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

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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

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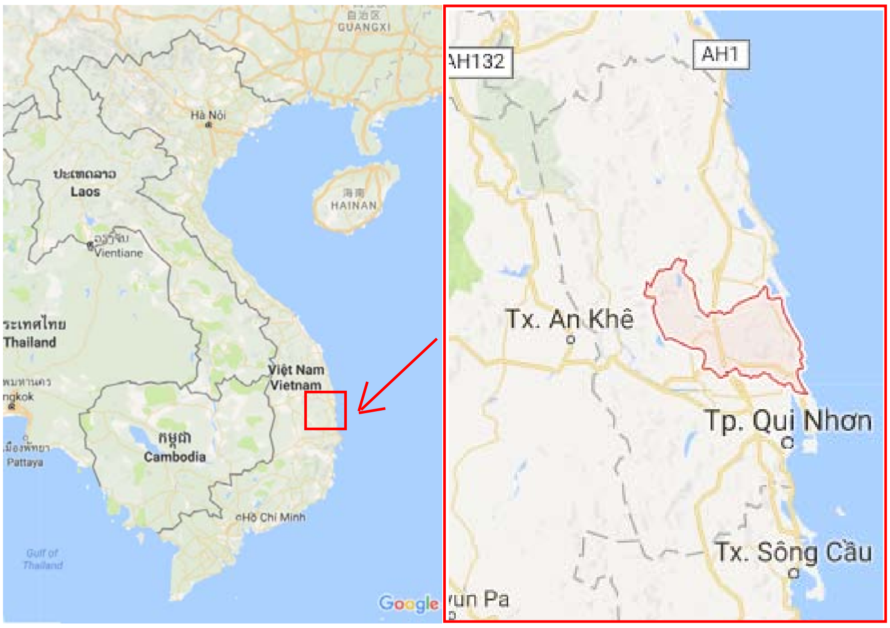
performances and to suggest an optimum fertilization mode for the growing conditions in the Central Coast of Vietnam. Six fertilization treatments were tested: Farmers' practice (FP) control, with N:P:K ratio of 95:40:100; NP-K_0, with 45 kg N ha^{-1}, 90 kg P_2O_5 ha^{-1}, and zero K; and NP-K_{30}; 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.

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.



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

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

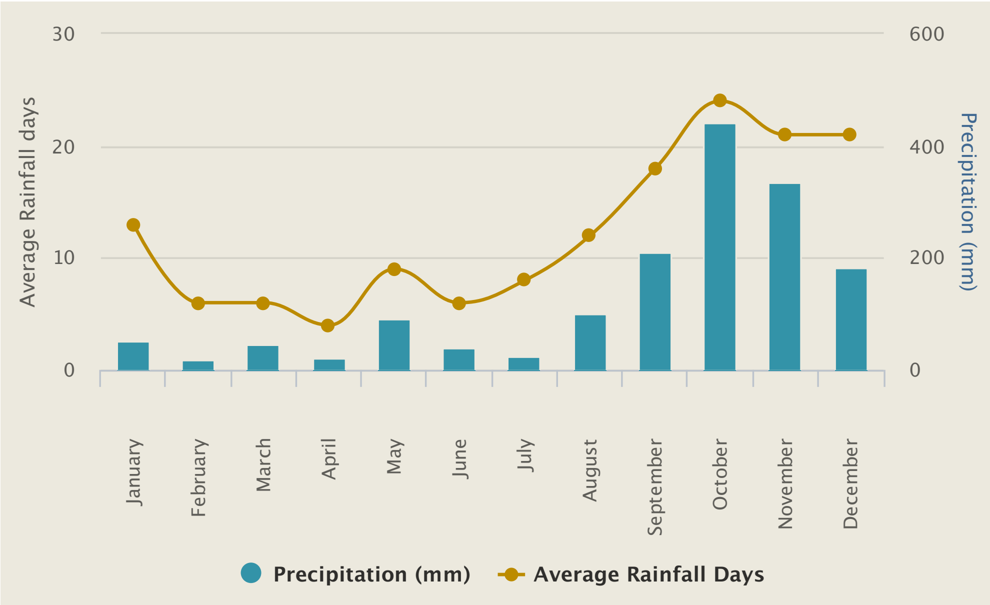


Fig. 1. Average monthly precipitation and number of rainy days at Binh Dinh Province, Vietnam, 2002-2012. *Source:* https://www.worldweatheronline.com/binh-dinh-weather-averages/vn.aspx.

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

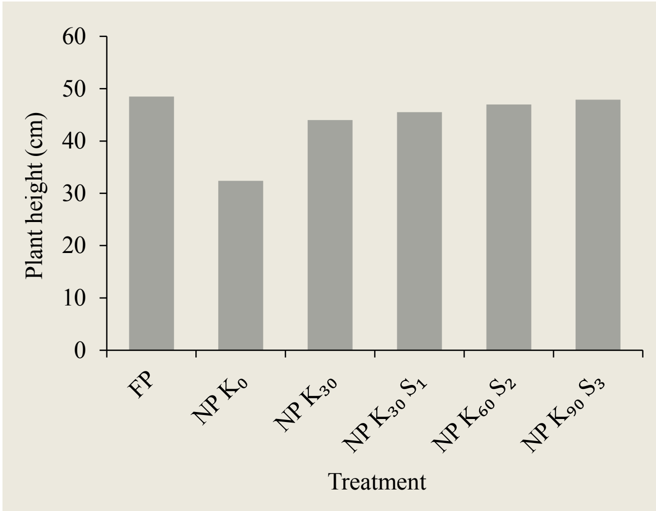


Fig. 3. Peanut plant height at the end of the growth period, 85 DAS, as a function of fertilization treatments.

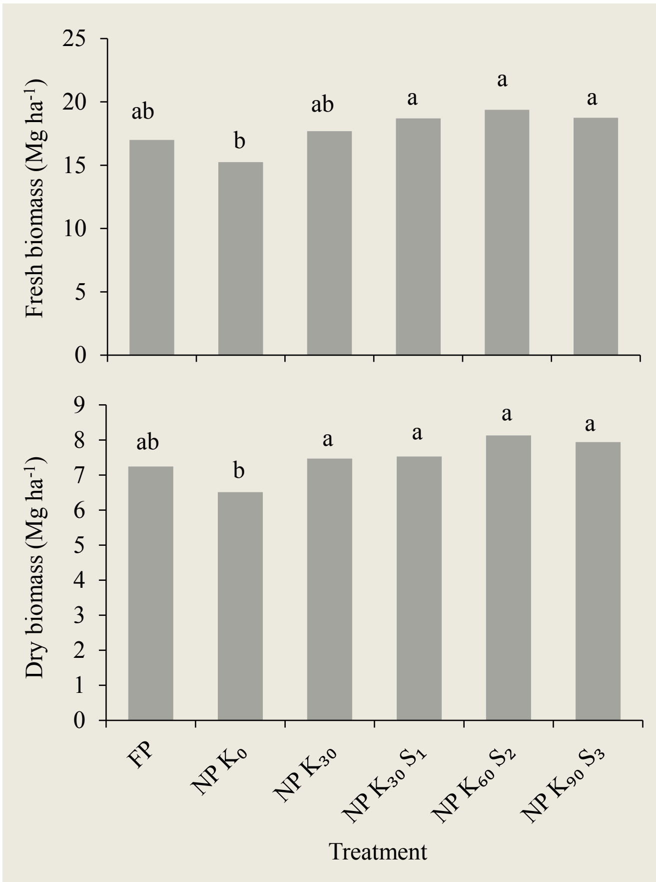


Fig. 4. Effects of fertilization treatments on peanuts' fresh and dry biomass. Different letters indicate statistically significant differences at P <0.05.

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.

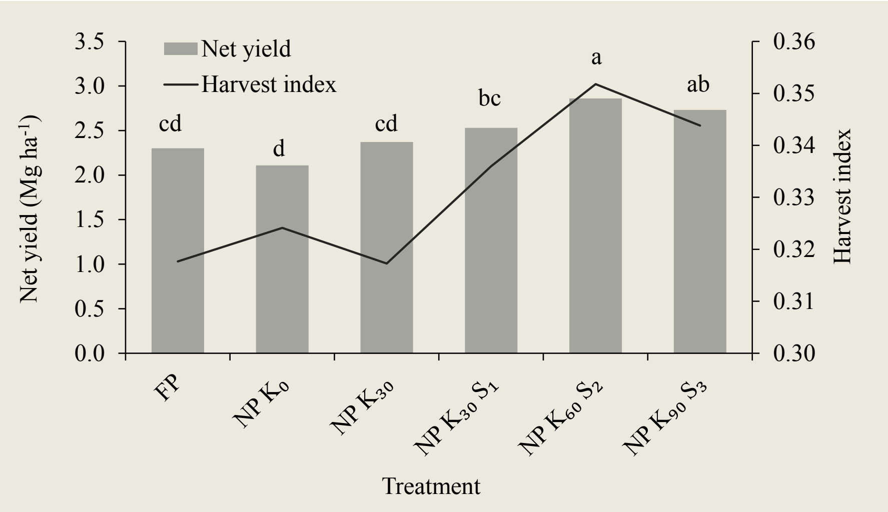


Fig. 5. Effects of fertilization treatments on peanut net yields and harvest index. Different letters indicate statistically differences in net yields at P <0.05.

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.

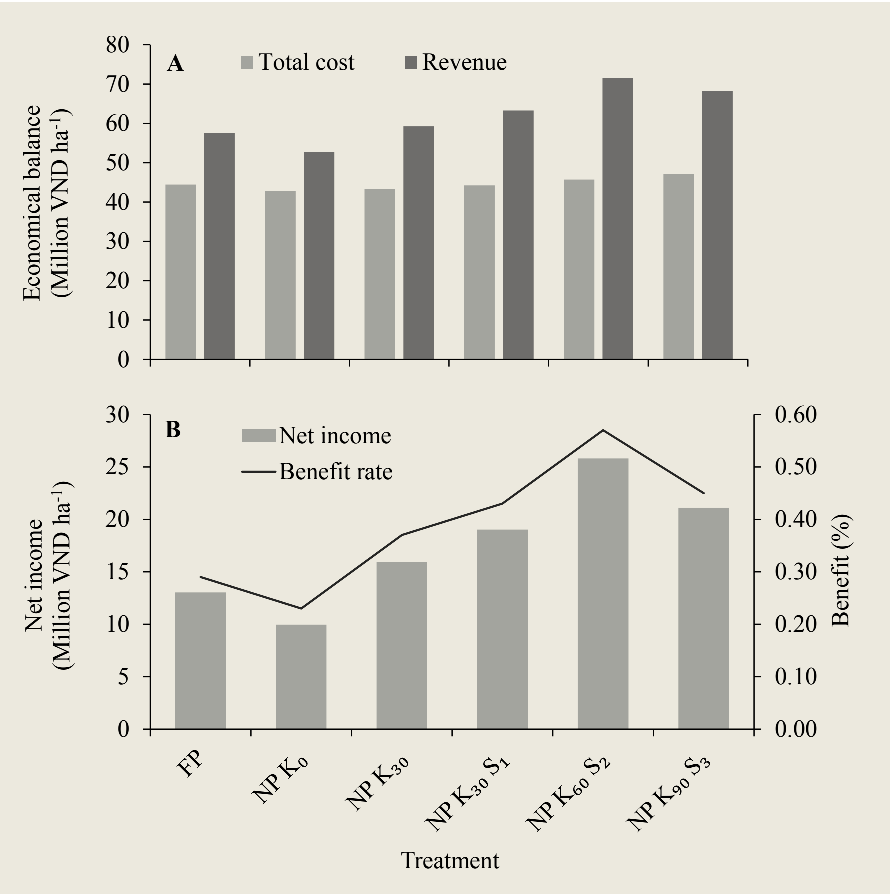


Fig. 6. Effects of fertilization treatments on cost and revenue (A), and on net income and benefit rate (B) from peanut production in 2016 at Cat Hai commune, Phu Cat district, Binh Dinh province, Vietnam.

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

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