
The 2nd World Biostimulants Congress will see over 1,000 delegates gather to explore the recently acquired scientific and technical knowledge on biostimulant products, which are increasingly used in crop production around the world, as well as the various aspects of legislation on these products in the main markets around the world. For more information visit www.biostimulants2015.com.

December 2015

The International Fertiliser Society 2015 Agronomic Conference on "Adapting Crop Nutrition Practices to Current Challenges and Constraints", 10-11 December 2015, Robinson College, Grange Road, Cambridge, UK.
The Conference will feature ten papers, covering aspects of fertiliser recommendation development, factors affecting nutrient uptake, the avoidance of wastage and run-off, and application accuracy. See more details on the ifs website.

March 2016

2nd Cassava World Africa, 1-2 March 2016, Accra, Ghana. The summit will focus on the "Roadmap to Raise Cassava Production and Investments of Higher Value-added Products".
The key highlights are "Progress and market prospects for cassava production of Starch, HQCF, Beer, Feed, Ethanol; Financing solutions and cassava investment projects across the continent; Cassava breeding and agronomy research to increase yields and quality including diseases management; Cost effective post-harvest logistics and processing technologies to increase cassava utilization; Mechanization of cassava production". For further information go to the event website.

CropWorld Global, 2-3 March 2016, Amsterdam RAI, Netherlands.
CropWorld Global is Europe's leading event dedicated to the latest developments & innovations on crop production, protection and agricultural technology. The event's new format connects a Congress & Expo. Leading global suppliers, buyers, scientists, regulators & key policy makers from the agriculture & crop industry will benefit from 2 days of first-rate networking and exposure to new business opportunities. See more details on the congress website.

First quarter 2016

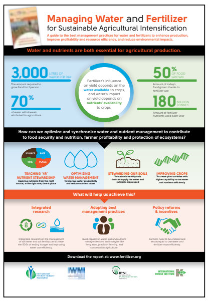
IFA and New Ag International join forces again to organize the **4th International Conference on Slow- and Controlled-Release and Stabilized Fertilizers in China** during the first quarter of 2016. The market for slow- and controlled-release and stabilized fertilizers develops at a sustained pace. Traditionally, these products have mainly been applied to specialty crops. However, they are progressively increasing their market share in the broad acre crop sector (maize in the United States, and rice in Japan and China, but also on other crops in other regions). How is this market expected to evolve in the medium- to long-term? What will be the key drivers of the growth: product development, economics or policy environment? How can the constraints to their wider use be alleviated? For more information go to www.newaginternational.com/index.php/news/399.

August 2016

5th Sustainable Phosphorus Summit 2016 (SPS 2016), 16-20 August 2016, Kunming, Yunnan, China.

SPS 2016 is the fifth in a successful series of Sustainable Phosphorus Summits that was launched in Linköping (Sweden) in 2010, and then went to Tempe (USA) in 2011, Sydney (Australia) in 2012 and Montpellier (France) in 2014, related to the Global Phosphorus Research Initiative. It is a global multidisciplinary event to discuss the phosphorus production and utilization, management and sustainability. The conference will be hosted by China Agricultural University and Yuntianhua Group. See First Circular on the IPI website/Events.

Publications



Managing Water and Fertilizer for Sustainable Agricultural Intensification. Infographic.

Published by IFA, IWMI, IPNI and IPI. August 2015.

The infographic is available on the IPI website/Infographics. To download the full publication go to the IPI website/Publications.

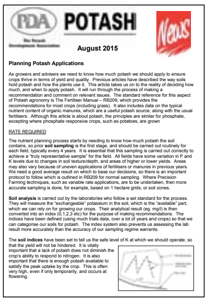
Publication by the PDA

The Role of Potash in Plants

POTASH News, May 2015.

Potassium is one of the major nutrients required by all crops and is present in large quantities in the plant in the form of the cation K+. It plays a major role in achieving the maximum economic yield, as part of a balanced approach to crop nutrition, as well as influencing crop quality.

Potassium is fundamental to many metabolic processes through the activation of a large number of enzymes required for chemical reactions. These include the synthesis of proteins and sugars required for plant growth. Only a relatively small proportion of the plant's total potassium requirement is needed for this. The majority is required for the essential role of maintaining the water content of plant cells. These roles are discussed below. Many are interlinked. Read more on the PDA website.



Planning Potash Applications

POTASH News, August 2015.

As growers and advisers we need to know how much potash we should apply to ensure crops thrive in terms of yield and quality. Previous articles have described the way soils hold potash and how the plants use it. This article takes us on to the reality of deciding how much, and when to apply potash. It will run through the process of making a recommendation and comment on relevant issues. The standard reference for this aspect of Potash agronomy is The Fertiliser Manual – RB209, which provides the recommendations for most crops (including grass). It also includes data on the typical nutrient content of organic manures, which are a useful potash source, along with the usual fertilisers. Although this article is about potash, the principles are similar for phosphate, excepting where phosphate responsive crops, such as potatoes, are grown. Read more on the PDA website.

Potash Development Association (PDA) is an independent organisation formed in 1984 to provide technical information and advice in the UK on soil fertility, plant nutrition and fertilizer use with particular emphasis on potash. See also www.pda.org.uk.

Scientific Abstracts

K in the Literature

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Historical and Technical Developments of Potassium Resources

Ciceri, D., D.A.C. Manning, and A. Allanore. 2015. Science of The Total Environment 502:590-601. DOI 10.1016/j.scitotenv.2014.09.013.

Abstract: The mining of soluble potassium salts (potash) is essential for manufacturing fertilizers required to ensure continuous production of crops and hence global food security. As of 2014, potash is mined predominantly in the northern hemisphere, where large deposits occur. Production tonnage and prices do not take into account the needs of the farmers of the

poorest countries. Consequently, soils of some regions of the southern hemisphere are currently being depleted of potassium due to the expansion and intensification of agriculture coupled with the lack of affordable potash. Moving away from mined salts towards locally available resources of potassium, such as K-bearing silicates, could be one option to improve this situation. Overall, the global potash production system and its sustainability warrant discussion. In this contribution we examine the history of potash production and discuss the different sources and technologies used throughout the centuries. In particular, we highlight the political and economic conditions that favored the development of one specific technology over another. We identified a pattern of needs driving innovation. We show that as needs evolved throughout history, alternatives to soluble salts have been used to obtain K-fertilizers. Those alternatives may meet the incoming needs of our century, providing the regulatory and advisory practices that prevailed in the 20th century are revised.

Zinc Application Affects Tissue Zinc Concentration and Seed Yield of Pea (*Pisum sativum* L.)

Rafique, E., M. Yousra, M. Mahmood-ul-hassan, S. Sarwar, T. Tabassam, and T.K. Choudhary. 2015. Pedosphere 25(2):275-281. ISSN 1002-0160/CN 32-1315/P.

Abstract: A 2-year field experiment was conducted to assess the effect of applied zinc (Zn) on the seed yield of pea (*Pisum sativum* L.) and to determine the internal Zn requirement of pea with emphasis on the seed and leaves as index tissues. The experiment was carried out at two different locations (Talagang, Chakwal district and National Agricultural Research Centre (NARC), Islamabad) in the Potohar Plateau, Pakistan by growing three pea cultivars (Green feast, Climax, and Meteor). The soils were fertilized with 0, 2, 4, 8, and 16 kg Zn ha^{-1} along with recommended basal fertilization of nitrogen (N), phosphorus (P), potassium (K), and boron (B). Zinc application increased seed yield significantly for all the three cultivars. Maximum increase in the pea seed yield (2-year mean) was 21% and 15% for Green feast, 28% and 21% for Climax, and 34% and 26% for Meteor at Talagang and NARC, respectively. In all cultivars, Zn concentrations in leaves and seed increased to varying extents as a result of Zn application. Fertiliser Zn requirement for near-maximum seed yield varied from 3.2 to 5.3 kg ha^{-1} for different cultivars. Zinc concentrations of leaves and seeds appeared to be a good indicator of soil Zn availability. The critical Zn concentration range sufficient for 95% maximum yield (internal Zn requirement) was 42-53 mg kg^{-1} in the pea leaves and 45-60 mg kg^{-1} in the seeds of the three pea cultivars studied.

Future of Agricultural Water Management in Africa

Valipour, M. 2015. Archives of Agronomy and Soil Science 61(7):907-927. DOI 10.1080/03650340.2014.961433.

Abstract: This paper aims to estimate ratio of area equipped for irrigation to cultivated area (AI) in Africa in 2035 and 2060 using studies of agricultural water management from 1962 to 2011. For this purpose, all necessary information was gathered from Food and Agriculture Organization of the United Nations (FAO) and their values were checked using The World Bank Group (WBG). Among all presented data in the FAO database, 10 indices were selected (due to more importance and more availability for all the regions in Africa). The selected indices were analysed for all seven regions in the study area and the amount of AI was estimated by three different scenarios and using other nine indices. The results show that changes of AI are 0.3% to 49.5% and 16.5% to 83.2% from 2011 to 2035 and 2060, respectively. Indian Ocean Islands has a better potential to increase AI in the future. A considerable note is the change of irrigation status in the future than the current status. In 2011, AI of Sudano-Sahelian is more than AI of Indian Ocean Islands, however, in the future; AI of Sudano-Sahelian would be less than AI of Indian Ocean Islands based on all scenarios.

Effects of Polymeric Slow Release Fertilizer on Chinese Cabbage Growth and Soil Nutrients

Cheng, D., Y. Wang, G. Zhao, and Y. Liu. 2015. Archives of Agronomy and Soil Science 61(7):959-968. DOI 10.1080/03650340.2014.965695.

Abstract: One pot experiment was conducted to study the effects of a new polymeric slow release fertilizer (PRF) on Chinese cabbage growth and soil nutrients. The experiment comprised three kinds of fertilizer (common compound fertilizer, 21% and 45% solubility of PRF in 25°C water, all fertilizers with N:P_2O_5:K_2O = 10:5.7:20) and three fertilizer levels (0, 21.6 and 43.2 g m^{-2}). Results showed that the high water-soluble PRFs (PRFHH and PRFHL) fit nutrient requirements of Chinese cabbage, and the high fertilization level significantly increased yield and improved quality of Chinese cabbage. Although the PRFHL treatment at 21.6 g fertilizer m^{-2} had one-half less supplied nutrient than that of common compound fertilizer treatment (43.2 g fertilizer m^{-2}), the yield of Chinese cabbage with PRFHH and PRFHL was 8.0% more. The soluble sugar, vitamin C and leaf chlorophyll contents of Chinese cabbage can be effectively improved with PRFHH (43.2 g m^{-2}), PRFHL (21.6 g m^{-2}) and PRFLH (low water-soluble PRF, 43.2 g m^{-2}). The PRF treatment reduced the nitrate content and improved soil capacity of supplying nutrient effectively, and there were no changes in values of pH and electrical conductivity of soil.

Crops Response to Applied Potassium in Vertisols Long-Term Fertilizer Experiment in India

Singh, M., and R.H. Wanjari. 2015. Indian J. Fert. 11(7):30-34.

Abstract: On going long-term fertilizer experiments (LTFE) were initiated in 1972 and until 2006 at 17 locations throughout India with the aim of monitoring the response of crops to nutrients in different soils and cropping systems in relation to the role of fertilization in sustaining soil health and crop productivity. Results generated over the years in LTFE indicated that at 5 Vertisols of associated Vertisol centres which were considered rich in potassium (K), crops began to show response to K fertilizer application. In order to assess the response of crops to the applied K, the data generated over the years have therefore been closely re-examined. At one of the locations in Jabalpur, a response to potassium was seen after a few years of experimentation in soybean-wheat and a gradual increase in magnitude of response to applied K has been observed with time. At another site in Akola, both sorghum and wheat showed response to applied K which also increased with time despite the available K content of the soil being greater than that generally considered as high status. Analysis of soil K status, of which soils revealed that absence of K in the fertilizer schedule resulted in a decline in K status from 2.1 to 9.7 kg ha^{-1} yr^{-1} and addition of N and P accelerated the mining of K. On the other hand, the decline in available K status was arrested by the addition of K (NPK and NPK+FYM) which in some cases it led to an increase in available K. The relationship between available K status and Bray's percent yield indicated ~330 kg K ha^{-1} as a threshold value for Vertisols rather than the current recommendation in India of 280 kg ha^{-1}. This finding indicates that there is need to modify or raise the critical limit for K rating of Vertisols, otherwise a lack of K could pose a threat to sustainability.

Cassava (*Manihot esculenta* Crantz) Tuber Quality as Measured by Starch and Cyanide (HCN) Affected by Nitrogen, Phosphorus, and Potassium Fertilizer Rates

Cuvaca, I.B., N.S. Eash, S. Zivanovic, D.M. Lambert, F. Walker, and B. Rustrick. 2015. J. Agric. Sci. 7(6):36-49. DOI 10.5539/jas.v7n6p36.

Abstract: Cassava (*Manihot esculenta* Crantz) is an important subsistence crop for many poor rural families in Africa. Cassava contains cyanogenic glucosides (linamarin and lotaustralin) which liberate hydrogen cyanide (HCN) during tuber processing. Once liberated, HCN attaches to the processed tuber. Continuous consumption of processed tuber containing high HCN concentration coupled with low protein intake causes Konzo – a paralyzing disorder that impacts children and women of childbearing age. There are ways to reduce HCN concentration during tuber processing; however, this can also reduce the overall starch content in the cassava tuber. A study comprising twenty treatments consisting of different combinations of nitrogen (N), phosphorus (P), and potassium (K) fertilizer rates was initiated in 2013 in the coastal Dondo District of Mozambique to assess cassava tuber quality as measured by starch and HCN. Significant differences were observed in starch content (CSC) of unprocessed tubers due to combined addition of N, P and K fertilizer rates, sample size, and estimation procedure. However, no significant differences were observed in HCN concentration in tubers due to the addition of N, P and K fertilizer. The HCN concentration in cassava tuber appears to be a function of the physiology of the crop or possibly cassava variety rather than the environment or conditions under which the crop is grown.

Function of Sodium and Potassium in Growth of Sodium-Loving Amaranthaceae Species

Mina Yamada, Chika Kuroda, Hideyasu Fujiyama. 2015. Soil Sci. Plant Nutr. DOI 10.1080/00380768.2015.1075365.

Abstract: We observed that the growth of three Amaranthaceae species was promoted by sodium (Na), in the order dwarf glasswort (*Salicornia bigelovii* Torr.) >> Swiss chard (*Beta Burgaris* L. spp. *cicla* cv. Seiyou Shirokuki) > table beet (*Beta vulgaris* L. spp. *vulgaris* cv. Detroit Dark Red). In the present study, these Na-loving plants were grown in solutions containing 4 mol m^{-3} nitrate nitrogen (NO_3-N) and 100 mol m^{-3} sodium chloride (NaCl) and potassium chloride (KCl) under six Na to potassium (K) ratios, 0:100, 20:80, 40:60, 60:40, 80:20 and 100:0, to elucidate the function of Na and K on specific characteristics of Na-loving plants. The growth of dwarf glasswort increased with increasing Na concentration of the shoot, and the shoot dry weight of plants grown in 100:0 Na:K was 214% that of plants grown at 0:100. In Swiss chard and table beet, growth was unchanged by the external ratio of Na to K. The water content was not changed in Swiss chard or table beet by the external Na to K ratio. These observations indicate that both Na and K have a function in osmotic regulation. However, dwarf glasswort could not maintain succulence at 0:100; therefore, Na has a specific function in dwarf glasswort for osmotic regulation to maintain a favorable water status, and the contribution of K to osmotic regulation is low. NO_3-N uptake was promoted by Na uptake in dwarf glasswort and Swiss chard. NO_3-N uptake and transport to shoots was optimal at 100:0 in dwarf glasswort and at 80:20 in Swiss chard. These functions are very important for the Na-loving mechanism, and the contribution of K was lower in dwarf glasswort than in Swiss chard.

Sulfur Fertilization: Improving Alfalfa Yield and Quality

Haupt, G., J. Jauzon, and B. Hall. 2015. Crops and Soils 48(4):26-30. DOI 10.2134/cs2015-48-4-9.

Abstract: With the decrease in sulfur (S) deposition levels from acid rain over the last few decades, there has been an increasing prevalence of suspect reports of S deficiencies in crops in southern Ontario and a number of U.S. states. This article discusses the results of S response trials on alfalfa in Ontario. Earn 1 CEU in Nutrient Management by reading this article and taking the quiz at www.certifiedcropadviser.org/certifications/self-study/720.

Fertilization with Nitrogen, Phosphorus and Potassium in Upland Rice Cultivars in the Southern Region of Rondônia, Brazil

Soares, E. , R. Fernandes, L. Silva Londero, L. Galon, F. Ferreira Pires, M. Andrade Barbosa, D. dos Santos, S. Sampaio Correa, E. Sampaio Correa, and R. dos Santos. 2015. Amer. J. Plant Sci. 6(14):2263-2271. DOI: 10.4236/ajps.2015.614229.

Abstract: The upland rice productivity in the state of Rondônia is still low, in view of the potential of culture. The use of cultivars adapted to different regions and more responsive to fertilizer employed is an essential practice which can change that. The aim of this study was to evaluate the agronomic characteristics and productivity of two upland rice cultivars with nitrogen, phosphorus and potassium (N-P-K) doses in two municipalities in the southern state of Rondonia region. The experimental design was a randomized block design with four replications in a factorial 2 × 2 × 5, with the first factor composed of two cultivars (hybrid Ecco and conventional farming AN Cambará), the second factor, the environment of the two municipalities, Cerejeiras and Vilhena and the third factor of five doses of N-P-K (0-0-0, 30-40-30, 60-60-60, 90-90-90 and 120-100-120 kg ha^{-1}). The characteristics evaluated were: tillering, number of integers and sterile grains per panicle, weight of 1000 grains, grain yield (kg ha^{-1}) and whole grain yield. There was no triple interaction between the three factors for any of the traits. The hybrid Ecco has higher tillering ability than AN Cambara and presents fewer sterile grains per panicle, heavier 1000 grains and hence greater productivity. For both cultivars, the highest yields are obtained with a dose of 120-100-120 kg ha^{-1} N-P-K. For the Ecco, the productivity is achieved with this dose and the dose of 90-90-90 kg ha^{-1} is statistically similar. There is no difference in productivity between the municipalities when the dose of N-P-K is less than 60-60-60 kg ha^{-1}. The highest yield of whole grains in function of N-P-K fertilization is obtained in Cerejeiras.

Content and Uptake of Nutrients with Plant Biomass of Potatoes Depending on Potassium Fertilization

Neshev, N., and I. Manolov. Agriculture and Agricultural Science Procedia 6:63-66. DOI 10.1016/j.aaspro.2015.08.039.

Abstract: The influence of potassium fertilizer source and the increasing potassium fertilization levels (0, 200, 400 and 600 mg K_2O kg^{-1} soil) supplied either as K_2SO_4 or KCl at equal nitrogen and phosphorus fertilizer background (200 mg N kg^{-1} and 150 mg P_2O_5 kg^{-1} soil) on the content and the uptake of nutrient elements from the soil in potato plant parts was studied. Pot experiment was carried out. The fertilization with K_2SO_4 decreased N content in roots from 2.91% at level K_{200} to 2.52% at level K_{600} and increased N content in aboveground biomass compared to the control and variants fertilized with KCl. The increasing KCl rates led to decreasing of N content in aboveground biomass from 4.03% at K_{200} to 2.34% at potassium level K_{400}. Nitrogen content in tubers at variants fertilized with K decreased compared to the control. Potassium fertilization did not influence considerably P content in the plant parts. The K content in plant parts at variants fertilized with KCl was higher than the plants fertilized with K_2SO_4. Approximately 74% of absorbed nitrogen from the soil was allocated in the above ground biomass. The rest of the nitrogen was distributed between roots (17%) and tubers (9%). The highest P uptake was determined in control plants. The quantity of the uptaken K allocated in aboveground biomass was the highest (83%). The rest of K was distributed between roots (11%) and tubers (6%).

The Pear Tree Response to Phosphorus and Potassium Fertilization

Brunetto, G., G. Nava, V. Gabriel Ambrosini, J.J. Comin, J. Kaminski. 2015. Rev. Bras. Frutic. 37(2):507-516 Jaboticabal, Apr./June 2015. DOI 10.1590/0100-2945-027/14.

Abstract: The aim of this study was to evaluate the response to phosphorus (P) and potassium (K) fertilization and to establish the critical levels of P and K in the soil and in the plant tissue in pear trees. Two experiments were conducted in São Joaquim (SC), Brazil. In experiment 1, the plants received annually the application of increasing rates of phosphate fertilizer (0, 40, 80, 120 and 160 kg P_2O_5 ha^{-1}), while in experiment 2, increasing rates of potassium fertilizer (0, 40, 80, 120 and 160 kg K_2O ha^{-1}) were applied annually. In the two experiments, soil was collected annually from the 0-10, 10-20 and 0-20 cm layers, and the available P (experiment 1) and exchangeable K (experiment

2) content was analyzed. Whole leaves were collected annually, which were subjected to analysis of total P (experiment 1) and total K (experiment 2) content. The number and weight of the fruits per plant and fruit yield were evaluated. Application of P on the soil planted with pear trees increased the nutrient content in the soil and, in most crop seasons, in the whole leaf, but it did not affect the yield components and fruit yield. The application of K on the soil with pear trees increased the nutrient content in the soil and, in most of the crop seasons, in the whole leaf, but the potassium content in the whole leaf decreased in the crop season with greater fruit yield. The yield components and fruit yield were not affected by K fertilization.

Read on

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A log of observations from the fields of San Joaquin County and the Delta. Leinfelder-Miles, M. 2015. Agriculture and Natural Resources, University of California.

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2015. Nature 524(415). DOI 10.1038/524415a.

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Herman, T., E.H. Murchie, and A.A. Warsi. 2015. Pertanika J. Trop. Agric. Sci. 38 (3):321-328.

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