e-ifc

Electronic International Fertilizer Correspondent *(e-ifc)*
Quarterly publication from IPI

No. 47 | December 2016

INTERNATIONAL POTASH INSTITUTE
SINCE 1952
Optimizing Crop Nutrition

Editorial

Dear readers,

With no major weather calamities, 2016 proved to be an excellent year for crop production. This is one of the reasons that food prices remained relatively low during the year, enabling hundreds of millions of people to increase their calorie intake. Nonetheless, the battle to reduce malnutrition will remain with us in the coming decades, and further improvements in crop production will remain one of the vital tools to achieve this.

However, the effort to improve crop production cannot be executed without people. In Pakistan, IPI initiated a program in 2015 to support young scientists to go out into the field and help farmers. There is no doubt that these young scientists also benefited from this process. More such initiatives are needed, as this is an effective tool to disseminate knowledge. Read more about the program in this edition (Promoting Precise and Balanced Use of Fertilizers in Pakistan at Farm-Gate Level; p. 20). The fertilizer industry is constantly striving to improve the 'last mile' delivery of agronomic knowledge to farmers. ICL, a fertilizer producer (and also IPI member) has established a joint research and training center with the Volcani Center, ARO, in Israel called the Center for Fertilization and Plant Nutrition (www.CFPN.center) with the aim to reach out to young scientists, mostly in developing countries.

Let us hope that the weather will continue to be favorable in 2017 and that our efforts to improve crop production may continue, even under less favorable conditions.

I wish you an enjoyable read.

Hillel Magen
Director

Photo cover page:
Cotton harvest in Brazil. Photo by F. Vale.

Research Findings

Experimental site at Binh Dinh Province, Vietnam. Photo by G. Kalyan.

Agronomic Efficiency of Polyhalite Application on Peanut Yield and Quality in Vietnam

Hoang Minh Tam[(1)*], Duong Minh Manh[(1)], Truong Thi Thuan[(1)], Ho Huy Cuong[(1)], and Pham Vu Bao[(1)]

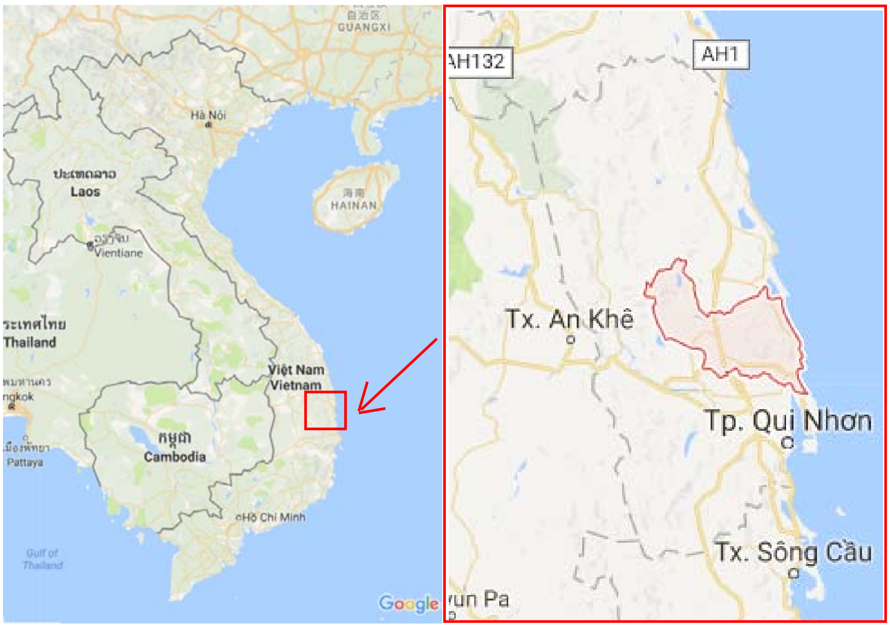
Abstract

Peanut (*Arachis hypogaea* L.) has an important role in traditional crop rotation in Vietnam, and particularly in Binh Dinh province, where the planting area ranges from 8,300-10,200 ha, and the average yield increased by 12%, from 2.67 to 2.99 Mg ha^{-1} during 2009 to 2014. The sandy (97%) acidic (pH 5.1) soils in this humid tropical climate require careful balanced fertilization that should support a sustainable cropping system and provide sufficient profits to the farmers. As peanut is a legume, small rates of nitrogen (N) are required but adequate sulfur (S) and potassium (K) rates are essential to obtain considerable yields. Polyhalite, a sedimentary marine evaporate, consists of a hydrated sulfate of K, calcium (Ca) and magnesium (Mg) with the formula: $K_2Ca_2Mg(SO_4)_4{\cdot}2(H_2O)$, which contains 48% S. The objectives of this study are to evaluate the effects of K and polyhalite application rates on peanut agronomic and economic

[(1)]Agricultural Science Institute for Southern Coastal Central of Vietnam (ASISOV)
*Corresponding author: khviennntb@yahoo.com

performances and to suggest an optimum fertilization mode for the growing conditions in the Central Coast of Vietnam. Six fertilization treatments were tested: Farmers' practice (FP) control, with N:P:K ratio of 95:40:100; NP-K_0, with 45 kg N ha^{-1}, 90 kg P_2O_5 ha^{-1}, and zero K; and NP-K_{30}; NP-K_{30}-S_1; NP-K_{60}-S_2, and NP-K_{90}-S_3, all of which were applied with similar N and P rates, K rates increasing from 30 to 90 kg K_2O ha^{-1}, and polyhalite at 107 (S_1), 214 (S_2), and 321 kg ha^{-1} (S_3), respectively. FP and NP-K_0 displayed the poorest performance in most parameters tested and obtained low peanut yield and benefit. The optimum treatment was achieved with NP-K_{60}-S_2, which resulted in 2.86 Mg ha^{-1} of grains, 24% more than the FP control, and in a 98% increase in the net benefit to the farmer. A further increase in K and S rates did not provide any further advantage. Soil examinations, before sowing and after harvest, indicated that while FP significantly reduced soil fertility, employing polyhalite to create a balanced N-P-K-S management led to enhanced soil fertility, thus supporting a sustainable cropping system.

Keywords: Acidic soils; *Arachis hypogaea* L.; Polysulphate; potassium; sulfur.



Map 1. Phu Cat district, Binh Dinh Province, Vietnam. *Source:* Google Maps.

Introduction

Peanut (*Arachis hypogaea* L.), a tropical plant which originated from South America, is a short-term industrial legume crop, which has a high economic value as a source of lipids and proteins for human and animal nutrition. Like most legumes, peanut harbors symbiotic nitrogen-fixing bacteria in root nodules. This capacity to fix nitrogen means peanut requires less nitrogen-containing fertilizer and improves soil fertility, making it valuable in crop rotations or inter-cropping, thus contributing to agricultural efficiency and sustainability.

Currently, peanut is grown in 112 countries around the world in Asia, Europe, the Americas, Africa and Oceania. In 2014, worldwide planted area was 25.7 million ha, with average yield of 1.65 Mg ha^{-1}, and production of 42.4 million tons (FAO, 2015). In Vietnam, peanut is distributed across multiple ecological zones. In recent years the peanut planting area in Vietnam has tended to decrease; it declined steadily from 2009 to 2014 by 15%, from 245,000 to 208,149 ha. The average peanut yield in Vietnam was 2.17 Mg ha^{-1} in 2014, and total production reached 453,332 Mg.

Peanut has an important role in the traditional crop rotation in Binh Dinh province (Map 1). According to recent statistics (2009 - 2014), peanut planting area of Binh Dinh province ranged from 8,300-10,200 ha, and the average yield increased by 12%, from 2.67 to 2.99 Mg ha^{-1}, during 2009 to 2014. In addition to tests of new, more productive cultivars, reasonable fertilizer use is expected to: contribute to improved productivity and produce quality; reduce crop susceptibility to pests; ensure environmental safety; and raise farmers' net income.

Typical to humid tropical regions (Fig. 1), where arable lands are reclaimed from native rain forests, soils tend to be very acidic, low in organic matter, and have low cation exchange capacity (CEC) (De Geus, 1973). Lime (CaO), which is a cheap base, is commonly used to reduce soil acidity. For peanut, the recommended pH range is 5.8 – 6.2. If pH is less than 5.8, zinc (Zn) toxicity problems could occur (Balota, 2014). In addition, urea application to acidic soils might further decrease soil pH (Bouman *et al.*, 1995; Tong and Xu, 2012), inhibit soil microflora (Geisseler and Scow, 2014), and weaken N_2-fixation by legume crops (Miller, 2016).

Peanut gets most of its nitrogen (N) from nitrogen-fixing bacteria (*Bradyrhizobium*) colonizing the plant's roots. Poorly inoculated fields will not usually show any yellowing until around the beginning of flowering, so checking for nodulation before flowering is important. Failure of natural inoculation can be expected in very humid soils. In such cases, N fertilizer should be applied carefully to reach the N sufficiency range (3.5-4.5%) in leaves at bloom set or early pegging (Balota, 2014). Peanut responds well to residual fertilizer, and typically no additional phosphorus (P) and potassium (K) are needed when the previous crop has been properly managed. This is because

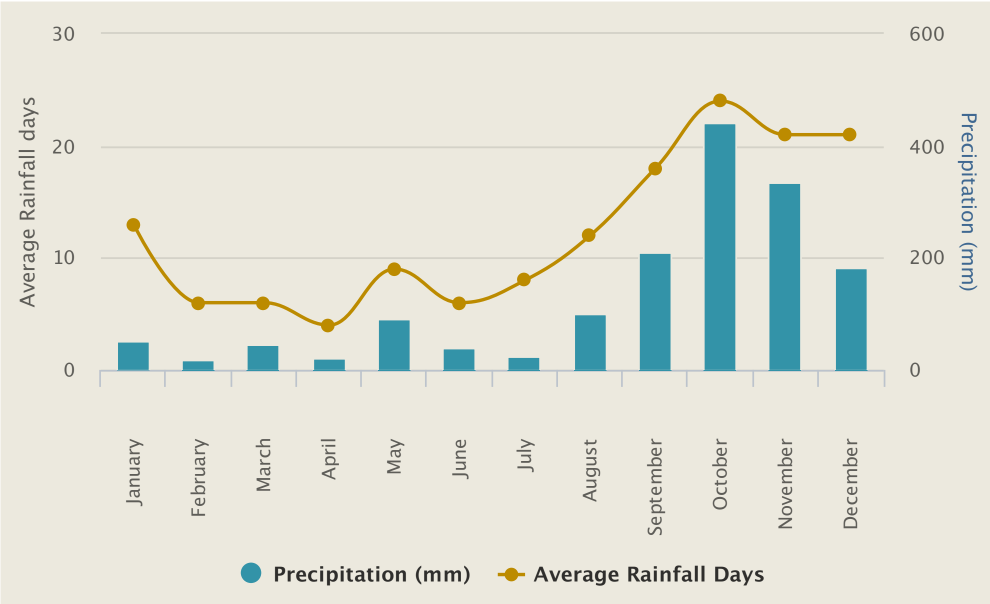


Fig. 1. Average monthly precipitation and number of rainy days at Binh Dinh Province, Vietnam, 2002-2012. *Source:* https://www.worldweatheronline.com/binh-dinh-weather-averages/vn.aspx.

Fig. 2. Symptoms of S deficiency in peanut plants. *Source:* Balota, 2014.

legumes have an exceptional ability to extract these nutrients, P and Zn in particular, with help from the vesicular arbuscular mycorrhizal fungi naturally present in most soils. Excess potash in the pegging zone can potentially interfere with calcium (Ca) uptake and cause pod rot (Pythium). On the other hand, K leaches easily from the soil top layer, particularly in sandy acidic soils. Calcium is critical for pod development. Adequate Ca uptake reduces pod rot and unfilled pods. The critical period for Ca absorption is at the beginning of pod stage (around 70 DAS) but it needs to be in the soil solution before this stage.

Sulfur (S) is important for peanut nutrition because, along with N, it forms proteins (Jamal *et al.*, 2010; Wang *et al.*, 2013). Because S is very mobile in the soil, its reserves decline where soils are cropped for many years without application of S-containing fertilizers. Leaf symptoms include pale yellowing of young leaves, while older leaves remain dark green (Fig. 2). Since S is essential for protein formation, its absence early in vegetation may reduce plant growth and, with it, the pod yield. Leaf S sufficiency is 0.2 to 0.5% (Balota, 2014).

A number of recent studies have demonstrated the significant contribution of S application to peanut yield and quality (Gashti *et al.*, 2012; Abd and Mona, 2013; Elseed *et al.*, 2015; Ramjeet Yadav *et al.*, 2015; Kannan *et al.*, 2016; Pratiwi *et al.*, 2016). Sulfur is commonly applied through gypsum, which is also a good source of Ca. Nevertheless, large amounts of gypsum are needed to provide sufficient S requirements because of its low S content (15-18%). Other S sources that include fertilizers with N, P, or K, such as ammonium sulfate, ammonium nitrate sulfate, ammonium phosphate sulfate, ammonium phosphate nitrate, potassium sulfate, and potassium magnesium sulfate, all of which contain low S levels (4.5-24%), are considered inefficient S contributors. Moreover, SO_4^-, 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. Thus, better alternatives for S fertilization are being sought.

Polysulphate (Cleveland Potash Ltd., UK) is the trade mark of the natural mineral 'polyhalite'. 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 offers attractive solutions to crop nutrition.

The objectives of the present study are to evaluate the effects of K and polyhalite application rates on peanut agronomic and economic performances and to suggest an optimum fertilization mode for the growing conditions in the Central Coast of Vietnam.

Table 1. Fertilization treatments for the peanut experiment carried out in 2016 at Cat Hai commune, Phu Cat district, Binh Dinh province, Vietnam.

Treatment	FYM	CaO	N	P_2O_5	K_2O		S
					KCl	Polysulphate	
	Mg ha⁻¹	-----	-----	-----	*kg ha⁻¹*	-----	-----
FP	10	500	95	40	100	0	0
NP-K_0	10	500	45	90	0	0	0
NP-K_{30}	10	500	45	90	30	0	0
NP-K_{30}-S_1	10	500	45	90	15	15	25
NP-K_{60}-S_2	10	500	45	90	30	30	50
NP-K_{90}-S_3	10	500	45	90	45	45	75

Table 2. Timing of fertilizer applications during the 2016 season.

Fertilizer	Before sowing	Days after sowing (DAS)	
		25-30	40-45
	-----	%	-----
N	50	50	-
P	100	-	-
K	50	50	-
S	50	50	-
CaO	50	-	50
FYM	100	-	-

Materials and methods

The experiment took place at Cat Hai commune, Phu Cat district, Binh Dinh province, Vietnam. Peanut seeds (cv. L14) were sown on 1-Apr, 2016 at a density of 50 seeds m^{-2} (20 cm between rows and 10 cm between plants). Shallow and careful hoeing was carried out several times from emergence until 7-10 days after full bloom to prevent weeds. Pests and diseases were managed according to their occurrence at threshold levels, implementing common recommendations.

The fertilization program of the experiment is illustrated in Tables 1 and 2. Farmer yard manure (FYM) at 10 Mg ha^{-1} was applied to all treatments before sowing. The lime (CaO) dose, 500 kg ha^{-1}, was divided into two applications, 50% before sowing, and the rest at 40-45 DAS. Fertilization treatments included a farmers' practice (FP) control, which received high doses of N and K (95 and 100 kg ha^{-1}, N and K_2O, respectively) and a low P dose (40 kg P_2O_5 ha^{-1}). The other five treatments received 45 kg N ha^{-1}, 90 kg P_2O_5 ha^{-1}, and differing K rates that gradually increased from zero (NP-K_0) to 90 kg K_2O ha^{-1} (NP-K_{90}-S_3). Polysulphate was applied to treatments NP-K_{30}-S_1, NP-K_{60}-S_2, and NP-K_{90}-S_3 at doses of 25, 50 and 75 kg S ha^{-1} (corresponding to 107, 214, and 321 kg Polysulphate ha^{-1}), respectively. Nitrogen was applied through urea, and P through superphosphate. Potassium was applied mainly through KCl but, as polyhalite comprises a significant K portion, KCl doses were reduced accordingly where necessary, adjusting to the designated K rate. While P was applied before sowing, N, P, and S doses were split into two even applications, the first one before sowing and the second at 25-30 DAS. All fertilizers were applied directly to the soil.

The experiment was set according to a random completed block design (RCBD) with four replications. Each replicate consisted of 24 m^2 (4 x 6m).

Crop development (plant height, plant survival, time of full bloom) was recorded for each plot from germination to harvest. Evaluations of pests and of major diseases were carried out along the season. At harvest, samples of 10 plants per plot were employed to determine fresh and dry plant biomass and yield determinants such as the number of filled pods per plant, the weight of 100 pods, and the weight of 100 dry (10% moisture content) seeds, as well as the total dry grain yield. Harvest index (HI) was calculated as the ratio between grain yield and dry plant biomass per unit area. The economic assessment was founded on calculation of costs (as influenced by the various fertilization practices), revenue (dry grain yield, quality, and price), net profit to the farmer, and the benefit rate (ratio between profit and cost).

Soil examinations were carried out for each plot before sowing and after harvest and included texture analysis, pH_{KCl}, organic matter (OM) (%), N (%), P_2O_5 (%) and P_2O_5 (mg 100 g^{-1}), K_2O (%) and K_2O (mg 100 g^{-1}), Ca (meq 100 g^{-1}), Mg (meq 100 g^{-1}), S (%), CEC (meq 100 g^{-1}). Data analysis was carried out using Statistix 8.2.

Results

Peanut plants germinated 6 DAS, began flowering at 24 DAS, and completed their major vegetative development at 85 DAS. Fertilization treatments did not have any influence on these phenological parameters. Plant height at 85 DAS, as a measure of plant vegetative development, was much smaller in the absence of any K application (NP-K_0). Plant height responded considerably where K rate was elevated to 30 kg ha^{-1} and increased slightly more, as K rate rose to 60 or 90 kg ha^{-1} with polyhalite application (Fig. 3). Notably, the control (FP) gave rise to the highest plants. Primary branching fluctuated from 4.2 to 4.5 branches, with no significant effects from the fertilization treatment.

Peanuts' fresh biomass yield ranged from 15.25 to 19.38 Mg ha^{-1}. Significantly smaller fresh biomass was obtained with NP-K_0. FP and NP-K_{30} displayed intermediate values, while all three treatments applied with polyhalite had slightly larger fresh biomass. A similar pattern was observed with the dry peanut biomass, which ranged from 6.51 to 8.13 Mg ha^{-1} (Fig. 4).

Susceptibility to common peanut diseases or pests was unaffected by any of the fertilization treatments (data not shown). Leaf rust (*Puccinia arachidis Speg*), braided brown spot (*Cercospora arachidicola* Hori), and black spot (*Cercospora personatum* (Berk & Curt)) diseases displayed medium infection rates (5-25%). The exception was NP-K_0 where the rust disease scored higher (25-50%). Root black rot (*Aspergillus niger*) and bacterial wilt (*Ralstonia solanacearum* Smith) remained low, less than 30%, among all treatments. Green aphids severely attacked the crop but no differences between treatments were observed.

Fertilization treatments did not have any influence on plant survival, which was very high (99%). The number of filled pods per plant was significantly low (6.6) at NP-K_0. It was slightly higher at the FP treatment, and further increased in treatments NP-K_{30} and NP-K_{30}-S_1. It was significantly high (9.1 and 8.4 pods $plant^{-1}$) at NP-K_{60}-S_2 and NP-K_{90}-S_3, respectively (Table 3). Treatments NP-K_0 and NP-K_{30}-S_1 displayed the lowest weight of 100 pods (145.5 g), while NP-K_{60}-S_2 and NP-K_{90}-S_3 gave rise to the highest values, 158.4 and 155.4 g, respectively. The weight of 100 seeds varied from 56 to 60 g, showing no significant influence of treatments, similar to the ratio between seeds and pods weight, which was stable at 69.6-70.1 (Table 3).

The net peanut yield ranged from 2.11 to 2.86 Mg ha^{-1}, at NP-K_0 and NP-K_{60}-S_2, respectively (Fig. 3). Treatment NP-K_{90}-S_3 yield was insignificantly lower than that of NP-K_{60}-S_2, while the net yield tended to decrease at the lower K rates. FP control was an exception; in spite of the high K rate it had been supplied with (100 kg ha^{-1}), its yield remained at a lower level. In fact, NP-K_{60}-S_2 obtained 24% more yield compared to the FP control, and 36% more than NP-K_0. Harvest index increased significantly from

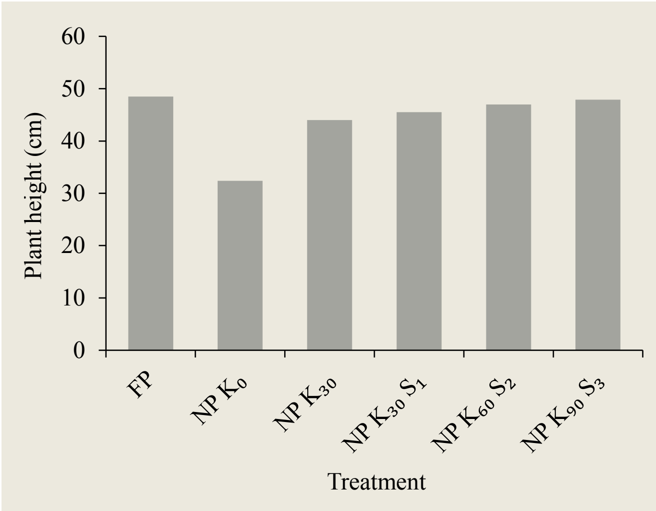


Fig. 3. Peanut plant height at the end of the growth period, 85 DAS, as a function of fertilization treatments.

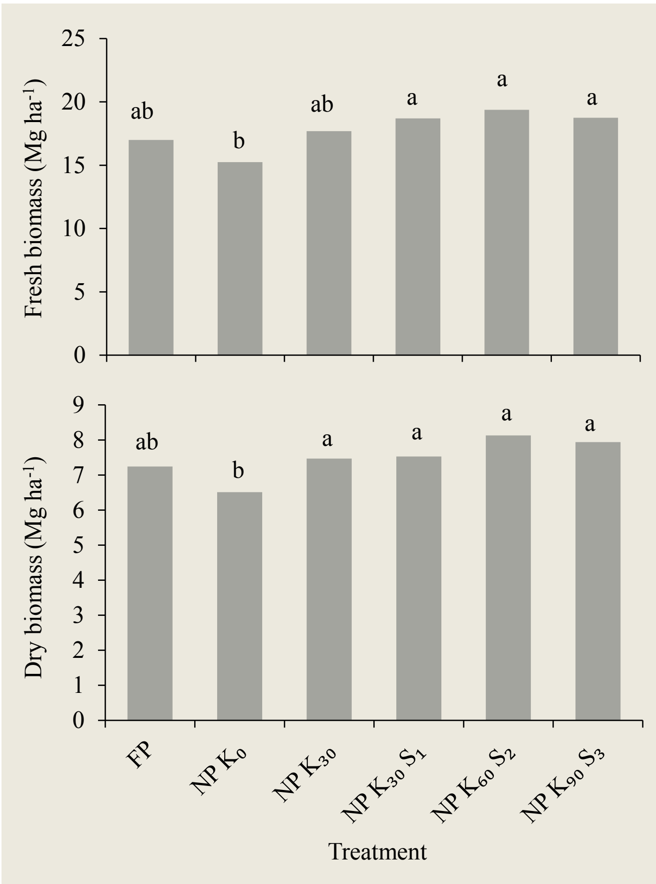


Fig. 4. Effects of fertilization treatments on peanuts' fresh and dry biomass. Different letters indicate statistically significant differences at P <0.05.

Table 3. Peanut yield parameters under the various fertilization treatments.

Treatment		Harvested plants m^{-2}	Filled pods $plant^{-1}$	Weight of 100 pods	Weight of 100 seeds	Seeds pod^{-1}
				---------------g---------------		------%------
T_1	FP	49.3	7.1^{bc}	151.4^{abc}	57.5	69.9
T_2	NP-K_0	49.5	6.6^{c}	145.3^{c}	57.0	69.6
T_3	NP-K_{30}	49.5	8.0^{ab}	149.1^{bc}	58.8	69.8
T_4	NP-K_{30}-S_1	49.5	8.2^{ab}	145.5^{c}	56.0	69.9
T_5	NP-K_{60}-S_2	49.3	9.1^{a}	158.4^{a}	59.1	70.1
T_6	NP-K_{90}-S_3	49.5	8.4^{a}	155.4^{ab}	60.0	69.8
CV (%)		1.4	9.5	3.2	3.5	0.6
LSD (0.05)		1.0	1.1	7.2	3.0	0.7

Note: Different letters indicate statistically significant differences at P <0.05 within a column.

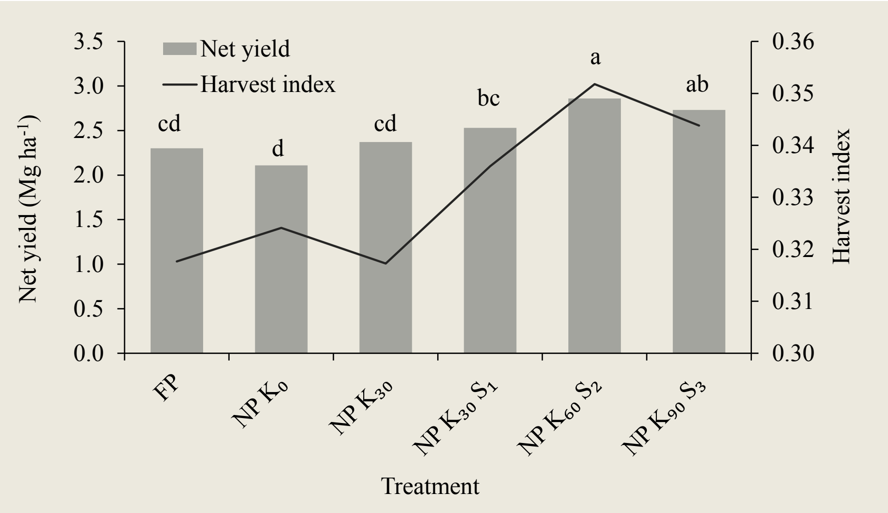


Fig. 5. Effects of fertilization treatments on peanut net yields and harvest index. Different letters indicate statistically differences in net yields at P <0.05.

Photo 1. Overview of the trial plots at Binh Dinh Province, Vietnam. Photo by G. Kalyan.

about 0.32 among treatments lacking S supply, to 0.353 at NP-K_{60}-S_2 (Fig. 5). Fertilization treatments did not show any significant effects, neither on the lipid (49.7-52.4%) nor on protein (25.2-27.9%) content in the seeds.

While the total cost varied slightly among treatments from about 43 to 47 million Vietnamese dong (VND), revenue was much more responsive (Fig. 6A), corresponding directly with the changes in the net yield. The net income grew from 9.97 million VND ha^{-1} for NP-K_0, to 25.82 million VND ha^{-1} for NP-K_{60}-S, an increase of 152%. Compared to the FP control, the additional net income of NP-K_{60}-S_2 was smaller, only 98%. The benefit rate, calculated as net income related to total cost, rose from 0.29 and 0.23 for FP and NP-K_0, respectively, up to 0.57 for NP-K_{60}-S_2 (Fig. 6B).

Most of the fertilization treatments had significant effects on soil properties measured at the end of the experiment (Table 4). Generally, soil acidity decreased - soil pH rose from 5.1 to 5.2-5.7 - however, this effect could not be attributed to the increasing K rate or to the polyhalite supply. Also, soil OM content increased in most treatments. Soil N concentration increased for FP and the three treatments applied with polyhalite, but remained unchanged for NP-K_{30} and even dropped for NP-K_0. Available soil P increased from 17.65 to about 26 for all treatments, excluding FP with 30.89 meq P_2O_5 100 g^{-1} soil. Available soil K declined considerably for FP and NP-K_0, slightly increased for NP-K_{30}, and rose dramatically with the increasing rate of polyhalite (Table 4). Available Ca and Mg rose by about 25% and 100-275%, respectively, among all treatments. Sulfur content fluctuated within a narrow range from 0.026 to 0.056%, without any clear respect to polyhalite application. Soil CEC remained quite stable at about 6.2-6.63 meq 100 g^{-1}, excluding a remarkable drop to 4.98 for FP, and an increase to 7.16 meq 100 g^{-1} for NP-K_{60}-S_2.

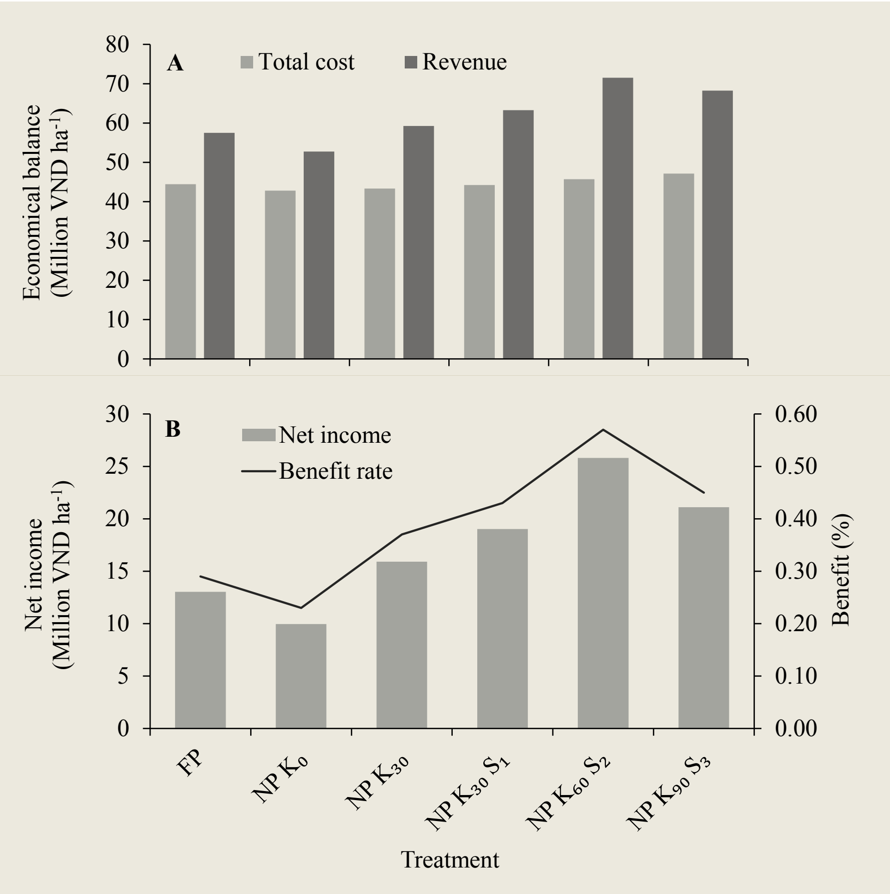


Fig. 6. Effects of fertilization treatments on cost and revenue (A), and on net income and benefit rate (B) from peanut production in 2016 at Cat Hai commune, Phu Cat district, Binh Dinh province, Vietnam.

Discussion

Appropriate crop nutrition management is crucial, particularly on sandy acidic soils in the tropics. The sandy soil (97%) has very low CEC, and the low pH (5.1) further reduces its ability to store nutrients. The substantial CaO supplement (500 kg ha^{-1}) used in the present study gave rise to significant though uneven rise in soil pH (Table 4). On this background of CaO application, polyhalite did not seem to provide any further contribution in elevating soil pH.

Peanut, a leguminous crop, does not require significant N inputs (Balota, 2014). Therefore, the FP control treatment, with its relatively high N and K supply rates (95 kg N ha^{-1} and 100 kg K_2O ha^{-1} vs. 45 and 0-90, respectively, for the other treatments), increased soil N content (Table 4). Lack of K, demonstrated by NP-K_0, led to diminished levels of both soil available N and K, which were gradually replenished with the rising K application rates and by polyhalite supply. These results indicate that K and S supply are essential for normal peanut plant development which, in turn, allows for adequate N_2-fixation by the peanut roots, and hence soil enrichment with N.

Table 4. Soil properties before and, as affected by the fertilization treatments, at the end of the experiment.

Indicators	Pre-experiment	Treatments: Post-experiment					
		FP	NP-K_0	NP-K_{30}	NP-K_{30}-S_1	NP-K_{60}-S_2	NP-K_{90}-S_3
pH_{KCl}	5.1	5.2	5.7	5.6	5.5	5.3	5.5
OM (%)	0.86	0.97	1.03	1.1	1.17	1.1	0.9
N (%)	0.042	0.063	0.027	0.041	0.053	0.071	0.075
P_2O_5 (%)	0.042	0.056	0.049	0.047	0.054	0.051	0.049
Avail. P_2O_5 (mg 100 g^{-1})	17.65	30.89	26.64	25.64	26.97	24.98	26.39
K_2O (%)	0.058	0.059	0.055	0.055	0.057	0.063	0.057
Avail. K_2O (mg 100 g^{-1})	16.87	9.40	12.29	20.61	34.7	51.51	70.85
Ca (meq 100 g^{-1})	0.88	1.10	1.08	1.05	1.05	1.00	1.00
Mg (meq 100 g^{-1})	0.20	0.75	0.6	0.55	0.45	0.40	0.50
S (%)	0.03	0.026	0.034	0.056	0.034	0.043	0.043
CEC (meq 100 g^{-1})	6.76	4.98	6.38	6.2	6.34	7.16	6.63
Sand (%)	97.3	96.63	96.8	96.69	96.72	96.61	97.14
Clay (%)	0.72	0.70	0.53	0.57	0.65	0.49	0.55
Limon (%)	1.98	2.67	2.67	2.73	2.63	2.91	2.31

Interesting, however, are the exhaustion of soil available K and the significant reduction in CEC under FP, in spite of the high K dose. The explanation may rely on soil pH, which remained too low throughout the season (Table 4). Overdose urea applications might damage soil microflora involved with nitrification and acidification processes (Geisseler and Scow, 2014; Tong and Xu, 2014), reinforcing low pH levels. In the absence of microflora, urea is rapidly leached away from the rhizosphere, along with K and other soluble cations. At soil pH 5, nitrification and subsequent N uptake or N_2-fixation by peanut plants was not sufficient to support satisfactory yield levels (Fig. 5). Treatment FP seems, therefore, inappropriate for sustainable and productive peanut cropping systems in Vietnam.

As demonstrated by NP-K_{30}, a threshold K rate of 30 kg K_2O ha^{-1} is essential to establish sufficient plant biomass (Fig. 3). Splitting that dose in time and source (KCl and polyhalite) did not have significant effects on biomass production (Fig. 3), but significantly contributed to pod and seeds set (NP-K_{30}-S_1, Table 3). Doubling K and S rates (NP-K_{60}-S_2) resulted in the maximum yield, with no significant increase in plant biomass. While the synergy between N and S uptake and metabolism in producing proteins and lipids is well documented (McGrath and Zhao, 1996; Kopriva *et al.*, 2002; Brosnan and Brosnan, 2006; Wang *et al.*, 2013), the interaction between K and S has gained much less attention. The combined effect of S and K in the present study seemed to enhance the reproductive phase, increasing grain yield and HI (Fig. 5). While K is known to support carbon translocation and strengthen sink organs, the S role here is obscure. Further increases in K and S rates did not have any influence on peanut yield. Subsequently, the highest profit to the farmer occurred at treatment NP-K_{60}-S_2, with benefit rate of 0.57, twice as high as that of FP (Fig. 6). Recent reports in other crop species also showed optimum patterns or saturation curves in response to polyhalite application (Tiwari *et al.*, 2015; PVFCCo, Vietnam, 2016; Satisha and Ganeshamurthy, 2016).

In conclusion, while the common farmers' fertilization practice in Vietnam failed in supporting sufficient peanut yield and benefit, optimum K (60 kg K_2O ha^{-1}) and polyhalite (214 kg ha^{-1}) doses, split into two applications, gave rise to 24% increase in yield, and to 98% increase in the net benefit to the farmer. In addition, soil examinations before sowing and at the end of the peanut crop indicated that, while FP reduced soil fertility, employing polyhalite to create a balanced N-P-K-S management led to enhanced soil fertility, thus supporting a sustainable cropping system.

Acknowledgement

The authors want to acknowledge the International Potash Institute (IPI), Switzerland, for financing this project.

References

Abd, E.K., and G. Mona. 2013. Effect of Sulfur Application and Foliar Spraying with Zinc and Boron on Yield, Yield Components, and Seed Quality of Peanut (*Arachis hypogaea* L.). Research Journal of Agriculture and Biological Sciences 9:127-135.

Balota, M. 2014. Peanut (*Arachis hypogaea* L.). Nutrition. https://vtechworks.lib.vt.edu/handle/10919/56116.

Bouman, O.T., D. Curtin, C.A. Campbell, V.O. Biederbeck, and H. Ukrainetz. 1995. Soil Acidification from Long-Term Use of Anhydrous Ammonia and Urea. Soil Science Society of America Journal 59:1488-1494.

Brosnan, J.T., and M.E. Brosnan. 2006. The Sulfur-Containing Amino Acids: An Overview. J. of Nutr. 136:16365-16405.

De Geus, J.G. 1973. Fertilizer Guide for Tropicals and Subtropicals. 2nd edition, Centre d'Etude de I' Azote Zurich. p. 440-471.

Elseed, S.M.H., S.O. Yagoub, and I.S. Mohamed. 2015. Effects of Jatropha Seed Cake (JSC) and Different Inorganic Fertilizers on Growth and Yield of Two Groundnut Cultivars under Three Harvesting Periods. American Journal of Experimental Agriculture 6:93.

Gashti, A.H., M.N.S. Vishekaei, and M.H. Hosseinzadeh. 2012. Effect of Potassium and Calcium Application on Yield, Yield Components and Qualitative Characteristics of Peanut (*Arachis hypogaea* L.) in Guilan Province, Iran. World Appl. Sci. J. 16:540-546.

Geisseler, D., and K.M. Scow. 2014. Long-Term Effects of Mineral Fertilizers on Soil Microorganisms - A Review. Soil Biology and Biochemistry 75:54-63.

Jamal, A., Y.S. Moon, and M.Z. Abdin. 2010. Enzyme Activity Assessment of Peanut (*Arachis hypogaea* L.) under Slow-Release Sulfur Fertilization. Australian J. of Crop Science 4:169-174.

Kannan, P., C. Swaminathan, and S. Ponmani. 2016. Sulfur Nutrition for Enhancing Rainfed Groundnut Productivity in Typical Alfisol of Semi-Arid Regions in India. J. Plant Nutri. (in Press). doi.org/10.1080/01904167.2016.1245329.

Kopriva, S., M. Suter, P.V. Ballmoos, H. Hesse, U. Krahenbuhl, H. Rennenberg, and C. Brunold. 2002. Interaction of Sulphate Assimilation with Carbon and Nitrogen Metabolism in Lemna Minor. Plant Physiol. 130:1406-1413.

McGrath, S.P., and F.J. Zhao. 1996. Sulphur Uptake, Yield Response and the Interactions Between N and S in Winter Oilseed Rape (*Brassica napus*). J. Agric. Sci. 126:53-62.

Miller, J.O. 2016. FS 1054: Soil PH and Nutrient Availability. http://drum.lib.umd.edu/handle/1903/18519.

Pratiwi, H., N. Aini, and R. Soelistyono. 2016. Effects of Pseudomonas Fluorescens and Sulfur on Nutrients Uptake, Growth and Yield of Groundnut in an Alkaline Soil. Journal of Degraded and Mining Lands Management 3:507-516.

PVFCCo, Vietnam. 2016. Polyhalite Application Improves Tea (*Camillia sinensis*) Yield and Quality in Vietnam.

IPI *e-ifc* 46:22-29. http://www.ipipotash.org/eifc/2016/46/3/english.

Ramjeet Yadav, L.K., S.N. Yadav, R.P. Singh, and P.K. Yadav. 2015. Effect of Gypsum on Growth and Yield of Groundnut (*Arachis hypogaea* L.). Environment & Ecology 33:676-679.

Satisha, G.C., and A.N. Ganeshamurthy. 2016. Bioefficacy of Polyhalite Application on Yield and Quality of Cabbage and Cauliflower. IPI *e-ifc* 44:21-31. http://www.ipipotash.org/eifc/2016/44/3/english.

Tiwari, D.D., S.B. Pandey, and N.K. Katiyar. 2015. Effects of Polyhalite as a Fertilizer on Yield and Quality of the Oilseed Crops Mustard and Sesame. IPI *e-ifc* 42:10-17. http://www.ipipotash.org/eifc/2015/42/2/English.

Tong, D., and R. Xu. 2012. Effects of Urea and $(NH_4)_2SO_4$ on Nitrification and Acidification of Ultisols from Southern China. Journal of Environmental Sciences 24:682-689.

Wang, Y.Y., J.L. Zhang, F. Zhang, C.T. Yang, F. Gao, T.T. Wei, and X.D. Li. 2013. Effects of Different S Fertilizer Application on Nitrogen Metabolism in Peanut. Journal of Peanut Science 1:002.

The paper "Agronomic Efficiency of Polyhalite Application on Peanut Yield and Quality in Vietnam" also appears on the IPI website at:

Regional activities/Southeast Asia

Research Findings

Photo by G. Kalyan.

Polyhalite Application Improves Coffee (*Coffea robusta*) Yield and Quality in Vietnam

Article from report contributed by PVFCCo, Vietnam[1]

Abstract

Vietnam produces around 1.2 million tons of coffee per year, the second highest yield in the world after Brazil. Improving resource utilization efficiency has recently been determined as the major strategic goal of the industry. Appropriate mineral nutrition practices are pivotal to achieving these goals. The humid, tropical climate and acid soils create considerable challenges to achieving the optimum balance for crop nutrition practices. The availability of alkaline elements, particularly potassium (K), calcium (Ca), and magnesium (Mg), is steadily declining. Polyhalite, a natural marine sedimentary mineral consisting of a hydrated sulfate of K, Ca, Mg and sulfur (S, 48%) was examined as a potential additive to composite NPK fertilizers. The mineral was tested as part of an alternative fertilization program for the coffee industry in the Lam Dong province. An experiment testing three fertilization practices (CT1 - farmers' practice control; CT2 - employing composite NPKS but lacking Ca and Mg; and, CT3 - similar to CT2, with additional polyhalite applications) was carried out in Bao Lam (reddish brown soil) and Di Linh (grey soil) during 2016. In both districts, CT2 was significantly more profitable than CT1, and CT3 more so than CT2. The results suggest that the common

[1]Petrovietnam Fertilizer and Chemicals Corporation (PVFCCo), Vietnam
Contact: ipi@ipipotash.org

coffee fertilization practice (CT1) in these regions of Vietnam may be considerably improved using additional S fertilizers. The availability of Ca and Mg appears to be significant to coffee crop production, and their increased application should be considered. Added to a systematic NPK fertilization program, polyhalite enhanced coffee yields and quality parameters, thus increasing productivity by 9-11.5% and raising profits by 10 and 14% at Di Linh and Bao Lam, respectively. Polysulphate demonstrated an ability to supply plant Ca and Mg requirements and maintain soil fertility, whilst supporting greater biomass production, compared to the alternative fertilization programs.

Keywords: calcium; *Coffea robusta*; mineral nutrition; Polysulphate; potassium; sulfur.

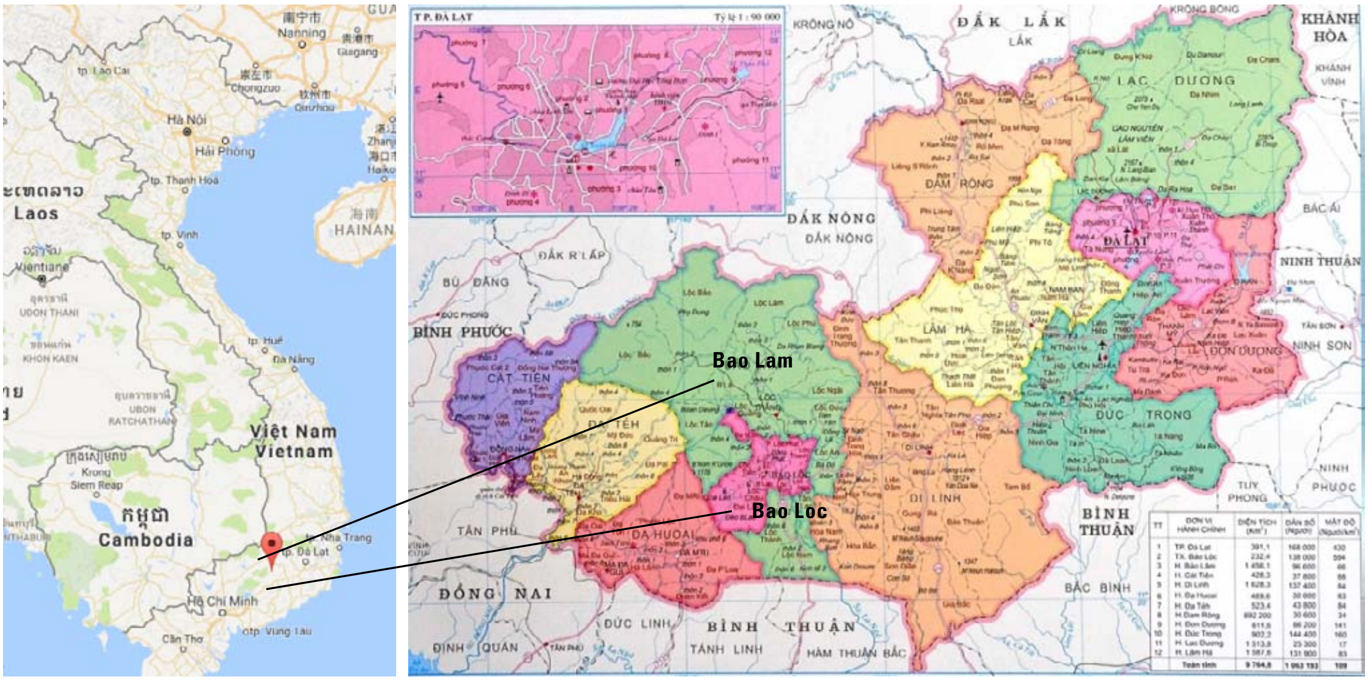
Introduction

Coffee is an important crop for Vietnam, producing around 1.2 million tons of coffee per year, the second highest yield in the world after Brazil. Exported coffee products contributed U$3.62 billion to the Vietnamese economy in 2014 alone (FAO, 2015).

Through intensified farming methods, including irrigation during the dry season, Vietnam has been able to develop robusta coffee (*Coffea robusta* or canephora) as a high yielding cash crop (Marsh, 2007). Nevertheless, the coffee industry in Vietnam is currently experiencing significant challenges (Amarasinghe *et al.*, 2015). Improving resource utilization efficiency has recently been determined as the major strategic goal of this industry.

With over 144,000 ha of coffee under cultivation and total annual output of about 347,000 tons, Lam Dong province is the country's second largest coffee-growing area (Lam Dong Portal, 2016). However, more than 50,000 ha comprise of old plantations planted 15-35 years ago, and are suffering from a decline in productivity. According to the province's coffee development plan, 33,300 ha of coffee were re-planted during 2015. Three new varieties, TR4, TR9 and TR11 developed by the Central Highlands Institute for Agro-Forestry Science and Technology were used. The new area is expected to produce an annual coffee output of 2.8-3.0 Mg ha^{-1} instead of the current 2.5 Mg ha^{-1} (Lam Dong Portal, 2016).

In addition to the necessary renewal of plant resources, appropriate mineral nutrition practices are pivotal to the enhancement of coffee productivity in Vietnam (Tiem, 1999). 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 ash. 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 (Tiem, 1999). Studying suitable soil properties for coffee production, Chiem and Nhan



Map 1. Vietnam map (left, Google Maps); and right the two experiment sites, Bao Lam and Bao Loc, in Lam Dong province (http://www.lamdong.gov.vn/EN-US/HOME/ABOUT/Pages/Lam-Dong-map.aspx).

(1974) showed that coffee yields are strongly affected by the content of organic matter - total nitrogen (N), potassium (K) and available phosphorus (P).

In recent years, intensive farming practices have been introduced to the Vietnamese coffee industry. The consequent rise in productivity has generated significant pressure on the mineral nutrition status of the soil (Sanh, 2009; Tien *et al.*, 2015a, b). The availability of alkaline elements - in particular K, calcium (Ca), and magnesium (Mg) - is steadily declining (Nam and Hong, 1993; Hong, 1997; Tien *et al.*, 2015b). The tropical climate of Lam Dong and frequent heavy precipitation accelerates soil weathering and nutrient loss through leaching from the root zone. Consequently, deficiency symptoms often occur in plantations that were previously highly productive (Sanh, 2009).

The recently introduced composite NPK fertilizers (Phu My products) are not diverse enough to meet all nutrient requirements at each stage of growth, and on differing soils. To obtain suitable fertilization formulas, Phu My NPK fertilizers are used in combination with additives, such as urea (NH_4^+), ammonium sulphate ($\{NH_4\}_2SO_4$) and potassium chloride (KCl). However, these do not always provide a sufficient solution for the declining alkaline cations (Forestier, 1969).

Sulfur (S) is recognized as the fourth major plant nutrient after N, P, and K (Khan *et al.*, 2005), and has been associated with high productivity (Zhao *et al.*, 1999; Saito, 2004; Kovar and Grant, 2011). Sulfur often interacts with N to significantly enhance crop productivity (Jamal *et al.*, 2010). However, current information regarding S application to acidic soils under tropical climates, is scarce.

Polysulphate (produced by Cleveland Potash Ltd., UK) is the trade mark of the natural mineral 'polyhalite', which occurs in sedimentary marine evaporates and consists 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, England, typically consist of 14% potassium oxide (K_2O), 48% sulfur trioxide (SO_3), 6% magnesium oxide (MgO), and 17% calcium oxide (CaO). Polyhalite has slow-release properties and due to this, it is postulated that if integrated into a fertilization program as an additive to Phu My NPK products, a more balanced and stable flow of nutrients could be achieved.

The objectives of the present study were to evaluate the agricultural efficiency of Polysulphate for coffee production in Vietnam, and to test economically, two novel alternative fertilization programs in comparison to traditional practice.

Table 1. Fertilizer compositions and programs (CT1, CT2, and CT3) used on robusta coffee plantations at Bao Lam and Di Linh districts, Vietnam.

Fertilizer	Amount of fertilizer		
	CT1 (Control; farmers' practice)	CT2 (Phu My Fertilizer)	CT3 (Phu My Fertilizer + Polysulphate)
	----------kg ha^{-1}----------		
Polysulphate	0	0	200
NPKS (16-16-8-13)	0	400	400
NPK (15-15-15)	0	500	500
NPKS (15-8-20-10)	0	500	500
Urea	715	250	250
Fused Ca-Mg-P	1,193	0	0
KCl	545	200	153

Materials and methods

Two parallel experiments were conducted at two districts, Bao Lam and Di Linh, of the Lam Dong province in Vietnam (Map 1). Ten year old robusta coffee plantations were studied at both sites. The experiments lasted from April to December 2015.

Three fertilization programs were tested (Table 1): CT1 (control) simulated farmers' common practice through which N was applied using urea, K through KCl (60% K_2O), and P through a local blend containing fused Ca, Mg, and P; CT2 employed commercially available Phu My composite fertilizers, one of which included S but none included Ca and Mg; CT3 was similar to CT2 but was fortified with Polysulphate. Fertilizer rates were similar at Bao Lam (reddish brown soil), and at Di Linh (grey soil), and KCl administration aimed at balancing K supply between the programs.

All treatments were applied with 15-20 m^3 ha^{-1} cattle manure, which was applied at early or mid-rainy season, embedded 10-15 cm deep in the soil under the tree canopy. For the CT1 program, the entire annual fertilizer dose, including fused Ca-Mg-P, was applied at the end of the dry season. For CT2 and CT3, fertilizer applications were distributed during the season as detailed in Table 2. During the dry season, fertilizer was applied toward the irrigation cycle.

Soil samples were taken (one sample from each experimental plot, 5-30 cm deep) once before fertilizer application and then again during harvest (December) to be analyzed for fertility parameters (Table 3). At the beginning of the experiment, soil at both sites was acidic, with pH_{KCl} ranging from 4.49-4.58 at Di Linh, and from 5.03-5.07 at Bao Lam. Soil organic matter (OM) content was much higher at Bao Lam (8.7%) than at Di Linh (4.6%). Soil fertility was far better at Bao Lam than at Di Linh, as indicated by almost all levels of soil available nutrients (Table 3).

Table 2. Time of fertilizer application during the season.

Time of year		Polysulphate	Urea	NPKS 16-16-8-13	NPK 15-15-15	NPKS 15-8-20-10	KCl
April	End of dry season	100	150	-	-	-	-
May-Jun	Early rainy season	-	100	400	-	-	-
Jul-Aug	Mid rainy season	-	-	-	500	-	153
Sep-Oct	Late rainy season	100	-	-	-	500	-

Table 3. Soil properties at the two experimental sites before and after the growing season.

Location	Soil property	Treatment					
		Before			After		
		CT1	CT2	CT3	CT1	CT2	CT3
Bao Lam (reddish brown soil)	pH_{KCl}	5.07	5.03	5.06	5.04	5.01	5.02
	OM (%)	8.72	8.74	8.75	8.68	8.70	8.70
	Total soil N (%)	0.293	0.295	0.295	0.294	0.296	0.297
	Total soil P_2O_5 (%)	0.24	0.25	0.24	0.24	0.25	0.25
	Total soil K_2O (%)	0.14	0.14	0.14	0.14	0.14	0.14
	Available P_2O_5 (mg 100 g^{-1})	14.6	14.7	14.8	14.8	15.0	15.1
	Available K_2O (mg 100 g^{-1})	26.9	26.8	26.9	26.9	27.0	27.0
	Ca^{++} (meq 100 g^{-1})	3.1	3.2	3.1	3.3	2.9	3.2
	Mg^{++} (meq 100 g^{-1})	2.7	2.8	2.5	2.8	2.5	2.6
	S (%)	0.019	0.018	0.019	0.017	0.018	0.020
Di Linh (grey soil)	pH_{KCl}	4.56	4.58	4.49	4.48	4.55	4.44
	OM (%)	4.63	4.64	4.66	4.65	4.65	4.68
	Total soil N (%)	0.193	0.195	0.195	0.195	0.197	0.196
	Total soil P_2O_5 (%)	0.12	0.12	0.12	0.12	0.12	0.12
	Total soil K_2O (%)	0.09	0.09	0.09	0.09	0.09	0.10
	Available P_2O_5 (mg 100 g^{-1})	7.6	7.7	7.8	7.8	7.8	8.0
	Available K_2O (mg 100 g^{-1})	13.3	13.5	13.5	13.5	13.6	13.7
	Ca^{++} (meq 100 g^{-1})	2.5	2.6	2.5	2.7	2.4	2.5
	Mg^{++} (meq 100 g^{-1})	2.2	2.2	2.1	2.3	2.0	2.2
	S (%)	0.015	0.016	0.016	0.014	0.017	0.017

However, no significant differences were observed regarding soil S contents.

Coffee plant leaf samples were taken 30 days before and after fertilizer application. In each experimental 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, samples were dried at 70ºC, ground to fine powder and analyzed for mineral content. Samples were digested with sulfuric acid (H_2SO_4) and hydrochloric acid (HCl), then N content was determined by Kjeldahl, K by flame photometer and P by spectrophotometer; Ca and Mg contents were determined by digesting samples with nitrous acid (HNO_2) and HCl, then determined by atomic absorption spectroscopy. Tree growth rate was evaluated through monthly measurements of the elongation and branching of four pre-designated branches per tree.

The infection rates of rust disease and green scale-bugs were determined monthly by a visual inspection of 50 trees per plot. After fruit set, a 1 m branch per tree was tagged and the fruitlets were counted monthly until harvest, determining fruitlet abscission rate. At harvest, fruit and core yields were determined for each plot and fruit samples were used to measure yield and quality parameters (fruit weight, volume, flesh/core ratio, core size). The economic efficiency of the fertilizer treatments was evaluated using total costs, revenue, and profit.

The experimental plan at each site comprised of nine 0.11 ha plots using a completely randomized block design with three repetitions.

Results and discussion

The impact of the different fertilization programs on soil fertility parameters was very small but complex (Table 3). Soil acidity tended to increase during the growing season at both locations, under all treatments. This trend indicates soil is undergoing active degradation processes and requires a significant supplementation of lime. Content of OM decreased slightly during the growing season at Bao Lam but increased marginally at Di Linh. Total OM as well as available NPK levels remained stable or increased very slightly (Table 3). No differences could be observed between treatments regarding the above mentioned soil parameters. Such results indicate that N, P and K were sufficiently applied in all three programs.

However, significant differences between treatments did occur with regard to Ca and Mg. While the content of these elements remained stable or even increased under the CT1 and CT3 programs, they tended to decline at CT2, suggesting a fragile balance between soil availability and coffee crop Ca and Mg requirements. At both sites, soil S content slightly decreased using the CT1 fertilizers, remained stable using CT2, and increased a little with CT3 (Table 3).

Nitrogen content ranges from 2.8-3.5% in the leaves of normally yielding *Coffea robusta* trees (Chiem and Nhan, 1974). Suitable P content range is between 0.11-0.13% (Nhan, 1988), and required K content is 2-2.20% (Forestier, 1969). These NPK values are in line with those mentioned by Wairegi and Asten (2012). According to Bragança and Venègas (1990), the contents of secondary elements should range from 0.6-0.9% Ca, 0.20-0.26% Mg and 0.12-0.17% S, twofold less than those found by Wairegi and Asten (2012) under East African conditions. Thus, leaf NPK contents before fertilizer application were at the lower, but acceptable levels at both sites. However, the contents of the secondary elements were at the lower range, indicating deficiency (Table 4), depending which reference values are used.

Table 4. Effect of fertilizer treatments on leaf N, P, K, Ca, Mg, and S contents (%) in *Coffea robusta* at Bao Lam and Die Linh in Vietnam.

Site	Element	Before fertilization			After fertilization		
		CT1	CT2	CT3	CT1	CT2	CT3
		----------------	----------------	----------------	% ----------------	----------------	----------------
Bao Lam	N	2.88	2.83	2.85	3.25	3.28	3.27
	P	0.116	0.113	0.115	0.126	0.124	0.127
	K	2.05	2.07	2.06	2.16	2.13	2.15
	Ca	0.66	0.64	0.65	0.84	0.52	0.81
	Mg	0.24	0.23	0.22	0.24	0.18	0.24
	S	0.126	0.127	0.124	0.112	0.155	0.156
Di Linh	N	2.80	2.79	2.82	3.11	3.14	3.13
	P	0.112	0.112	0.110	0.121	0.123	0.122
	K	2.01	2.01	1.99	2.09	2.11	2.09
	Ca	0.61	0.63	0.59	0.74	0.50	0.72
	Mg	0.19	0.21	0.20	0.22	0.17	0.22
	S	0.122	0.120	0.121	0.108	0.147	0.149

Thirty days after fertilizer applications, leaf N contents significantly increased by 13%, while increases in leaf P and K contents were moderate or low - 8.5 or 5%, respectively (Table 4). Fertilization effects on leaf Ca and Mg differed significantly among treatments. CT1 and CT3 brought about a significant increase in leaf Ca content and maintained Mg levels. CT2, which did not provide Ca and Mg, resulted in a considerable drop in these nutrients at both sites. No advantage was observed for any of the fertilizers, fused Ca-Mg-P or Polysulphate, as a source of Ca or Mg. However, it is questionable whether the additional Ca/Mg from fertilizer applications were sufficient to support maximum yield production. It is possible that fertilizer doses should be increased further.

Leaf S content following CT1 treatment, where fertilizers lacked S, declined significantly during the season. The CT2 and CT3 treatments contained an amount of 102 kg S ha^{-1} applied through NPKS fertilizers (Tables 1 and 2), which may explain why leaf S content rose markedly (Table 4). The additional dose of 28 kg S ha^{-1} provided by Polysulphate in CT3 did not bring about any further rise in leaf S content. It appears then, that for the reddish brown soil in Bao Lam and the grey soil in Di Linh, an S rate of 100 kg ha^{-1} would be appropriate.

Tree growth, exhibited by branch elongation, was significantly affected by the fertilization treatments (Fig. 1). The CT3 fertilization program led to a significantly higher growth rate than CT1, while CT2 showed intermediate values. Trees grew faster at Bao Lam than at Di Linh.

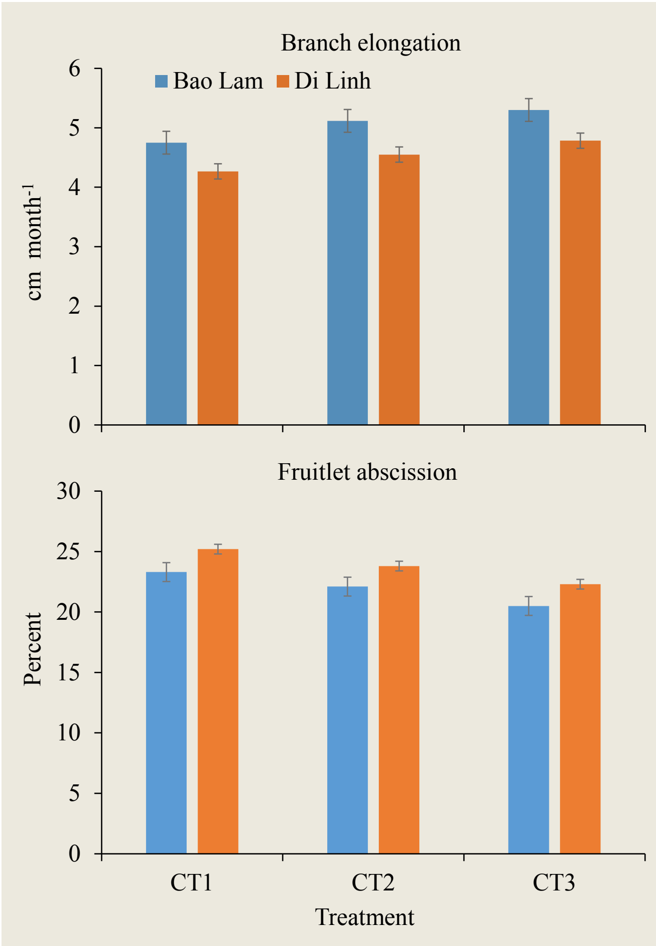


Fig. 1. Effect of fertilizer treatments on branch elongation and on fruitlet abscission in *Coffea robusta* trees grown at Bao Lam and Di Linh districts, Lam Dong province, Vietnam. Bars indicate LSD at 5%.

Photo by G. Kalyan.

Infection rates of rust disease were somewhat higher at Bao Lam (4-6%), compared to Di Linh (2-4%), but no differences occurred among treatments in this regard. The frequency of green scale-bugs was relatively high at Bao Lam (8-10%), but much lower at Di Linh (2-4%). Again, no differences occurred between treatments.

During the reproductive phase of the coffee tree, immature fruit (fruitlets) often tend to abscise. The reasons for fruitlet abscission may include physiological disorders, stormy weather, water stress as well as inadequate mineral nutrition (Mitchell, 1988; Wilson, 2004). In the present study, fruitlet abscission rates were the highest at CT1, slightly lower at CT2, and significantly less at CT3 (Fig. 1). Abscission rates were consistently higher at Di Linh than at Bao Lam.

The CT3 treatment gave rise to a 10-11.5% increase in coffee yield compared to the CT1 control treatment (Fig. 2). The CT2 program resulted in a somewhat higher yield than the control, but significantly lower than CT3. Also here, CT2 yields at Di Linh were always lower than at Bao Lam. Under the CT1 treatment, fruit weighed 92.8 g 100 fruit^{-1} and 93.8 g 100 fruit^{-1} at Di Linh and Bao Lam, respectively, 93.9/94.7 g under CT2, and 94.6/95.3 g under CT3 (Fig. 2). Nevertheless, the significantly higher yield of CT3 should be attributed to the accumulative effect of many small changes, such as the number and length of platform branches carrying the reproductive organs, and the decrease in fruitlet abscission. Both factors contribute to an elevated number of tree fruit.

Fertilizer treatments also influenced fruit quality. Flesh/core ratio decreased steadily from 4.42 and 4.45 in CT1, to 4.37 and 4.40 in CT2, and further to 4.28 and 4.31 in CT3, at Bao Lam and Di Linh, respectively. A core diameter greater than 6.3 mm is an indicator of high-quality fruit; the rate of A-size core production climbed consistently from about 19.5% in CT1 to 20-21.5% in CT2, and further to 22.2% in CT3 (Fig. 2).

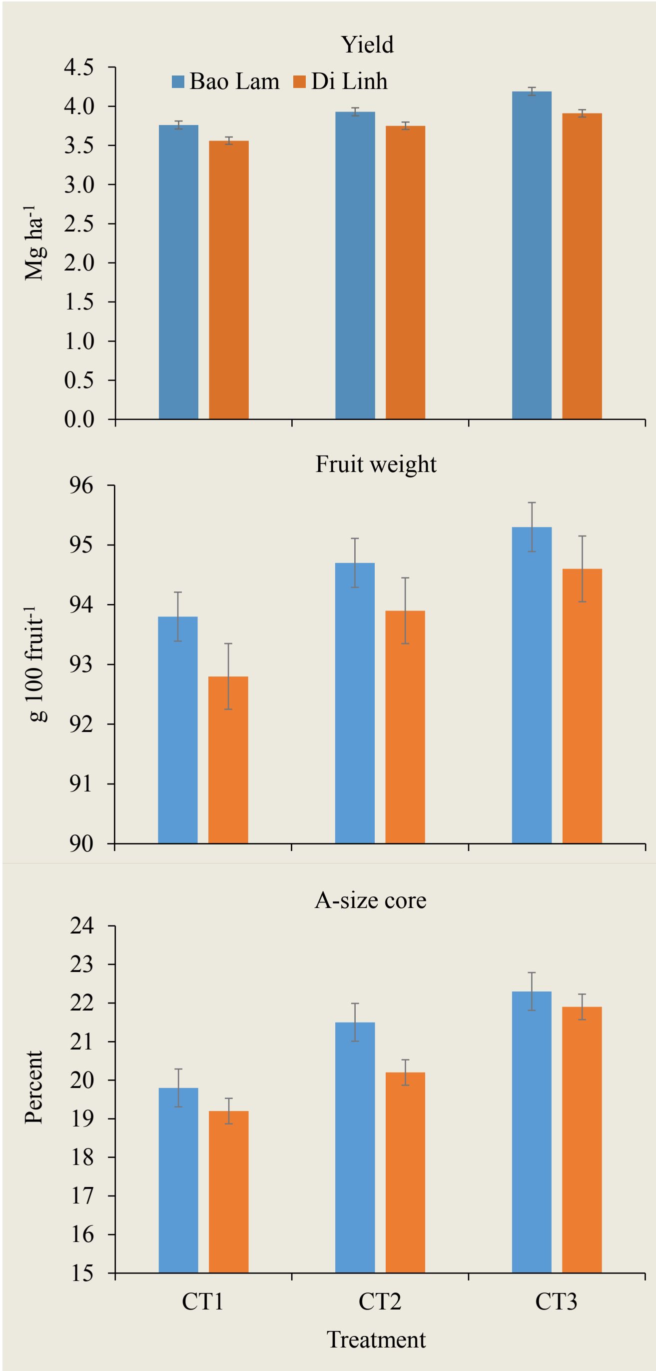


Fig. 2. Effect of fertilizer treatments on core yield, fruit weight, and fruit quality in *Coffea robusta* trees grown at Bao Lam and Di Linh districts, Lam Dong province, Vietnam. Bars indicate LSD at 5%.

Compared with CT1, the farmers' practice control, CT2 enhanced coffee crop performance (Figs 1 and 2). This is probably due to the more even distribution of fertilizer application throughout the season, and to the diverse nature of the fertilizer. The considerable

Fig. 3. Effect of fertilizer treatments on the total costs, revenue, and profit of *Coffea robusta* grown at Bao Lam and Di Linh districts, Lam Dong province, Vietnam.

disadvantage of CT2 i.e. the lack of Ca and Mg, seems to have been largely compensated for by the addition of S from composite NPKS fertilizers. Yet, the consequent rising production costs deducted from the surge in revenue, so the profits of CT1 and CT2 equalized (Fig. 3). CT3 demonstrated the advantage of combining a more even application of diverse composite NPKS fertilizers with the employment of Polysulphate, a stable, slow-release, source of Ca, Mg, S, and K. By providing sufficient nutrient uptake (Table 4), this combination can fully replace the cheaper but less efficient basal application of urea, KCl, and fused Ca-Mg-P practiced under the CT1 program. Possible advantages of splitting K fertilizer annual dose or using slow-release sources of Ca, Mg, S and K were already envisaged in previous studies carried out on similar soil types in neighboring Dak Lak district in Vietnam (Tien *et al.*, 2015a, b). Thus, in spite of a 10% increase in costs, CT3 brought about profit increases ranging from 10-14% more than CT1 (Fig. 3) and maintained profit rates of 49-56% - also slightly higher than that of CT1.

Conclusions

In both districts, CT2 was significantly more profitable than CT1, and CT3 more so than CT2. These results suggest that the common coffee fertilization practice (CT1) in the Bao Lam and Di Linh regions of Vietnam may be considerably improved using additional S fertilizers. While no direct effect of S could be observed, it may have facilitated N uptake and metabolism by coffee plants leading to yield enhancement. The availability of nutrients such as Ca and Mg, appears to be significant for coffee crop production and their increased application should be considered. Polysulphate, added to a systematic NPK fertilization program for coffee plants grown on reddish brown soil at Bao Lam or on grey soil at Di Linh, enhanced coffee yields and quality parameters, thus increasing productivity by 9-11.5%. Overall, Polysulphate application gave rise to profit increases of 10% and 14% at Di Linh and Bao Lam, respectively. Polysulphate demonstrated an ability to supply plant Ca and Mg requirements and maintain soil fertility, while supporting greater biomass production, compared to the alternative fertilization programs.

References

Amarasinghe U., C.T. Hoanh, D. D'haeze, and T.Q. Hung. 2015. Toward Sustainable Coffee Production in Vietnam: More Coffee with Less Water. Agricultural Systems 136:96-105.

Bragança, S.M., and V.H.A. Venègas. 1990. Evaluation of the Nutritional Status of the Coffee (*Coffea canephora*) Cultivar Conilon in the North of the State of Espírito Santo, by Means of the Diagnosis and Recommendation Integrated System (DRIS). Pesquisa em Andamento-EMCAPA (57).

Chiem, N.T., and D.T. Nhan. 1974. Change of Some Soil Chemical and Physical Properties in Basaltic Soil Cultivated with Coffee and Rubber in Phu Quy. Soil and Fertilizer Research 4:3-26.

Food and Agriculture Organization of the United Nations - Production FAOSTAT. Retrieved February 2014.

Forestier, F. 1969. New Problems Used Mineral Fertilizer on Coffee in Republic of Middle Africa. The Café - Cacao 1/1969.

Hong, T. 1997. Determining Suitable NPK Compound Fertilizers for Robusta Coffee on Reddish Brown Basaltic Soil in Dak Lak Province and Grey Granite Soil in Kon Tum Province. PhD Thesis, Institute of Agricultural Science for Southern Vietnam, Ho Chi Minh City.

Jamal, A., Y-S., Moon, and M.Z. Abdin. 2010. Sulphur - A General Overview and Interaction with Nitrogen. Australian J. Crop Sci. 4:523-529.

Khan, N.A., M. Mobin, and Samiullah. 2005. The Influence of Gibberellic Acid and Sulfur Fertilization Rate on Growth and S-Use Efficiency of Mustard (*Brassica juncea*). Plant and Soil 270:269-274.

Kovar, J.L., and C.A. Grant. 2011. Nutrient Cycling in Soils: Sulfur. Publications from USDA-ARS/UNL Faculty. Paper 1383. http://digitalcommons.unl.edu/usdaarsfacpub/1383.

Lam Dong Portal. 2016. Lam Dong to Re-Plant 33,000 Hectares of Coffee. http://www.lamdong.gov.vn/en-US/home/news/hotnews/Pages/Lam-Dong-to-re-plant-33,000-hectares-of-coffee.aspx.

Photo by G. Kalyan.

Marsh, A. 2007. Diversification by Smallholder Farmers: Viet Nam Robusta Coffee. Agricultural Management, Marketing and Finance Working Document 19. FAO, Rome.

Mitchell, H.W. 1988. Cultivation and Harvesting of Arabica Coffee Tree. *In:* Clarke, R.J., and R. Macre (eds.). Coffee. Agronomy, Elsevier Applied Science, London 4:43-90.

Nam, T.N.T., and T. Hong. 1993. Research Results of Applying NPK Compound Fertilizers for Robusta Coffee on Two Sites of Basaltic Soil in Dak Lak Province. Scientific Report for Ministry of Agriculture and Rural Development.

Nhan, D.T. 1988. Investigation on Soil, Leaf Analysis and Fertilizer Use for Coffee in the North of Vietnam and Central Highlands. Report. 12. International Scientific Colloquium on Coffee (No. 633.73063 C714 1987). Association Scientifique Internationale du Café, París (Francia).

Sanh, N.V. 2009. Research on Nutrient Deficiency Diagnostic in Coffee Leaf and its Application for Fertilizer Recommendation for Robusta Coffee in Dak Lak Province. PhD Thesis, Hanoi Agricultural University, Hanoi.

Saito, K. 2004. Sulfur Assimilatory Metabolism. The Long and Smelling Road. Plant Physiol. 136:2443-2450.

Tiem, H.T. 1999. The Vietnamese Coffee. Agricultural Publishing House, Hanoi.

Tien, T.M., H.C. Truc, and N.V. Bo. 2015a. Effects of Annual Potassium Dosage on the Yield and Quality of *Coffea robusta* in Vietnam. IPI *e-ifc* 41:13-20.

Tien, T.M., H.C. Truc, and N.V. Bo. 2015b. Potassium Application and Uptake in Coffee (*Coffea robusta*) plantations in Vietnam. IPI *e-ifc* 42:3-9.

Wilson, K.C. 2004. Coffee, Cocoa, and Tea. Series of Crop Production Science in Horticulture, 8. CABI Pub.: Oxon, UK; Cambridge, Mass.

Wairegi, L.W.I., and P.J.A. Van Asten. 2012. Norms for Multivariate Diagnosis of Nutrient Imbalance in Arabica and Robusta Coffee in the East African Highlands. Expl. Agric. 48:448-460.

Zhao, F.J., M.J. Hawkesford, and S.P. McGrath. 1999. Sulfur Assimilation and Effects on Yield and Quality of Wheat. J. Cereal Sci. 30:1-17.

The paper "Polyhalite Application Improves Coffee (*Coffea robusta*) Yield and Quality in Vietnam" also appears on the IPI website at:

Regional activities/Southeast Asia

Research Findings

IPI intern in a meeting with a farmer. Photo by authors.

Promoting Precise and Balanced Use of Fertilizers in Pakistan at Farm-Gate Level

Wakeel, A.[(1)(2)*], and M. Ishfaq[(1)]

Introduction

Pakistan is an agricultural country where the agriculture sector is not only feeding a huge and perpetually increasing population, but it also provides significantly (~21%) to the GDP of Pakistan (Economic Survey of Pakistan, 2014-15). The use of chemical fertilizers, especially nitrogen (N) and phosphorus (P), began in Pakistan after the Green Revolution (1960-1970) and is continuing to increase every year to fulfil crops' nutritional requirements. The majority of the farming community in Pakistan relies upon N and P fertilizers, according to their economic resources and awareness, while the use of potash is severely neglected. Potassium (K) is considered an indispensable element for plants due to its role in enzyme activation, charge balance and osmotic regulation (Reddya *et al*., 2004; Marschner, 2012; Wakeel, 2013). In addition, K improves the quality of agricultural products and extends shelf life.

[(1)]Institute of Soil and Environmental Sciences, University of Agriculture, Faisalabad-38040, Pakistan.
[(2)]IPI Consultant for Pakistan, International Potash Institute (IPI), Zug, Switzerland
*Corresponding author: abdulwakeel77@gmail.com

Although Pakistani soils are rich in K due to the presence of mica and illite clay minerals (Bajwa, 1994), ~40% of Pakistani soils are deficient in available K for plant growth and development (Akhtar *et al.*, 2003). Canal water is considered a good source of K and could partially fulfil potash requirements, however, canal water availability is inadequate in Pakistan's major cultivation areas. Furthermore, high yielding crop varieties/hybrids are also removing more K than is annually applied to the soil (Ranjha *et al.*, 1990). The per ha yield increase for rice, wheat and maize is 100%, 40% and 200%, respectively when compared to 1994 (Economic Survey of Pakistan, 2014-15). As a result of these high yielding varieties/hybrids and intensive agricultural practices, it is estimated that approximately 0.265 million Mt of K are depleted annually from Pakistani soils (Bajwa, 1994), while the annual addition of K fertilizers is ~0.03 Mt K_2O. This is very precarious for sustainable agriculture. Therefore, there is an immediate need to promote the use of K fertilizers for sustainable and economical agricultural production in Pakistan.

Unawareness of the importance of potash and the lack of soil analysis facilities are among the major constraints to balanced fertilizer use. The need to communicate the important aspects of K fertilization to farmers is dire, especially considering the significance of K fertilization during biotic and abiotic stresses which are very common in Pakistan. A number of private and public sector organizations are providing advisory services to farmers, however, the focus is not on K fertilizer use as the market share of K fertilizers is much less than N and P.

Objectives of internship

- To convey the significance of potash fertilization directly to farmers at the farm gate.
- To observe the nutrient deficiency symptoms of various crops and inquire about fertilizer use and cropping patterns.
- To obtain soil samples, carry out analyses and provide the farmers with fertilizer recommendations based on soil analysis.

Internship program 2015

A three month internship program was launched in 2015 by the International Potash Institute (IPI), Switzerland, purely dedicated to highlighting the importance of K and the balanced use of fertilizers in different areas of Pakistan. Interns were sent to four selected regions (Faisalabad, Multan, Sukkur and Matiari) in collaboration with Engro Fertilizers and Fauji Fertilizer Company (FFC) to interact with farmers, collect important on-farm information and soil samples, and to provide farmers with fertilizer recommendations based on soil analysis reports. Positive impacts were observed and an increase in K fertilizer demand occurred following the internship program. The 2015 internship report has been published on the IPI website: http://www.ipipotash.org/publications/detail.php?i=453.

Internship program 2016

In 2016, the internship program was carried out again with slight modifications based on experiences of the previous year. The interns - agricultural graduates selected from two Pakistani universities - were sent to a cotton growing area where they interacted with the farmers. They were allocated to the district of Vehari and Multan after a pre-internship training workshop held on 12 February 2016 at the University of Agriculture Faisalabad, in coordination with IPI.

Representatives of FFC, Engro Fertilizer and the Fatima Fertilizer Company were invited for an introductory lecture where they explained to the interns the advisory systems provided to their respective farmers. An introduction to IPI and the field experiences of the previous year were also presented. The purpose of the workshop was to acquaint the interns with the required knowledge to communicate fertilizer use, and specifically the importance of potash fertilization, to farmers. At the end of the workshop, IPI kits (field bag with literature and other accessories) were distributed to selected interns.

During the program, interns were expected to obtain soil samples and file these for analysis to make precise fertilization applications in cotton growing areas of Pakistan.

IPI intern collecting soil samples at farmer's field. Photo by authors.

Each intern was assigned to interview at least 75 farmers individually and collect their basic farm-data such as the total area of land under cultivation, the source of irrigation, fertilizer use during the last five years, cropping pattern, per acre yield, previous soil analysis report (if any) and fertilizer recommendations. In addition, they were required to collect and analyze soil samples and provide the farmers with soil fertility status and fertilizer recommendations. Each farmer interviewed was also provided with the booklet 'Potassium - A Nutrient Essential for Life' (translated to Urdu).

The program commenced in mid-February and ended in mid-May, 2016. All interns completed their assigned work within the specified timeframe. Interns were encouraged to carry out field visits on a regular basis, guided by FFC, Engro and Fatima Fertilizer Company (third leading fertilizer company of Pakistan) field officers. Performance reports were submitted at the end of each month detailing all the activities for that period. On completion of the internship, interns submitted a hard copy of their three month report as well as their excel data files. A meeting was conducted before the end of the internship program on 14-15 April 2016 to monitor intern performance. At Vehari, a city in southern Punjab, three interns working with Engro and Fatima Fertilizers Company were interviewed. Their performance in the field, working schedules and recent activities were evaluated. Each intern was then questioned about their particular farmer's cropping pattern, total land holding area and soil samples collected and analyzed.

IPI intern interviewing a farmer during internship in Multan Disctrict. Photo by authors.

The IPI coordinator recommended the interns keep in touch with the small land holder to encourage the farmers in balanced use of fertilizers after the soil analysis. He also suggested the interns should cover various cultivated areas with different cropping patterns. Following this, there were discussions about the interns' working schedules, farmer responses and problems encountered. Similarly, the remaining five IPI interns were interviewed by the IPI coordinator at the FFC regional office at Jail Road, Multan. Dr. Sajid Fareed (FFC executive marketing officer) explained the company's major achievements and recent activities. He described FFC as a leading fertilizer organization in Pakistan, possessing basic farming data (fertilizer use, cropping pattern, per acre yield etc.) for various farmers from different regions of Pakistan. The organization collects soil samples according to a precise schedule with the help of a GPS coordinated system. Following analysis, FFC advise farmers on their soil's fertility status and provide fertilizer recommendations. Dr. Fareed also explained that recently FFC has been finalizing data regarding the metrological conditions of different regions in order to facilitate farmers more accurately. One intern added that, with FFC collaboration, he had recently reached roughly 1,500 farmers in farmer meetings and collected 58 soil samples from different villages. There had been a great response from farmers, another intern told. At the end of the meeting IPI interns were given time for questions which were jointly answered by IPI coordinator and FFC representatives. During questioning there was also a general discussion on the decline of cotton yields and the associated impacts on fertilizer demand.

Results

Both small and progressive farmers (having >10 ha land holdings performing mechanized farming) were contacted by IPI interns in cotton growing regions of Pakistan. More than 700 farmers holding a total of ~8,740 ha were reached. The land holding data indicated that out of the total cultivated area covered, roughly 21% was held by smallholders who owned less than 5 ha each and 31% was cultivated by farmers with 5-10 ha each. The majority (48%) of the area covered was owned by the farmers who owned more than 10 ha each (Fig. 1).

Underground water in most parts of the cotton growing regions of Pakistan contains excessive soluble salts which is a major contributor to land degradation. Approximately 6% of farmers in this region are only using tube-well water, while 9% of the farmers are dependent on canal water for irrigation. Roughly 87% of farmers are using both canal and tube-well water in different

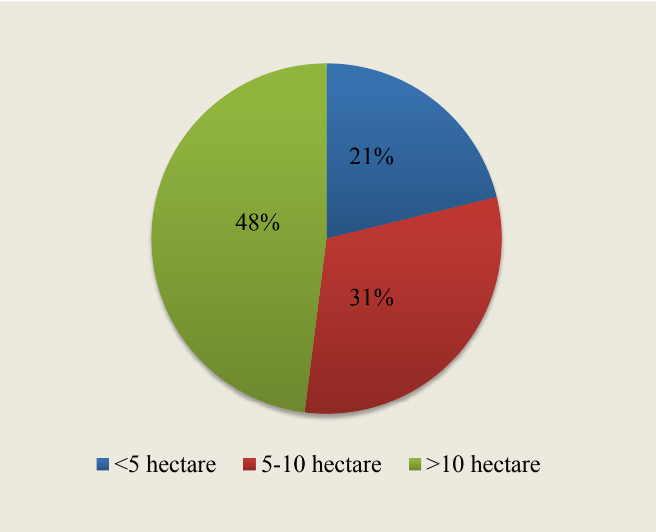


Fig. 1. Average land holding of farmers surveyed by interns in cotton growing areas of Pakistan.

proportions. Among those, the majority of farmers (30%) are using canal and tube-well water in 1:3 ratio, 29% use canal and tube-well water in equal proportion, and 28% use canal and tube-well water in 3:1 ratio to meet the irrigation demands of their crops (Fig. 2).

One composite soil sample was collected from each farmer's land and a total of 727 samples were analyzed by the interns. Samples were examined in the respective soil and water testing laboratories developed by the Fauji, Engro and Fatima Fertilizer Company. It was found that only 6% of soils in the cotton growing areas were severely deficient in available K (<80 mg kg^{-1}), while 15% of the soils have available K contents <120 mg kg^{-1}. Based

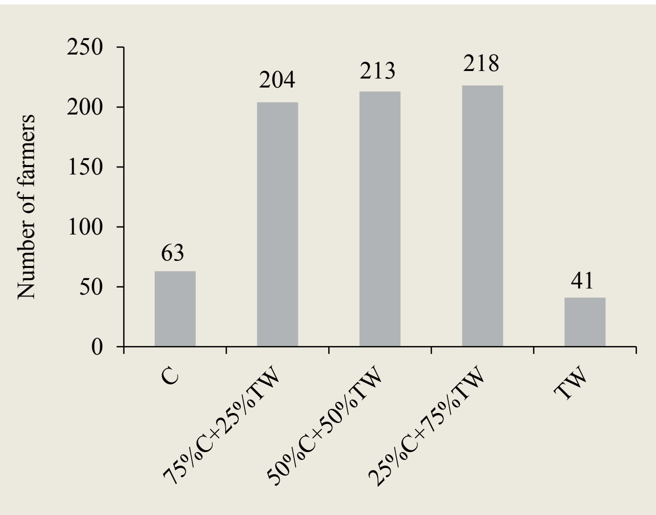


Fig. 2. The ratio of canal and tube-well irrigation water used by farmers in cotton growing areas of Pakistan (C=canal; TW= tube-well).

on previous experiences, most fertilizer companies consider soils containing less than 160 mg kg^{-1} available K are deficient, and K fertilization would be beneficial. From soil sample analyses, it was observed that 44% of the sampled soils have K contents less than 160 mg kg^{-1}, whilst 56% contain >160 mg kg^{-1} K (Fig. 3). The majority of soils in the identified areas are deficient in P with 67% demonstrating <8 mg kg^{-1} P contents, ~30% possessed 8-15 mg kg^{-1} P, while only 2.2 % soils showed a sufficient P content for crop growth of >15 mg kg^{-1} (Fig. 4).

Many farmers in cotton growing regions of Pakistan are using N and P fertilizers, while a small minority (16%) are using K fertilizers (Fig. 5). Among those, the majority (60%) use sulfate of potash as a K source, while 24%, 8% and 7% farmers are applying

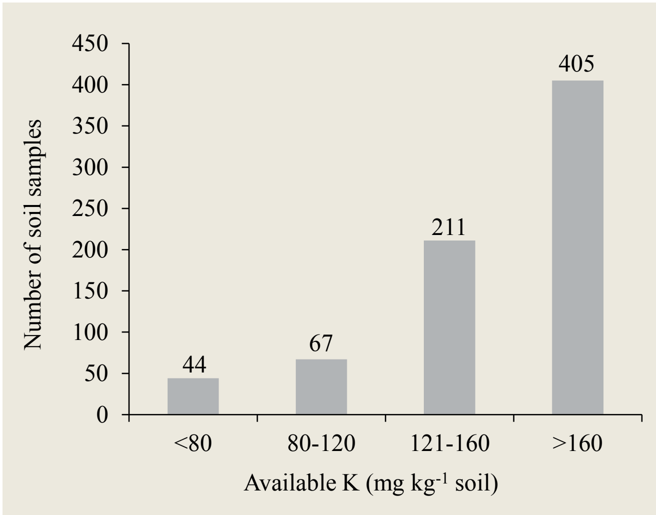


Fig. 3. Soil-potassium (K) content in cotton growing areas of Pakistan.

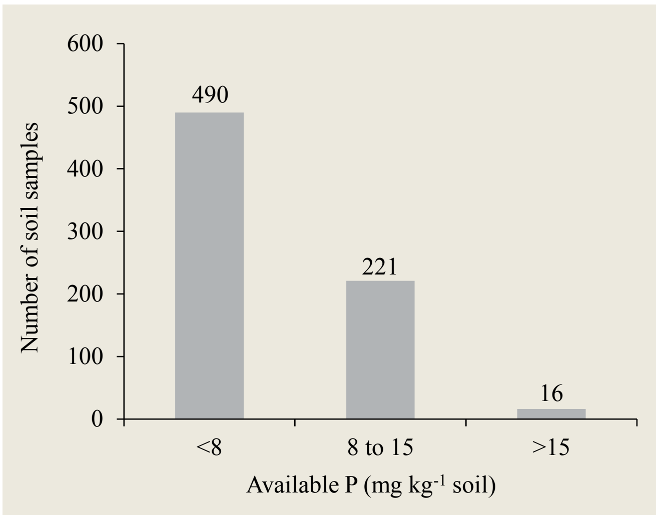


Fig. 4. Phosphorus (P) soil content in cotton growing areas of Pakistan.

NPK, muriate of potash and potassium nitrate, respectively (Fig. 6).

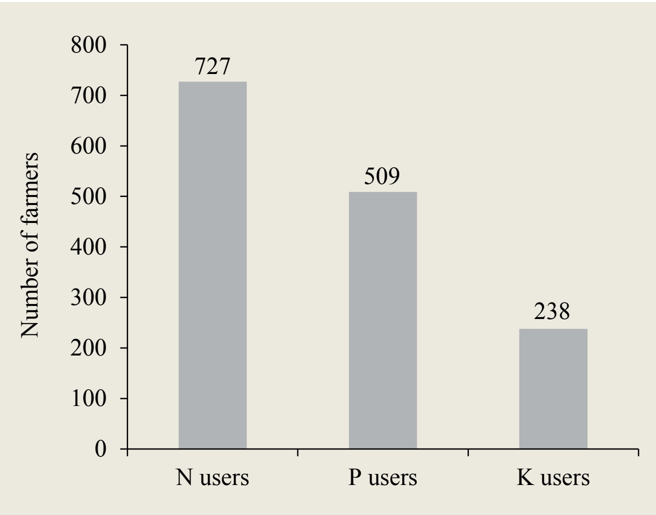


Fig. 5. Farmers using N, P and K in cotton growing areas of Pakistan.

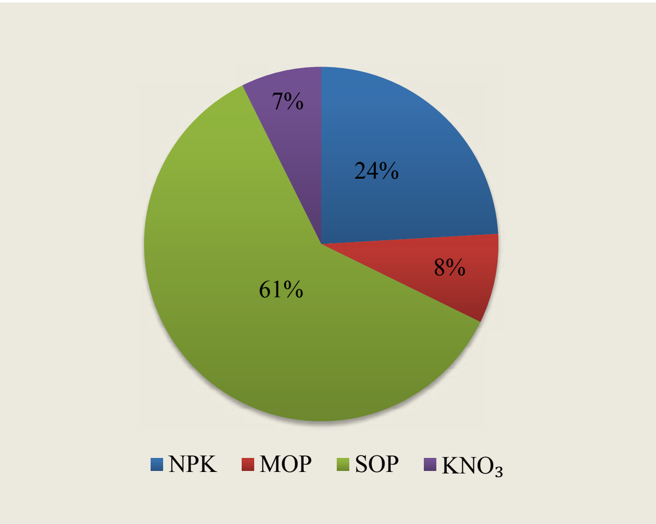


Fig. 6. Different K sources used by farmers in cotton growing areas of Pakistan.

Discussion and conclusion

The imbalanced use of fertilizers, especially N, P and K, not only has environmental implications but also results in low economic returns. The farming community in Pakistan applies N fertilizers significantly more than P, due to its quicker and more economic crop responses. In some cases, the overuse of N fertilizers has been reported in Pakistan. Soil analysis conducted by the IPI interns demonstrated that the majority of soils in the cotton growing areas of Pakistan are deficient in available N and P. Roughly 100% of farmers are using N and ~70% are using P fertilizers. However, potash usage is very low at 16%, despite 44% of soil samples analyzed being K deficient with less than 160 mg K kg^{-1} soil.

Pakistani soils are alluvial and developed from mica, therefore several decades ago the indigenous soil K may have been sufficient for low yielding crop varieties. However, due to intensive agricultural practices and the cultivation of high yielding varieties, particularly maize hybrids, soil K content has been greatly depleted. Canal water is considered a significant source of K but its availability is limited.

This report revealed that approximately 29% of farmers are using canal and tube-well water at a 1:1 ratio. Only 6% are using 100% tube-well water, else tube-well water is being used in different ratios with canal water, therefore due to the limited availability of canal water, K from canal irrigation water is also decreased. Among potash users, around 24% use an NPK compound fertilizer and 8% and 61% use KCl and K_2SO_4, respectively. NPK fertilizers are significantly contributing to K use with less effort; this should be further promoted to optimize K use.

The evidence of the benefits of K application to crops is clear and there is great potential for enhanced potash use in Pakistan. However, there is a need to promote potash use in a strategic way. The rapid depletion of available K from soils is a threat to agricultural sustainability in Pakistan. The benefits of K use in agriculture must be highlighted, and policymakers should consider subsidizing fertilizer prices for agricultural sustainability. Furthermore, accurate and balanced use of K fertilizers is critical to increase the economic returns, therefore fertilizer recommendations should be revised according to soil characteristics. In the instance of Pakistan, the following benefits of K fertilization have been noted:

a) The application of K to K deficient crops increases growth and yield.
b) Potassium enhances the quality of produce increasing protein, oil and vitamin C content in cereals. In fruits and tuber crops, K increases the size and improves color, flavor, storage and shipping quality.
c) Potassium improves resistance against drought, salinity, frost and pests.
d) Synergistic effect of K to N and P improves the efficiency of nitrogenous and phosphatic fertilizers.

The internship program launched by IPI has been encouraged by all stakeholders (fertilizer companies, progressive farmers, agriculture extension department etc.). Direct communication with farmers via agricultural graduates is reliable, cheap and preferred by farmers over conventional methods of dissemination. This internship program will continue to run every year in collaboration with the local fertilizer industry with modifications where necessary.

References

Akhtar, M.E., M.T. Saleem, and M.T. Stauffer. 2003. Potassium in Pakistan Agriculture. Pakistan Agricultural Research Council, Islamabad. 80 p.

Bajwa, M.I. 1994. Soil Potassium Status, Potassium Fertilizer Usage and Recommendations in Pakistan. Potash Rev. 20(3):128.

Economic Survey of Pakistan. 2014-2015. Agriculture. 23 p.

Marschner, P. 2012. Marschner's Mineral Nutrition of Higher Plants. (3rd ed.). Academic Press, London, UK. p. 178-189.

Ranjha, A.M., A. Jabbar, and R.H. Qureshi. 1990. Effect of Amount and Type of Clay Minerals on K Fixation in Some Alluvial Soils of Pakistan. Pakistan J. Agri. Sci. 27:187-92.

Reddya, A.R., K.V. Chaitanya, and M. Vivekanandanb. 2004. Drought-induced responses of photosynthesis and antioxidant metabolism in higher plants. J. Plant Physiol. 161:1189-1202.

Wakeel, A. 2013. Potassium-Sodium Interactions in Soil and Plant under Saline-Sodic Conditions. J. Plant Nutr. Soil Sci. 176:344-354.

An intern at a farmers gathering providing advisory services. Photo by authors.

Group photo of the interns and other resource persons together with the Director of the Institute of Soil and Environmental Sciences, University of Agriculture Faisalabad, Pakistan. Photo by A. Wakeel.

The paper "Promoting Precise and Balanced Use of Fertilizers in Pakistan at Farm-Gate Level" also appears on the IPI website at:

Regional activities/WANA

Events

International Symposia and Conferences

March 2017

The 15th New Ag International Conference & Exhibition, 15-17 March 2017, Maritim Hotel, Berlin, Germany. The World's Leading Event on High-Tech Agriculture.

The three day meeting will feature selected presentations delivered by world renowned speakers/organisations. For more information go to the New Ag conference website.

August 2017

18th International Plant Nutrition Colloquium, 21-24 August 2017, Copenhagen, Denmark.

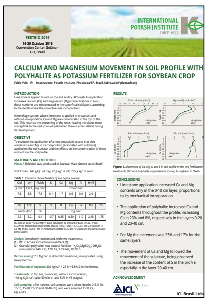
The venue will be the Tivoli Hotel and Congress Center, situated right in the middle of Copenhagen. The main theme of the 18th International Plant Nutrition Colloquium is: "Plant Nutrition for Global Green Growth". For more information go to the IPNC 2017 website.

Publications

Potasyum - Yaşam için Mutlak Gerekli bir Element
Potassium - a Nutrient Essential for Life

We have just published this booklet in *Turkish* available for download on the IPI website/Publications. For hardcopies, please contact Dr. Menachem Assaraf, IPI Coordinator for Europe & Turkey.

This publication is also available in the following languages for download on the IPI website/Publications: *Amharic, Arabic, Chinese, English, French, Hindi, Portuguese, Ukrainian, and Urdu.*

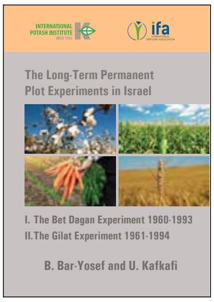


Calcium and Magnesium Movement in Soil Profile with Polyhalite as Potassium Fertilizer for Soybean Crop

Dr. Fabio Vale, IPI Coordinator for Latin America, presented this poster at FERTBIO (Brazilian Meeting of Soil Science and Plant Nutrition) in October 2016.

The poster "Calcium and Magnesium Movement in the Soil Profile Using Polyhalite in Potassium Fertilization in Soybean" summarises a recent experiment. The experiment showed that the application of Polysulphate increased Ca and Mg in the whole soil profile, increasing Ca by 23% and 8% respectively in layers 0-20 and 20-40 cm. For Mg this increase was 25% and 17% for the same layers. An increased S content was measured in the soil profile, especially in the 20-40 cm layer.

The poster is available in *English* and *Portuguese*. To download the poster go to the IPI website/Publications. For more details contact Dr. Fabio Vale.



The Long-Term Permanent Plot Experiments in Israel
I. The Bet Dagan Experiment 1960-1993
II. The Gilat Experiment 1961-1994

Data compilation and evaluation by B. Bar-Yosef and U. Kafkafi. Published by IPI and IFA. 2016. 202 p.

This publication is a report of two long-term fertilization experiments (LTFE) which were established in Israel in 1961 by the Volcani Institute of Agricultural Research to provide a scientific basis to support the transition from rain-fed to irrigation-fed agriculture that was occurring in many parts of the country. The objectives of the experiments were to develop and test new fertilization regimes under controlled irrigation conditions in semi-arid and arid climates; to adopt new cash crops grown under irrigation and to study their short and long-term response to fertilizer and manure application rates; and to improve and calibrate soil tests for evaluating nutrients' availability to plants. The first LTFE was established in central Israel at Bet Dagan experimental station, representing semi-arid growth conditions (400-500 mm winter rain), deep alluvial soils, and mechanically-harvested field crops. The second LTFE was founded in southern Israel at the Gilat experimental station, representing arid growth conditions (200-300 mm winter rain), loessial soils, and small farm vegetable crops. The experiments continued until 1993 at Bet Dagan and 1994 at Gilat. The crops grown at Bet Dagan included cotton (grown 11 times), wheat (8), corn (2) and sugar beet (2); and, at Gilat, potato (3 times), Chinese cabbage (3), cucumber (3), onion (3), and carrot (2).

The results in both experiments are presented chronologically. For each year, all the obtained crop, soil and meteorological data are compiled according to treatments in uniform Excel files which are accessible to readers. In addition, graphs or tables summarizing the crop response to the main treatments or resulting soil factors are included in the main text. Over the years all of the important crops grown in Israel were characterized with respect to their yield response to nitrogen (N) application rate in relation to phosphorus (P) and potassium (K) status in soil.

The evaluated long-term effects include fertilizer and manure application rate effects on soil fertility, fertilizer use efficiency, leaching of nitrate and chlorides to underground water, crop yield, and N uptake response to available P and K soil concentrations. The report includes the main conclusions from these experiments.

Original Data

The pdf of the publication contains individual hyperlinks to the original data files on the IPI website. These links are to individual Excel spreadsheet files.

In addition, we have also provided (as a separate download) the entire collection of Excel spreadsheets in a zip archive (approx. 3 MB), making the documents available offline.

To download the booklet go to the IPI website/Publications/Reports. For hardcopies, please contact ipi@ipipotash.org.

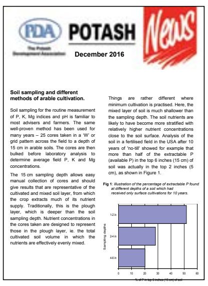
Publications by the PDA


PDA POTASH News
December 2016
Forage Maize – Phosphate & Potash offtakes

Forage Maize - Phosphate & Potash Offtakes

POTASH News, December 2016.

With the huge increase in growing forage maize to feed anaerobic digesters, especially in the arable areas of Eastern England, it seems appropriate to consider the harvested offtakes of phosphate and, especially, the high amounts of potash removed. Read more on the PDA website.


PDA POTASH News
December 2016
Soil sampling and different methods of arable cultivation.

Soil Sampling and Different Methods of Arable Cultivation

POTASH News, December 2016

Soil sampling for the routine measurement of P, K, Mg indices and pH is familiar to most advisers and farmers. The same well-proven method has been used for many years - 25 cores taken in a 'W' or grid pattern across the field to a depth of 15 cm in arable soils. The cores are then bulked before laboratory analysis to determine average field P, K and Mg concentrations. 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

Follow us on Twitter on: https://twitter.com/IPI_potash

Follow our Facebook on: https://www.facebook.com/IPIpotash?sk=wall

A Potassium-Dependent Oxygen Sensing Pathway Regulates Plant Root Hydraulics

Zaigham Shahzad, Z., M. Canut, C. Tournaire-Roux, A. Martinière, Y. Boursiac, O. Loudet, and C. Maurel. 2016. Cell 167(1):87-98. DOI: http://dx.doi.org/10.1016/j.cell.2016.08.068.

Abstract: Aerobic organisms survive low oxygen (O_2) through activation of diverse molecular, metabolic, and physiological responses. In most plants, root water permeability (in other words, hydraulic conductivity, Lp_r) is downregulated under O_2 deficiency. Here, we used a quantitative genetics approach in *Arabidopsis* to clone *Hydraulic Conductivity of Root 1 (HCR1)*, a Raf-like MAPKKK that negatively controls Lp_r. HCR1 accumulates and is functional under combined O_2 limitation and potassium (K^+) sufficiency. HCR1 regulates Lp_r and hypoxia responsive genes, through the control of RAP2.12, a key transcriptional regulator of the core anaerobic response. A substantial variation of HCR1 in regulating Lp_r is observed at the *Arabidopsis* species level. Thus, by combinatorially integrating two soil signals, K^+ and O_2 availability, HCR1 modulates the resilience of plants to multiple flooding scenarios.

Adequate Supply of Potassium Improves Plant Water-Use Efficiency but not Leaf Water-Use Efficiency of Spring Wheat

Jákli, B. M. Tränkner, M. Senbayram, and K. Dittert. 2016. J. Plant Nutr. Soil Sci. 179(6)733-745. DOI: 10.1002/jpln.201600340.

Abstract: Enhancing crop water-use efficiency (WUE) is a major research objective in water-scarce agroecosystems. Potassium (K) enhances WUE and plays a crucial role in mitigating plant stress. Here, effects of K supply and PEG-induced water deficit on WUE of spring wheat *(Triticum aestivum* L. var. Sonett), grown in nutrient solution, were studied. Plants were treated with three levels of K supply (0.1, 1, 4 mM K^+) and two levels of PEG (0, 25%). WUE was determined at leaf level (WUE_L), at whole-plant level (WUE_P), and via carbon isotope ratio ($\delta^{13}C$). Effects of assimilation and stomatal conductance on WUE_L were evaluated and compared with effects of biomass production and whole-plant transpiration (E_P) on WUE_P. Adequate K supply enhanced WUE_P up to 30% and by additional 20% under PEG stress, but had no effect on WUE_L. E_P was lower with adequate K supply, but this effect may be attributed to canopy microclimate. Shoot

$\delta^{13}C$ responded linearly to time-integrated WUE_L in adequately supplied plants, but not in K-deficient plants, indicating negative effects of K deficiency on mesophyll CO_2 diffusion. It is concluded that leaf-scale evaluations of WUE are not reliable in predicting whole-plant WUE of crops such as spring wheat suffering K deficiency.

Postseason Diagnosis of Potassium Deficiency in Soybean Using Seed Potassium Concentration

Parvej, Md.R., N.A. Slaton, M.S. Fryer, T.L. Roberts, and L.C. Purcell. SSSAJ 80(5):1231-1243. DOI: 10.2136/sssaj2016.02.0030

Abstract: Soybean [*Glycine max* (L.) Merr.] seed nutrient concentrations may be useful for postseason diagnosis of nutrient deficiencies to identify reasons for lower-than-expected yields. Our objective was to determine the relationships between seed-K and soil-K concentrations and relative soybean yield and to develop potential seed-K concentration thresholds for diagnosis of K deficiency as a yield-limiting factor. Soil-test K and seed-K concentrations and yield data were collected from published and unpublished K fertilization research conducted in Arkansas (33 site-years), Indiana (1 site-year), Iowa (34 site-years), Missouri (1 site-year), Tennessee (6 site-years), Virginia (1 site-year), and Canada (24 site-years). Seed-K concentrations accounted for 66% of the variation in relative yield of soybean receiving no fertilizer K for Arkansas, 48% for Iowa, 78% for Canada, and 60% for North America from a database that included 100 site-years. The critical seed-K concentration ranges were 15.6 to 17.0 g K kg^{-1} for Arkansas, 17.4 to 20.0 g K kg^{-1} for Iowa, 14.6 to 16.2 g K kg^{-1} for Canada, and 16.5 to 17.7 g K kg^{-1} for North America. Seed-K concentrations below the lower threshold for North America accurately predicted positive yield responses to fertilizer K at 77% of the sites classified as deficient. The difference between seed-K concentration of soybean grown with and without fertilizer K decreased linearly as soil-K concentration increased and plateaued when soil-K concentration was ≥87, 139, 73, and 104 mg K kg^{-1} for Arkansas, Iowa, Canada, and North America, respectively. Results suggest that seed-K concentrations can be used to aid in the diagnosis of K deficiency at maturity.

Fertilizer Microdosing in the Humid Forest Zone of Ghana: An Efficient Strategy for Increasing Maize Yield and Income in Smallholder Farming

Okebalama, C.B., E.Y. Safo, E. Yeboah, R.C. Abaidoo, and V. Logah. 2016. SSSAJ 80(5):1254-1261. DOI: 10.2136/sssaj2016.03.0065.

Abstract: High fertilizer costs pose a challenge in smallholder farming; optimizing fertilizer recommendations that are affordable to resource-poor farmers could increase crop yield and income. The study aimed to determining the yield and economic effects of N–P–K fertilizer microdosing on maize (*Zea mays* L.) crops on Gleyic Plinthic Acrisol (GPA) and Plinthic Acrisol (PA) in the semideciduous rainforest zone of Ghana using a split-plot randomized complete block design with three replications. The field trial included two cropping systems (continuous maize cropping [CMC] and cowpea [*Vigna unguiculata* (L.) Walp.]–maize rotation [CMR]) as main plots with four treatments ($N_0P_0K_0$, $N_0P_{20}K_{20}$, $N_0P_{40}K_{20}$, and $N_{20}P_{40}K_{20}$) and the recommended fertilizer rate ($N_{90}P_{60}K_{60}$) as subplots. Fertilizer treatment effects on maize stover and grain yields were assessed. The microdose treatments increased maize yields by 32 to 99% across cropping systems and soil types. Maize grain yield increase was higher on the GPA than on the PA. The $N_{90}P_{60}K_{60}$ and $N_{20}P_{40}K_{20}$ treatments resulted in higher grain and stover yields than the other treatments across cropping systems and soil types. Among the treatments maximum grain yield increases of 76 and 99% were obtained with $N_{20}P_{40}K_{20}$ on the PA and the GPA, respectively, under CMC. Under CMR, grain yield increased by 46% with $N_0P_{40}K_{20}$ (PA) and 74% with $N_0P_{20}K_{20}$ (GPA). The largest net return was obtained with $N_{20}P_{40}K_{20}$ under CMC across both soil types and with $N_0P_{20}K_{20}$ (GPA) and $N_0P_{40}K_{20}$ (PA) under CMR. These fertilizer microdoses can be considered appropriate for increasing maize yield and the income of smallholder farmers.

Tuber Quality Parameters of Potato Varieties Depend on Potassium Fertilizer Rate and Source

Manolova, I. N. Nesheva, and V. Chalovab. 2016. Agriculture and Agricultural Science Procedia 10:63-66. DOI: http://dx.doi.org/10.1016/j.aaspro.2016.09.010.

Abstract: The influence of potassium fertilizer source (K_2SO_4 and KCl) and fertilizer rates on potato tuber quality parameters under pot and field experimental conditions were studied. The pot experiment included high rate of potassium fertilizers providing 600 mg K_2O kg^{-1} soil from both sources, studded at four varieties. The field experiment included two fertilizer rates - 100 and 200 kg K_2O ha^{-1}. The dry matter content in tubers from the plants of the pot experiment was the highest for the controls of the three studied varieties - 19.78% for "Louisiana"; 17.16 for "Riviera" and 17.26% for "Hussar". The highest dry matter content (20.98%) in field conditions was observed for variant K_{200} (K_2SO_4). For all variants from the pot trial fertilized with KCl the starch content was decreased approximately with 2.2 to 2.4% in comparison to controls. The highest tuber starch content was observed also for the control (15.24%) from the field study. The fertilization did not influence the reducing sugars content in tubers. The content was around 0.40% independently of the trial conditions and cultivars. The application of KCl decreased the content of vitamin C in tubers for all variants from the pot trial compared to the controls (from 46% at variety "Louisiana" to 61% to Agria). In the field

experiment the high rate of K_{200} KCl reduced vitamin C content with approximately 54% (8.40 mg 100 g^{-1}) in comparison to variant K_{100} K_2SO_4 (18.10 mg 100 g^{-1}). Positive influence of KCl on crude protein content in tubers at all varieties from both trials was recorded.

Potassium Retention in Leaf Mesophyll as an Element of Salinity Tissue Tolerance in Halophytes

Perceya, W.J., L. Shabalaa, Q. Wua, N. Sua, M.C. Breadmorec, R.M. Guijtd, J. Bosea, and S. Shabalaa. 2016. Plant Physiology and Biochemistry 109:346-354. DOI: http://dx.doi.org/10.1016/j.plaphy.2016.10.011.

Abstract: Soil salinity remains a major threat to global food security, and the progress in crop breeding for salinity stress tolerance may be achieved only by pyramiding key traits mediating plant adaptive responses to high amounts of dissolved salts in the rhizosphere. This task may be facilitated by studying natural variation in salinity tolerance among plant species and, specifically, exploring mechanisms of salinity tolerance in halophytes. The aim of this work was to establish the causal link between mesophyll ion transport activity and plant salt tolerance in a range of evolutionary contrasting halophyte and glycophyte species. Plants were grown under saline conditions in a glasshouse, followed by assessing their growth and photosynthetic performance. In a parallel set of experiments, net K^+ and H^+ transport across leaf mesophyll and their modulation by light were studied in control and salt-treated mesophyll segments using vibrating non-invasive ion selective microelectrode (the MIFE) technique. The reported results show that mesophyll cells in glycophyte species loses 2–6 fold more K^+ compared with their halophyte counterparts. This decline was reflected in a reduced maximum photochemical efficiency of photosystem II, chlorophyll content and growth observed in the glasshouse experiments. In addition to reduced K^+ efflux, the more tolerant species also exhibited reduced H^+ efflux, which is interpreted as an energy-saving strategy allowing more resources to be redirected towards plant growth. It is concluded that the ability of mesophyll to retain K^+ without a need to activate plasma membrane H^+-ATPase is an essential component of salinity tolerance in halophytes and halophytic crop plants.

Effect of Moderate High Temperature on the Vegetative Growth and Potassium Allocation in Olive Plants

Benlloch-González, M., J.M. Quintero, M. Paz Suárez, R. Sánchez-Lucas, R. Fernández-Escobar, and M. Benlloch. 2016. J. Plant Physiol. 207:22-29. DOI: http://dx.doi.org/10.1016/j.jplph.2016.10.001

Abstract: There is little information about the prolonged effect of a moderately high temperature on the growth of olive (*Olea europaea* L.). It has been suggested that when the temperature of the air rises above 35°C the shoot growth of olive is inhibited while there is any reference on how growth is affected when the soil is warmed. In order to examine these effects, mist-cuttings and young plants generated from seeds were grown under moderate high temperature (37°C) for 64 and 42 days respectively. In our study, plant dry matter accumulation was reduced when the temperature of both the air and the root medium was moderately high. However, when the temperature of the root medium was 25°C, the inhibitory effect of air high temperature on plant growth was not observed. The exposure of both the aerial part and the root to moderate high temperature also reduced the accumulation of K^+ in the stem and the root, the water use efficiency and leaf relative water content. However, when only the aerial part was exposed to moderate high temperature, the accumulation of K^+ in the stem, the water use efficiency and leaf relative water content were not modified. The results from this study suggest that the olive is very efficient in regulating the water and potassium transport through the plant when only the atmosphere surrounding the aerial part is warmed up. However, an increase in the soil temperature decreased root K^+ uptake and its transport to the aerial parts resulting in a reduction in shoot water status and growth.

Nitrogen, Phosphorus, Calcium, and Magnesium Applied Individually or as a Slow Release or Controlled Release Fertilizer Increase Growth and Yield and Affect Macronutrient and Micronutrient Concentration and Content of Field-Grown Tomato Plants

Cole, J.C., M.W. Smith, C.J. Penn, B.S. Cheary, and K.J. Conaghan. 2016. Scientia Horticulturae 211:420-430. DOI: http://dx.doi.org/10.1016/j.scienta.2016.09.028

Abstract: The U.S. Environmental Protection Agency (USEPA) has restricted concentrated animal feeding operation (CAFO) release of waste products into U.S. waters. These waste products must be disposed of using best management practices. Most of the waste is spread on cropland, but some operations have found other creative uses for waste products. Use of a phosphorus (P) reduction system to remove P from wastewater results in magnesium ammonium phosphate (MAP), a slowly soluble fertilizer. Using a P reduction system will not eliminate the need for land application of manure and wastewater, but it reduces the nutrient load in the waste that is applied thereby making compliance with regulations easier. In the first year of this study, MAP was compared to a controlled release fertilizer (CRF) with a similar nutrient element ratio on plant growth, fruit yield, nitrogen (N), P, potassium (K), calcium (Ca), magnesium (Mg), iron (Fe), manganese (Mn), and zinc (Zn) concentration in tomato (*Solanum lycopersicum* L. 'Mountain Fresh Plus') plant

parts. Plant growth and fruit production were similar with the two fertilizers, but the number of tomato culls was greater with either fertilizer than on control plants. Foliar N, P, Ca, and Mg concentration did not differ regardless of fertilizer treatment. Plants fertilized with CRF had a greater leaf K concentration than those fertilized with MAP, but foliar K concentration did not differ between fertilized and nonfertilized plants. Iron and Mn concentration in above-ground vegetative plant parts (stems and leaves) did not differ regardless of fertilizer treatment, but Zn concentration increased linearly as CRF increased. In the second year, MAP, each of the essential elements contained in MAP separately, and a hand mixture of each of these elements was tested for their effect on tomato plant growth, fruit yield, and tissue N, P, K, Ca, Mg, Fe, Mn, and Zn concentration and content. Magnesium ammonium phosphate and the hand mixture of fertilizer resulted in greater above-ground biomass excluding fruit stem weight and fruit yield than any of the individual nutrient treatments. Calcium sulfate resulted in a greater number and weight of tomatoes harvested than MAP. Nitrogen concentration did not differ among the fertilizer treatments for roots, stems, or leaves, but N content was greater in red fruit with the hand mix of fertilizer than with no fertilizer or with ammonium sulfate or Mg oxide. In immature green fruit at termination of the study, N content was greater with no fertilizer or Ca sulfate than with MAP or triple superphosphate (TSP). Phosphorus, K, and Ca concentrations did not differ among fertilizer treatments for any tissue tested. Magnesium concentration in green tomatoes differed among fertilizer treatments such that Mg concentration of green tomatoes from plants fertilized with TSP was greater than Mg concentration of green tomatoes fertilized with ammonium sulfate or Mg oxide. Phosphorus and K content of green fruit differed among fertilizer treatments with P and K concentration highest in green fruit from plants fertilized with Ca sulfate and lowest in green fruit from plants fertilized with MAP or TSP. Iron and Mn concentrations did not differ among fertilizer treatments for any tissue tested. Zinc concentration in leaves was greater when plants were fertilized with MAP, TSP, Ca sulfate, or Mg oxide than with ammonium sulfate. Zinc concentration of green fruit was greater when fertilized with MAP than with the hand mix, Ca sulfate or Mg oxide. Iron content was highest in green fruit from plants fertilized with TSP and lowest in plants fertilized with ammonium sulfate or control plants. Manganese content of leaves from control plants was greater than that of plants receiving ammonium sulfate while red fruit from plants fertilized with the hand mix had a greater Mn content than red fruit from any other treatment. Foliar Zn content was greater in plants fertilized with Ca sulfate than in those fertilized with the hand mix, ammonium sulfate, or TSP. In contrast, Zn content of red fruit fertilized with the hand mix was greater than for red fruit in any other treatment. Green fruit from control plants and those receiving MAP had a greater Zn content than plants fertilized with the hand mix, TSP, or Mg oxide. Fertilizer application increased Fe, Mn, and Zn content of several plant tissues. None of the labels of fertilizers applied stated that they contained micronutrients; however, small amounts of contamination were possible. Differing micronutrient contents of various plant tissues among fertilizer treatments were probably associated with other elements affecting plant growth or nutrient uptake. The nutrient elements present in the various fertilizers were not always the nutrient elements affected in the plants likely due to another element that may have limited plant growth or nutrient uptake.

Balanced Fertilizer Management Strategy Enhances Potato Yield and Marketing Quality

Xue-Lian Tanab, Tian-Wen Guo, Shang-You Song, Ping-Liang Zhang, Xu-Cheng Zhang, and Cai Zhao. 2016 Agron. J. 108(6):2235-2244. DOI: 10.2134/agronj2016.05.0302.

Abstract: Optimizing nutrient supply can promote plant growth, minimize production input, and enhance economic returns in crops. Here, we determined the effect of different fertilizer strategies on the tuber yield and economic outcomes in potato (*Solanum tuberosum* L.). Six fertilizer treatments were arranged in a randomized, complete block design at Dingxi Research Station (104°35’ E, 35°36’ N), Gansu Academy of Agricultural Sciences, from 2008 to 2010. Balanced fertilizer strategy (i.e., N, P, and K nutrients were combined in an appropriate ratio) was compared with imbalanced treatments where N, P, or K nutrient was omitted in decrement in the fertilizer strategy. On average, the balanced strategy increased tuber yield by 25% in 2008, 35% in 2009, and 14% in 2010, compared with imbalanced treatments, and 74% in 2008, 81% in 2009, and 33% in 2010, compared with no-fertilizer control. Among the three nutrient elements, N component contributed an average of 18% of the increased tuber yield, P contributed 14%, and K contributed 13%. The combination of N, P, and K together in a package led to an additional 18% yield increase on the top of the yield contributed individually by each of the three nutrient components. The balanced strategies also led to 11% greater net return than the imbalanced treatments and 29% greater net return compared with the control. The combination of N, P, and K in an appropriate ratio can serve as an effective fertilizer strategy to achieve additional tuber yield, improve marketing quality, and enhance economic returns in potato production.

Critical Trifoliolate Leaf and Petiole Potassium Concentrations during the Reproductive Stages of Soybean

Parvej, Md.R., N.A. Slaton, L.C. Purcell, and T.L. Roberts. 2016. Agron J. 108(6):2502-2518. DOI: 10.2134/agronj2016.04.0234.

Abstract: The critical K concentration in soybean [*Glycine max* (L.) Merr.] has been determined only for leaf tissue at the

R2 (full bloom) stage. Our research objective was to develop critical K concentrations in soybean for both leaves and petioles across reproductive stages. Fifteen fully-expanded, uppermost trifoliolate leaves with petioles $plot^{-1}$ were collected 7 to 12 times from the V5 to R7 stages in five research trials that evaluated multiple fertilizer-K rates and/or cultivars from different maturity groups (MGs). Both leaf- and petiole-K concentrations, regardless of site-year, cultivar, and fertilizer-K rate, peaked around R2 stage and declined linearly with time at average rates of -0.198 g K kg^{-1} d^{-1} for leaves and -0.559 g K kg^{-1} d^{-1} for petioles. The leaf- and petiole-K concentrations at the R2 to R6 stages explained 48 to 80% and 41 to 85%, respectively, of the variation in relative yield (RY). Petiole-K concentration was a better predictor of RY than leaf-K at the R2 stage where the predicted critical range (CR) concentrations were 14.6 to 19.0 g leaf-K kg^{-1} and 30.1 to 38.3 g petiole-K kg^{-1}. The wider CR of petiole-K at the R2 stage followed by a greater linear decline rate across reproductive stages indicates that growth stage as well as deficiency and sufficiency thresholds for petiole-K could be more easily categorized than for leaves. Overall, the ability to interpret the K nutritional status in soybean tissues at numerous reproductive growth stages will improve K management.

The Effects of Potassium Nutrition on Water Use in Field-Grown Maize (*Zea mays* L.)

Martineau, E., J.-C. Domec, A. Bosc, P. Denoroy, V. Asensio Fandino, J. Lavres Jr., and L. Jordan-Meille. 2017. Environmental and Experimental Botany 134:62-71. DOI: http://dx.doi.org/10.1016/j.envexpbot.2016.11.004.

Abstract: Water is about to become increasingly limited for crop production, which jeopardizes the whole maize sector. Potassium (K) nutrition has been proposed to mitigate water deficit in plants, but field-scale studies involving grain yield components are scarce. In this study, we aimed at analyzing the effect of K nutrition on grain yield, vegetative growth and physiological parameters of maize subjected to water deficit. The effect of K nutrition on water use efficiency was also calculated at the whole-crop level (WUE) and through leaf gas exchange measurements (WUE_i). A large-scale field experiment was designed, combining three levels of K fertilization (low, normal and high K) and two water supply scenarios (normal and 30% deficit based on a water balance model). Water deficit induced a strong decrease in leaf area, which was essentially due to a lower leaf elongation rate. The grain yield of the water-stressed plants was 25% lower than that of the well-irrigated ones. Grain yield was even worse when K deficiency was superimposed on water deficit, with a specific effect of K on grain filling. The optimal K fertilization helped the plants mitigate the effect of water deficit, through a better WUE (+30%), which was related to lower leaf evapotranspiration (ET). Moreover, under water deficit, leaf rolling was more pronounced when K was added, which also prevented water losses. Leaf water potential measurements suggested that the isohydric behaviour (maintenance of close stomata during water stress) of the maize was made possible thanks to K fertilization. When calculated at field scale, ET was higher with K fertilization, due to its positive effect on leaf area, in spite of a better stomata control and better WUE. We concluded that K addition, in K deficient soils, can help maize to cope with droughts and could be used as a new management option.

Ability to Remove Na^+ and Retain K^+ Correlates with Salt Tolerance in Two Maize Inbred Lines Seedlings

Yong Gao, Yi Lu, Meiqin Wu, Enxing Liang, Yan Li, Dongping Zhang, Zhitong Yin, Xiaoyun Ren, Yi Dai, Dexiang Deng, and Jianmin Chen. 2016. Front. Plant Sci. 16 November 2016. DOI: https://doi.org/10.3389/fpls.2016.01716.

Abstract: Maize is moderately sensitive to salt stress; therefore, soil salinity is a serious threat to its production worldwide. Here, excellent salt-tolerant maize inbred line TL1317 and extremely salt-sensitive maize inbred line SL1303 were screened to understand the maize response to salt stress and its tolerance mechanisms. Relative water content, membrane stability index, stomatal conductance, chlorophyll content, maximum photochemical efficiency, photochemical efficiency, shoot and root fresh/dry weight, and proline and water soluble sugar content analyses were used to identify that the physiological effects of osmotic stress of salt stress were obvious and manifested at about 3 days after salt stress in maize. Moreover, the ion concentration of two maize inbred lines revealed that the salt-tolerant maize inbred line could maintain low Na^+ concentration by accumulating Na^+ in old leaves and gradually shedding them to exclude excessive Na^+. Furthermore, the K^+ uptake and retention abilities of roots were important in maintaining K^+ homeostasis for salt tolerance in maize. RNA-seq and qPCR results revealed some Na^+/H^+ antiporter genes and Ca^{2+} transport genes were up-regulated faster and higher in TL1317 than those in SL1303. Some K^+ transport genes were down-regulated in SL1303 but up-regulated in TL1317. RNA-seq results, along with the phenotype and physiological results, suggested that the salt-tolerant maize inbred line TL1317 possesses more rapidly and effectively responses to remove toxic Na^+ ions and maintain K^+ under salt stress than the salt-sensitive maize inbred line SL1303. This response should facilitate cell homoeostasis under salt stress and result in salt tolerance in TL1317.

Grading of Potato Tuber as Influenced by Potassium Level and Mulch Materials

Md. Ashraful Islam Pulok, Tuhin Suvra Roy, Md. Nazmul Haque, Md. Shahjalal Hossain Khan, Md. Nahid Parvez. 2016. Focus on Science 2(4). DOI: 10.21859/focsci-020449

Abstract:
Introduction: Effect of potassium (K) and mulch materials on grading of different types of tuber were investigated at the Agronomy research field of Sher-e-Bangla Agricultural University, Dhaka, Bangladesh during the period from November 2013 to March 2014.
Methods: The experiment comprised of four different doses of K viz., 0 kg K ha^{-1}, 100 kg K ha^{-1}, 125 kg K ha^{-1}, 150 kg K ha^{-1} and four different types of mulch materials viz., soil mulch, rice straw, water hyacinth and saw dust. The experiment was laid out in a splitplot design with 3 replications. Statistical analysis done by using MSTAT-C program and mean differences among the treatments were compared by Least Significant Difference (LSD) at 5% level of significance.
Results: Maximum large sized tubers were produced by 150 kg K ha^{-1} with rice straw mulch. Application of 125 kg K ha^{-1} with rice straw produced maximum seed potato and tuber for French fry. Without K and soil mulch produced highest tuber for chips (% by t ha^{-1}).
Conclusions: Application of 125 kg K ha^{-1} with rice straw mulch seems to be more suitable for getting higher seed potato (% by number and % by weight) and French fry for BARI (Bangladesh Agricultural Research Institute) TPS-I.

Soil Potassium in Relation to Soil Fertility

Cooper, H.P., O. Schreiner, and B.E. Brown. 1938. USDA.

What is the importance of potassium to plants? What plants need it most? What are the effects of potash hunger on cotton, tobacco, potatoes, and other crops? How is the soil depleted of potash? Why does potash act differently in different soils? These and other questions are discussed in this article.

Effects of Combined Application of Nitrogen and Potassium Fertilizer on Yield and Quality of Fresh-eating Sweet Potato in Soil with High Fertility

Wang Meng, Fang Zengguo, Liang Bin, Zeng Lusheng, Li Junliang. 2016. Acta Agriculturae Boreali-Sinica 31(5):199-2014. DOI: 10.7668/hbnxb.2016.05.030.

Abstract: To explore the effect of potassium(K) and nitrogen (N) on yield and quality of tuber of sweet potato YS25 in soil with high fertility, used two factors of three levels completely randomized block design of experiment, with 3 N treatments (0, 45, 90 kg/ha) and 3 K_2O treatments (0, 75, 150 kg/ha), included 9 combinations of K and N treatments, were designed. The results showed that: High fertility soil nitrogen fertilizer could be added sweet potato vine length, shoot fresh weight, T/R value (Ratio of fresh weight of stem and leaf to fresh weight of underground), and improve the tuber of sweet potato protein, glucose and sucrose content and high fertility soil nitrogen fertilizer situation and root dry mass of fresh, the content of starch and fructose decreased. K fertilizer could significantly increase the root fresh and dry weight, potato rate and starch and glucose content; promote the sweet potato of Mg absorption, decreased the uptake of Ca by sweet potato. In nitrogen and potassium interaction conditions, sweet potato branching number, tuber number and Vc, protein, sucrose, glucose, fructose content with no fertilizer treatment were improved compared; fresh tuber yield and N fertilizer and potash fertilizer application interaction, namely when no N and K_2O 150 kg/ha, sweet potato yield reached the highest, with no fertilization treatment increased 10,825.5 kg/ha, an increased of 29.2%. At the same time in the implementation of N 90 kg/ha, without K_2O, the sweet potato yield was lowest, compared with no fertilization treatment was 1,435.5 kg/ha, a declined of 3.9%. Therefore, in the high fertility soil, the high yield and good quality of fresh edible sweet potato should be obtained by the application of no or less nitrogen fertilizer and the appropriate amount of potassium fertilizer.

Effect of Nitrogen and Potassium Fertilization on Morpho-Agronomic Traits of Three Elephant Grass (*Pennisetum purpureum* Schum.) Genotypes for Biomass Production

Antonio Alonso Cecon Novo, Rogério Figueiredo Daher, Geraldo de Amaral Gravina, Ernany Santos Costa, Juares Ogliari, Kleberson Cordeiro Araújo, Bruna Rafaela da Silva Menezes, Niraldo José Ponciano, Érik da Silva Oliveira, and Verônica Britos Silva. 2016. African Journal of Biotechnology 15(43):2411-2423. DOI: 10.5897/AJB2016.15615

Abstract: Elephant grass has been proposed for the energy sector as a possible source of renewable energy, because of its high biomass production. The aim of this study was to evaluate the effect of the mineral nutrients nitrogen and potassium on the morpho-agronomic traits (dry mater yield (DMY), percentage of DM (%DM), number of tillers per linear meter (NT), plant height (PH), stem diameter (SD) and leaf blade width (LW)) in different elephant grass genotypes in a randomized-block experimental treatment in a split-plot arrangement with three replications, in which the genotype factor ('Cuban Pinda' - G1; 'IAC Campinas' - G2; and 'Cameroon' - G3) was randomized in the plot, and the N and K factor was randomized in the sub-plot. The increase in nitrogen and potassium doses utilized influenced very little or almost did not influence the response of the three genotypes for the different morpho-agronomic traits assessed. The three

genotypes had high number of tillers, height, and stem diameter at the lowest N and K doses, demonstrating a possible trend of high doses not providing a highly significant increase in these traits. The study of DMY showed that under a low nitrogen dose and with increase in potassium concentrations, dry matter yield increased; however, as the nitrogen dose increased in associated with potassium doses, dry matter yield did not augment, but was rather suppressed. The three elephant grass genotypes: 'Cuban Pinda', 'IAC Campinas', and 'Cameroon', had average dry yields of 52.66, 50.60, and 48.57 t ha^{-1}, respectively. Results are highly promising and prove the possibility of using elephant grass as an alternative source for biomass production.

Chemometric Soil Analysis on the Determination of Specific Bands for the Detection of Magnesium and Potassium by Spectroscopy

Demattê, J.A.M. L. Ramirez-Lopez, K.P.P. Marques, A.A. Rodella. 2017. Geoderma 288:8-22. DOI: http://dx.doi.org/10.1016/j.geoderma.2016.11.013

Abstract: The laboratory soil analysis is traditionally used to establish elements, such as those related with fertility. It is costly and time consuming, which insures issues for future of precision agriculture, which is stagnated in some countries. Reflectance spectroscopy has recently emerged as a potential tool to reduce these issues. However, chemical elements are usually only underlined with spectra by a "coincidently" statistics and doesn't provide real detection. This study aims to investigate to interaction of K^+ and Mg^{2+} with electromagnetic energy for decrease the demand of soil analysis and rationalize the use of fertilizers. The experiment was carried out using three major soil classes with different textures from tropical environment in Brazil. To reach K^+ and Mg^{2+} saturation in different levels, the soils were saturated with concentrated solutions of KCl and $MgCl_2$ in vertical columns and then washed with distilled and deionized water to extract the residual elements. A second experiment was made by incubation of these elements in soils during four days in room temperature around 30°C. Laboratory spectral sensing was carried out in the VIS-NIR-SWIR regions (350-2,500 nm). Spectra were processed by the Continuum Removal, the Principal Components Analysis (PCA) and Partial Least Squares regression. The PCA showed a high degree of association between spectral and chemical variations. There was no alteration on mineralogy, texture, organic matter, moisture and effective cation exchange capacity (CEC) after the experiment occurs. On the other hand, differences on spectral, mainly where occurs CEC around 2200 nm, did change. Thus, the incident energy interacts with K^+ and Mg^{2+} which promoted these alterations, mostly for Arenosol and Ferrasol. In Cambisol (2:1 mineralogy) we had a double effect due to effective CEC and cations alteration. Were encountered specific bands which altered features due to K^+ and Mg^{2+} content mainly in 2186, 2189 and 2,200 nm. Based on the results, the identified bands (related to K^+ and Mg^{2+} contents in the soil) were extracted from the spectral data of soil samples obtained from a Brazilian soil spectral library. Indeed calibrations of K^+ and Mg^{2+} models allowed to quantify these elements with 0.66 R^2 for the selected bands and 0.64 for the entire spectrum. Thus, the results indicate that it is possible to detect chemical elements, such K^+ and Mg^{2+} in VIS-NIR-SWIR, looking forward on to assist soil analysis and all inherent approaches.

Water and Radiation Use Efficiencies Explain the Effect of Potassium on the Productivity of Cassava

Ezui, K.S., A.C. Franke, P.A. Leffelaar, A. Mando, J. van Heerwaarden, J. Sanabria, J. Sogbedji, and K.E. Giller. 2017. European Journal of Agronomy 83:28-39. DOI: http://dx.doi.org/10.1016/j.eja.2016.11.005.

Abstract: We studied the effects of potassium (K) and its interactions with nitrogen (N), phosphorus (P) and harvest time on the productivity, water use efficiency (WUE) and radiation use efficiency (RUE) of cassava under rain-fed conditions. A field experiment was conducted during two consecutive years on K-deficient soils in Djakakope and on relatively K-rich soils in Sevekpota in Southern Togo, West Africa. Fifteen fertiliser combinations involving K and N rates of 0, 50 and 100 kg ha^{-1} each, and P rates of 0, 20 and 40 kg ha^{-1} were tested. Monthly measurements of leaf area index from 3 to 11 months after planting and daily weather data were used to estimate light interception, RUE, potential water transpiration and WUE of cassava. Overall WUE was 3.22 g dry matter kg^{-1} water transpired and RUE was 1.16 g dry matter MJ^{-1} intercepted photosynthetic active radiation (PAR). On the K-deficient soils, application of K increased WUE and RUE by 36-41% compared with 2.81 g dry matter kg^{-1} water transpired and 0.92 g dry matter MJ^{-1} intercepted PAR achieved without K, respectively. However, the effect of K on cassava growth depended on N availability. Applications of N had relatively weak effects on RUE and WUE, but induced a positive correlation between RUE/WUE and K mass fractions in the plant, and increased the cumulative amount of light intercepted by 11-51%, and the cumulative amount of water transpired through increased leaf area by 13-61%. No significant effect of P on WUE and RUE was observed. Increased cassava yields could be achieved under rain-fed conditions in West Africa through enhanced K management to increase RUE and WUE, along with sufficient N supply for improved light interception and water transpiration by the crop.

Read on

Closing Yield Gaps in China by Empowering Smallholder Farmers
Weifeng Zhang, Guoxin Cao, Xiaolin Li, Hongyan Zhang, Chong Wang, Quanqing Liu, Xinping Chen, Zhenling Cui, Jianbo Shen, Rongfeng Jiang, Guohua Mi, Yuxin Miao, Fusuo Zhang, and Zhengxia Dou. 2016. Nature 537:671-674. DOI: 10.1038/nature19368.

First Farm to Grow Veg in a Desert using only Sun and Seawater
Klein, A. 14 October 2016. New Scientist.

How Big Data will Revolutionize the Global Food Chain
Magnin, C. August 2016. McKinsey&Company.

A Giant Crop-Scanner Is Turning Heads in Arizona
ARS scientists and their partners are using a giant electronic scanner in Maricopa, Arizona to study the growth characteristics of sorghum plants as part of a project designed to speed biofuel crop development. O'Brien, D. 11 October 2016. USDA.

Global Demand for Food Is Rising. Can We Meet It?
Elferink, M., and F. Schierhorn. 7 April 2016. Harvard Business Review.

Impressum *e-ifc*
ISSN 1662-2499 (Online); ISSN 1662-6656 (Print)

Publisher: International Potash Institute (IPI)
Editors: Amnon Bustan, Israel; Susanna Thorp, WRENmedia, UK; Patrick Harvey, Green-Shoots, UK; Hillel Magen, IPI
Chief editor Chinese edition: Youguo Tian, NATESC, Beijing, China
Layout & design: Martha Vacano, IPI
Address: International Potash Institute
Industriestrasse 31
CH-6300 Zug, Switzerland
Telephone: +41 43 810 49 22
Telefax: +41 43 810 49 25
E-mail: ipi@ipipotash.org
Website: www.ipipotash.org

Quarterly e-mail newsletter sent upon request and available on the IPI website. Links in this newsletter appear in the electronic version only.

To subscribe to the *e-ifc*, please go to the subscription page on the IPI website.
To unsubscribe from the *e-ifc* mailing list, please use the unsubscribe link at the bottom of the quarterly newsletter email.

IPI member companies:
Cleveland Potash Ltd., Dead Sea Works Ltd., and Iberpotash S.A.