Research Findings

Tea plantation in Vietnam. Photo by G. Kalyan.

Polyhalite Application Improves Tea (*Camillia sinensis*) Yield and Quality in Vietnam

Article from report contributed by PVFCCo, Vietnam[1]

Abstract

The tea industry in Vietnam has a 3,000 year history and plays a vital role in income improvement and poverty alleviation in rural areas. 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. However, consequent to the rising productivity of tea plants, the mineral status of soils has been compromised. 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, and Mg, was examined as a potential additive to composite N-P-K fertilizers, as part of an alternative fertilization program for the tea industry in the Lam Dong district. Polyhalite enhances the density, weight and size of tea buds, thus increasing tea productivity by 14-15.5%, and improves tea quality parameters. Overall, polyhalite gave rise to profit increases of 10 and 12.7%, in the Kim Tuyén and TB14 cultivars, respectively. While no direct effect of S could be observed, yield enhancement may be attributed to facilitated N uptake and metabolism.

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Polyhalite demonstrated the ability to supply plant Ca and Mg requirements and maintained soil fertility, whilst supporting greater biomass production, as compared to the alternative fertilization programs.

Keywords: Calcium; *Camellia sinensis*; mineral nutrition; polyhalite; Polysulphate; potassium; sulfur.

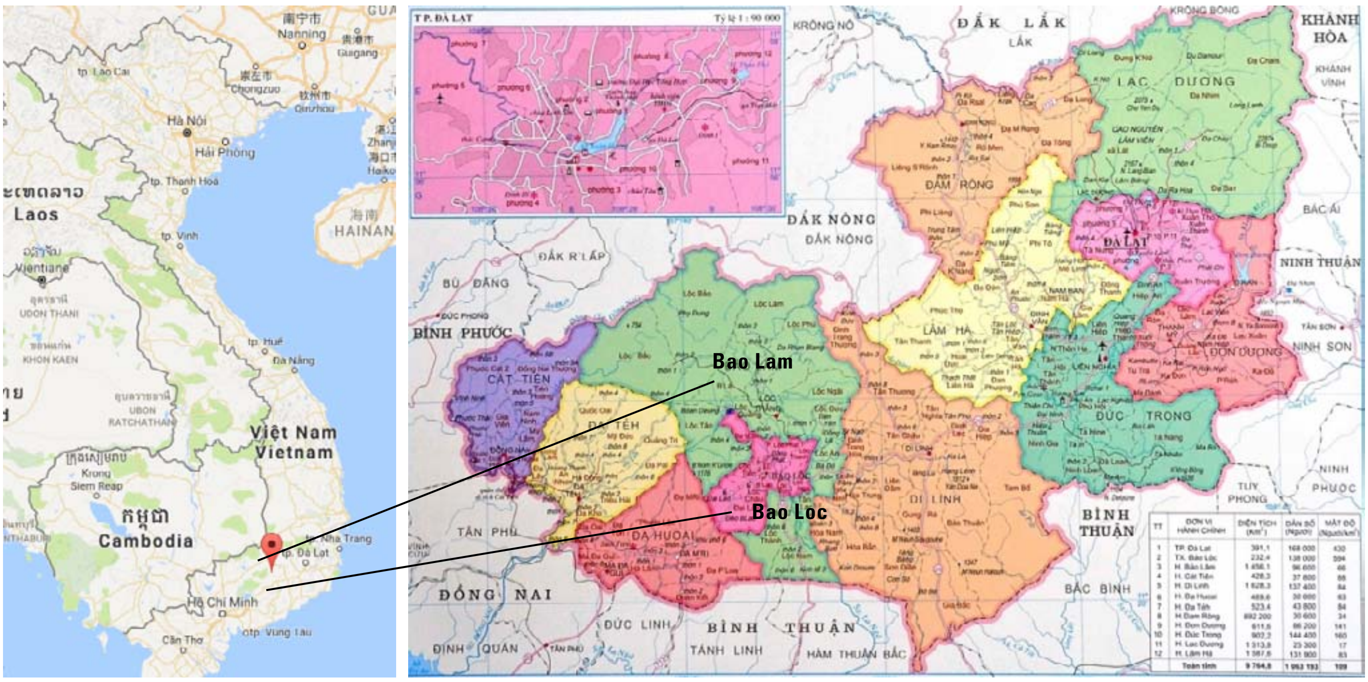
Introduction

With a 3,000 year history, Vietnam is known as one of the most ancient homes of tea. The tea industry in Vietnam plays a vital role in income improvement and poverty alleviation in rural areas (Khoi *et al*., 2015). Following China and India who dominate world tea production (about 60%), and Kenya and Sri Lanka (8% and 7%, respectively), Vietnam is the fifth largest tea producer in the world (about 4%), with 214,230 tons produced each year (FAO, 2014; Khoi *et al*., 2015). In the Lam Dong province, there are 22,000 ha of bud tea (Lam Dong Portal, 2016).

Nevertheless, the tea industry in Vietnam is currently experiencing significant challenges. Improving the resource utilization efficiency has recently been determined as the major strategic goal of this industry (Hong and Yabe, 2015). Furthermore, updating tea farming technologies to increase yield and quality is essential to restoring the traditional status of the Vietnamese tea industry (Khoi *et al*., 2015). Appropriate mineral nutrition practices are pivotal to achieving these goals.

The young vegetative buds of the tea plant are repeatedly harvested, thus a maintenance of continuous new growth is essential. In addition to suitable ranges of temperature and air humidity, and water availability (Wilson, 2004; Namita *et al*., 2012), tea requirements for soil mineral nutrition must be carefully met (Wang *et al*., 2016). Moreover, the mineral composition of the leaves affects produce quality and depends very much on local soil properties and nutritional status (Ferrara *et al*., 2001; Erturk *et al*., 2010). Due to the low soil pH and the precipitation regime in tea growing regions, phosphorus (P) nutrition has become a concern (Zoysa *et al*., 1999). Practically, P is supplied using fused calcium-magnesium phosphate (Ca-Mg-P, P_2O_5 15%, SiO_2 20%, MgO 12%, CaO 45%, at pH 8.5). In contrast, an acidic root environment (pH 4-5) promotes nitrogen (N) uptake and biomass growth (Ruan *et al*., 2007). The form of N has significant importance; tea plants acquire NH_4^+ far better than NO_3^- (Ruan *et al*., 2007), justifying the traditional N supply through urea. Potassium (K) has seldom been supplied in tea plantations in Vietnam.

In recent years, intensive farming practices have been introduced to the Vietnamese tea industry. The consequent rise in productivity has generated significant pressure on the mineral nutrition status of the soil. The availability of alkaline elements - in particular K, calcium (Ca), and magnesium (Mg) - is steadily declining. The tropical climate of Lam Dong and frequent heavy precipitation accelerates soil weathering and loss of nutrients through leaching below or away from the root zone. Consequently, deficiency symptoms often occur in plantations that were previously highly productive.



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).

The recently introduced composite N-P-K 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 provide a sufficient solution for the declining alkaline cations.

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% K_2O, 48% SO_3, 6% MgO, and 17% 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 N-P-K 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 tea production in Vietnam, and to test, economically, two novel alternative fertilization programs in comparison to traditional practice.

Materials and methods

Two parallel experiments were conducted in two districts of the Lam Dong province, Vietnam (Map 1). Seven year old tea plantations were employed at both sites, with Kim Tuyén and TB14 cultivars at Bao Loc and Bao Lam districts, respectively. The experiments lasted from April to December 2015.

Three fertilization programs were tested (Table 1): CT1 (control), simulated the common farmers' 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 twice as high at Bao Loc (cv. Kim Tuyén), excluding Polysulphate (200 and 150 kg ha^{-1}, at Bao Loc and Bao Lam, respectively), and KCl administration aimed at balancing K supply between the programs.

Fertilizer application began in mid-April with N, P_2O_5, and K_2O basal doses with 1,472, 503, and 499 kg ha^{-1} at Bao Loc, and 736, 252, and 280 kg ha^{-1} at Bao Lam, respectively. The rest of the annual fertilizer dose was distributed during the season, as detailed in Table 2.

The soil at both sites was acidic, with $pH_{(KCl)}$ ranging from 4.2-4.28. Table 3 demonstrates that soil organic matter content was higher at Bao Loc (8.5%) than at Bao Lam (5.7%). Soil fertility was better at Bao Loc, as indicated by the slightly higher N content, and by the significantly higher levels of available P and K (Table 3). Also, the soil at Bao Lam contained much less Ca and Mg than that of Bao Loc. However, no differences were observed regarding soil S contents.

Three-leaf buds were continuously picked throughout the harvesting season. Bud density was determined at each harvest and samples were taken for measurements of bud weight and length. Once a month, 200 buds were sampled from each plot and the infection rates of red spider and green bug were recorded. The elemental (N, P, K, Ca, Mg, and S) composition of the tea buds was examined a few days before, and 20 days after fertilizer application

Table 1. Fertilizer compositions and programs (CT1, CT2, and CT3) examined in tea plantations at Bao Loc and Bao Lam districts, Vietnam.

Fertilizer	Bao Loc (cv. Kim Tuyén)			Bao Lam (cv. TB14)		
	CT1 (Control)	CT2 (Phu My Fertilizer)	CT3 (Phu My Fertilizer + Polysulphate)	CT1 (Control)	CT2 (Phu My Fertilizer)	CT3 (Phu My Fertilizer + Polysulphate)
	Amount of fertilizer (kg ha^{-1})					
Polysulphate	0	0	200	0	0	150
NPKS (16-16-8-13)	0	800	800	0	400	400
NPK (15-15-15)	0	1,000	1,000	0	500	500
NPK (25-9-9)	0	1,500	1,500	0	750	750
NPK (27-6-6)	0	1,500	1,500	0	750	750
Urea	3,200	900	900	1,600	450	450
Fused Ca-Mg-P	3,353	0	0	1,677	0	0
KCl	832	100	53	466	100	65

Table 2. Time of year of fertilizer applications during the season.

Time of year	Fertilizer
Mid-April	Polysulphate; NPKS (16-16-8-13)
Early June	NPK (12-10-9)
Mid-July	NPK (25-9-9)
Mid-September	Polysulphate; NPK (27-6-6)
Early November	Urea; KCl

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 Loc	pH_{KCl}	4.21	4.25	4.22	4.18	4.20	4.18
	OM (%)	8.51	8.55	8.55	8.30	8.42	8.44
	Total soil N (%)	0.281	0.278	0.280	0.282	0.284	0.286
	Total soil P_2O_5 (%)	0.23	0.22	0.23	0.23	0.23	0.23
	Total soil K_2O (%)	0.14	0.14	0.14	0.14	0.14	0.15
	Available P_2O_5 (mg/100 g)	15.4	15.6	15.7	15.5	15.8	15.8
	Available K_2O (mg/100 g)	26.7	26.3	26.5	26.8	26.9	27.0
	Ca^{++} (meq/100 g)	3.1	3.3	3.1	3.2	3.0	3.2
	Mg^{++} (meq/100 g)	2.5	2.5	2.4	2.7	2.1	2.6
	S (%)	0.018	0.018	0. 017	0.016	0.019	0.018
Bao Lam	pH_{KCl}	4.28	4.23	4.26	4.22	4.20	4.22
	OM (%)	5.62	5.66	5.70	5.41	5.48	5.59
	Total soil N (%)	0.246	0.241	0.247	0.248	0.249	0.250
	Total soil P_2O_5 (%)	0.20	0.21	0.21	0.20	0.21	0.22
	Total soil K_2O (%)	0.11	0.12	0.11	0.11	0.12	0.12
	Available P_2O_5 (mg/100 g)	9.4	9.4	9.5	8.5	8.7	8.8
	Available K_2O (mg/100 g)	16.6	16.5	16.7	16.8	16.9	17.0
	Ca^{++} (meq/100 g)	2.6	2.7	2.5	2.7	2.3	2.5
	Mg^{++} (meq/100 g)	1.9	1.9	1.9	1.9	1.6	2.0
	S (%)	0.015	0.015	0.016	0.015	0.015	0.016

Table 4. Effect of fertilizer treatments on leaf N, P, K, Ca, Mg, and S contents (%) in Kim Tuyén and TB14 tea cultivars.

Variety	Element	Before fertilization			After fertilization		
		CT1	CT2	CT3	CT1	CT2	CT3
		--%--					
Kim Tuyén	N	3.07	3.05	3.06	3.38	3.41	3.37
	P	0.155	0.154	0.154	0.167	0.163	0.166
	K	1.24	1.24	1.22	1.41	1.37	1.40
	Ca	0.38	0.40	0.39	0.61	0.33	0.58
	Mg	0.19	0.17	0.18	0.55	0.16	0.53
	S	0.14	0.14	0.14	0.13	0.27	0.30
TB14	N	3.03	3.05	3.03	3.35	3.32	3.34
	P	0.155	0.153	0.152	0.162	0.164	0.161
	K	1.23	1.22	1.21	1.38	1.38	1.39
	Ca	0.35	0.37	0.34	0.51	0.31	0.50
	Mg	0.16	0.16	0.15	0.46	0.14	0.44
	S	0.12	0.13	0.12	0.11	0.25	0.27

(Table 2). Tea bud quality was inferred by dry matter content and by the rates (%) of the soluble fraction, tannins, and caffeine in the dry matter.

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 complex (Table 3). Soil acidity and content of organic matter (OM), tended to increase during the growing season at both locations. This tendency may indicate active soil degradation processes that require a significant supplementation of organic manure. The total N-P-K levels remained stable or slightly increased. Available P_2O_5 increased a little at Bao Loc, but significantly dropped at Bao Lam. Available K_2O showed some increase in both locations. No differences could be observed between treatments regarding the above mentioned soil parameters. These results indicate that N-P-K were sufficiently applied in all three cases.

However, significant differences between treatments did occur with regard to Ca and Mg. While the content of these elements remained stable or even increased at CT1 and CT3, they declined markedly at CT2, suggesting a fragile balance between soil availability and tea crop requirements of Ca and Mg. At Bao Loc, soil S content slightly decreased at CT1 but remained stable at CT2 and CT3, while no changes were observed at Bao Lam (Table 3).

The influence of the different fertilization programs on nutrient content in the leaves was examined shortly before, and 20 days after the fertilizer application (Table 1). Nitrogen content increased from 3.06 to roughly 3.4% of dry leaf weight, however, no differences occurred between treatments. Similarly, leaf contents of P and K increased slightly, from 0.155 to 0.165%, and from 1.24

to 1.4%, respectively, with no significant effect of particular treatment. These results show the efficiency of a balanced N-P-K application, in spite of employing different types of fertilizers.

The response was different with Ca, Mg, and S; Ca and Mg contents increased significantly in CT1 and CT3 and slightly decreased in CT2. No advantage was observed for any of the fertilizers, fused Ca-Mg-P or Polysulphate, as a source of Ca or Mg. Leaf contents of S doubled at CT2 and CT3, with Polysulphate proving to be slightly more effective than the N-P-K-S fertilizer, as an S source (Table 4). Interestingly, Ca, Mg, and S leaf contents were somewhat lower in the TB14 cultivar than in Kim Tuyén.

Tea yield components, such as three-leaf-bud density, weight, and length, were significantly affected by the different fertilization programs (Fig. 1). There were dramatic differences in all yield

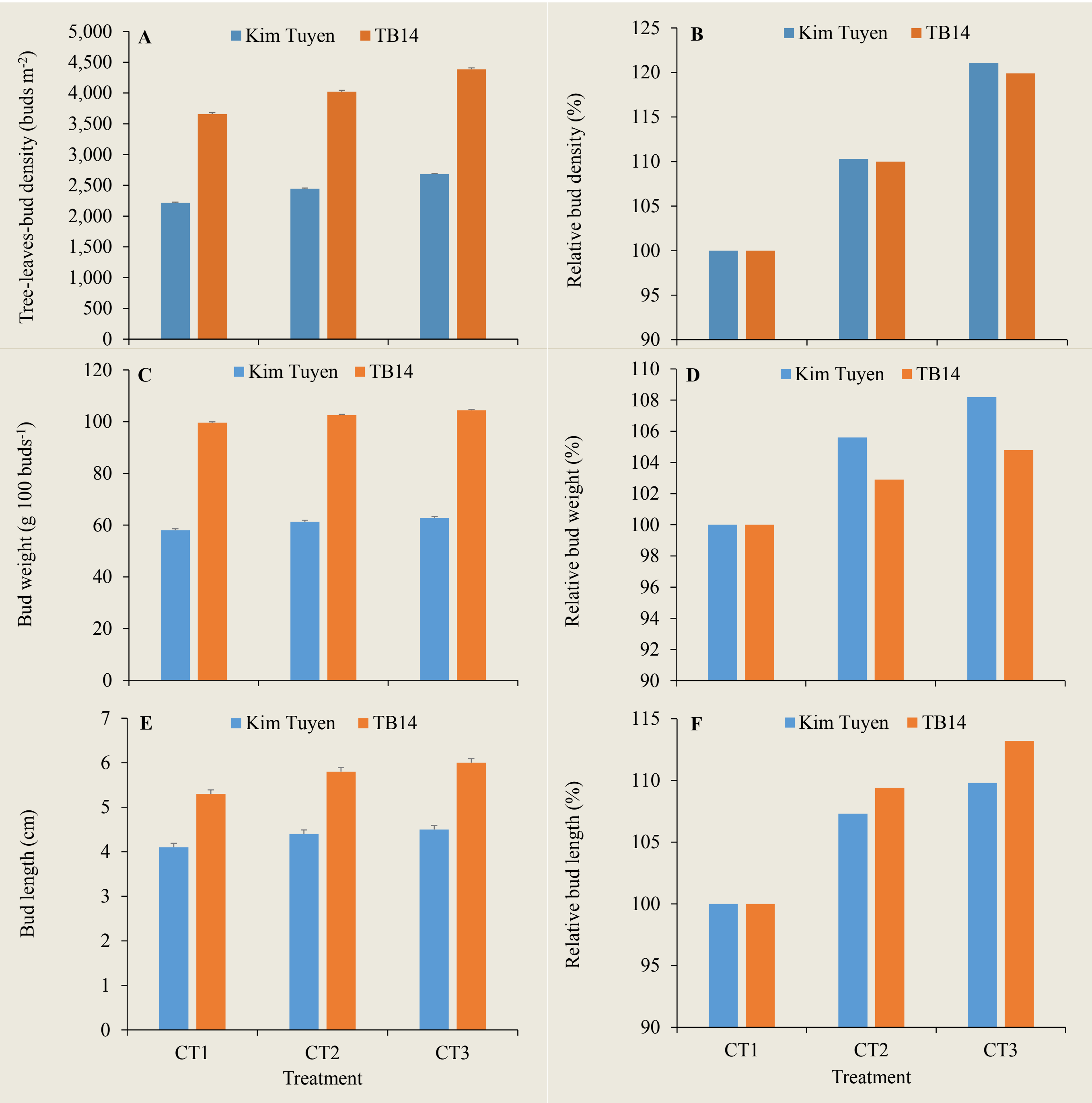


Fig. 1. Effect of fertilizer treatments on three-leaf-bud absolute and relative yield components (density, weight, and length) of the Kim Tuyén and TB14 cultivars. Bars indicate LSD at 5%.

parameters between the two cultivars. TB14 displayed much higher bud density, weight, and length (Fig. 1A, C, E). Bud density increased by 10 and 20-21% at CT2 and CT3, respectively, relative to CT1, showing no differences between the cultivars (Fig. 1B). Bud weight, which was more responsive in cultivar Kim Tuyén, increased by 5.6 and 8.5% at CT2 and CT3, respectively and relative to CT1, while, in TB14, bud weight increased by only 2.9 and 4.8%, respectively (Fig. 1D).

In contrast, bud length was more responsive in TB14, where it increased by 9.4 and 13.2% at CT2 and CT3, respectively and relative to CT1. Bud length of Kim Tuyén increased by 7.3 and 9.8% in response to CT2 and CT3, respectively (Fig. 1F).

In general, TB14 obtained much greater yields than Kim Tuyén (35.4 vs. 12.9 Mg ha^{-1}) at the control treatment, CT1 (Fig. 2A). The overall increase of the tea bud yield was 9.3 and 10.5% for Kim Tuyén and TB14, respectively, at CT2 relative to CT1. The increase is significantly higher at CT3, 15.5 and 14.1%, respectively (Fig. 2B).

The different fertilization programs did not seem to have any influence on the rates or severity of the green bug infections (1-2% of 200 plants examined), or the red spider infections (2-2.5%).

Considering that N-P-K rates and application timings were similar among all fertilization programs, the advantage displayed by CT2 may be attributed to S enrichment through the N-P-K-S fertilizer. Nevertheless, with a similar S rate, split to two applications, CT3 brought about a more significant yield increase. The advantage of CT3 may also be attributed to soil enrichment with Ca and Mg, both provided through the Polysulphate application, but absent in CT2. Additionally, the slow-release effect of Polysulphate with regard to S and K availability might have had a positive influence on plant growth.

Table 5 indicates that the lack of Ca and Mg appears to influence green tea quality parameters. CT2 consistently obtained lower rates of dry matter content, soluble fraction, tannins, and caffeine, compared to CT1. Conversely, CT3 displayed the highest rates for these parameters. In this regard, cultivar Kim Tuyén displayed

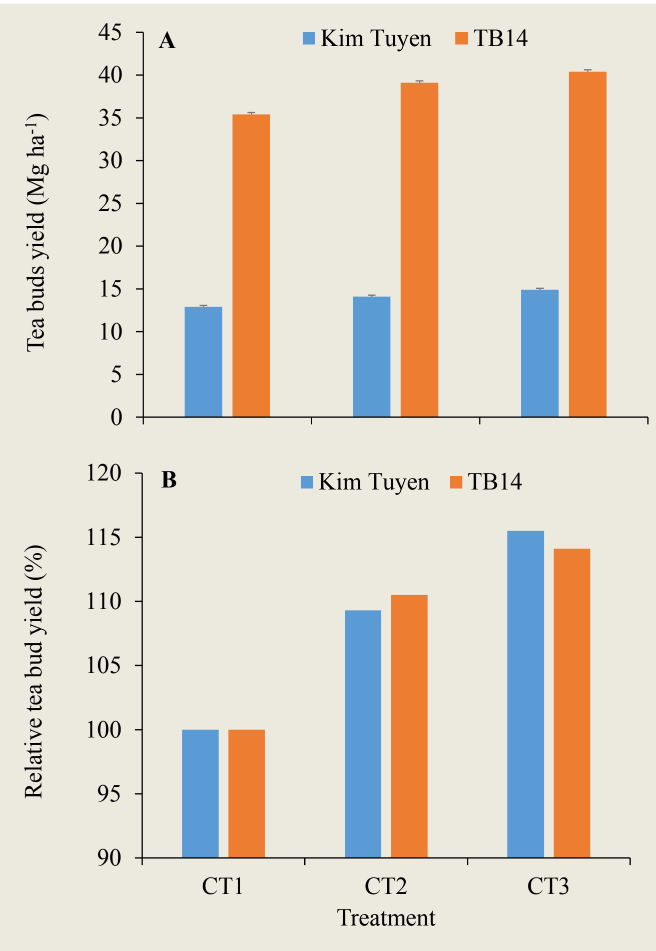


Fig. 2. Effect of fertilizer treatments on the absolute and relative yield of Kim Tuyén and TV14 tea cultivars in Vietnam. Bars indicate LSD at 5%.

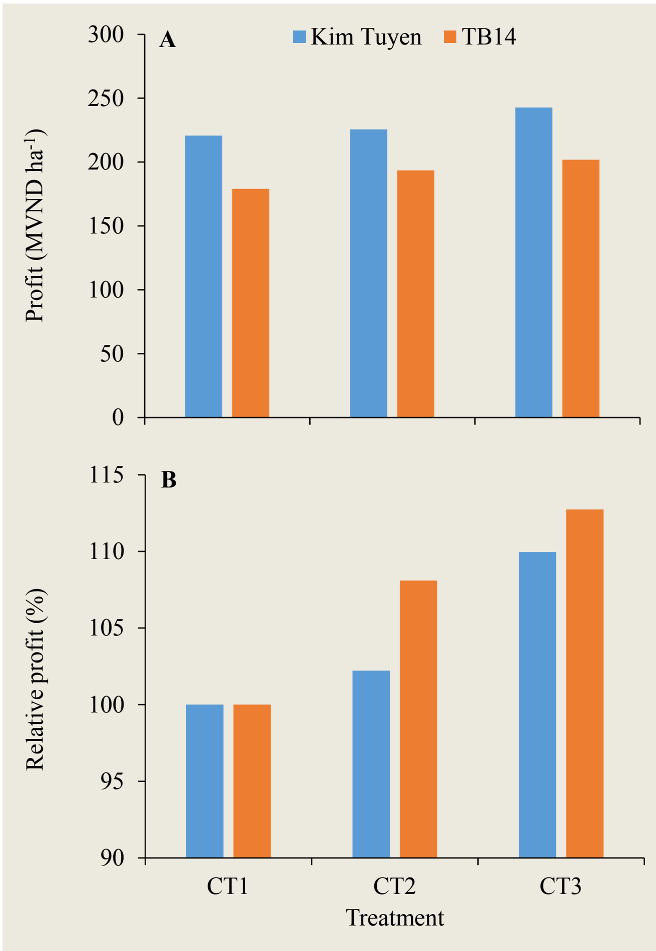


Fig. 3. Effect of fertilizer treatments on the profit of two tea cultivars in Vietnam.

Table 5. Effects of fertilizer treatments on physical and chemical quality parameters of two tea cultivars in Vietnam.

Variety	Treatment	Dry matter	Soluble fraction	Tannins	Caffeine
		% of fresh weight	-------------------*% of dry weight*------------------		
Kim Tuyén	CT1	73.55	44.36	26.91	3.05
	CT2	72.09	43.11	25.64	2.93
	CT3	74.00	45.12	27.41	3.11
TB14	CT1	72.75	40.10	24.82	2.86
	CT2	71.52	39.66	23.71	2.74
	CT3	73.11	41.26	25.59	2.97

Table 6. Economic balance of three fertilization programs for Kim Tuyén and TB14 green tea cultivars grown in Vietnam.

Cultivar	Fertilization program	Total cost	Total income
		---------------------*million VND* ha^{-1}---------------------	
Kim Tuyén	CT1	75.9	296.7
	CT2	98.6	324.3
	CT3	99.9	342.7
TB14	CT1	93.6	272.6
	CT2	107.5	301.1
	CT3	109.3	311.1

consistently higher quality rates than TB14.

The Kim Tuyén cultivar is highly appreciated in green tea markets and its high retail cost compensates for relatively low yields (Fig. 2). Thus, in spite of the almost doubled fertilizers input (Table 1), Kim Tuyén is more profitable than TB14 for any of the tested fertilization programs (Fig. 3). In both cultivars, CT2 was significantly more profitable than CT1, and CT3 more than CT2. These results suggest that the common tea fertilization practice (CT1) in these regions of Vietnam may be considerably improved using additional S fertilizers, although the exact role of this element in tea plants is still obscure.

The availability of nutrients, such as Ca and Mg, appears to be significant for tea crop production and their increased application should be considered. Polyhalite, comprising Ca, Mg, K and S seems to provide the most profitable solution, particularly due to significant yield improvement at a reasonable cost (Fig. 3; Table 6).

Conclusions

Polysulphate, added to a systematic N-P-K fertilization program for tea plants grown on reddish brown soil in Lam Dong, Vietnam, enhanced the density, weight and size of tea buds, thus increasing tea productivity by 14-15.5%. Also, Polysulphate slightly improved tea quality parameters such as dry matter content and the concentrations of soluble substances, tannins, and caffeine. Overall, Polysulphate gave rise to profit increases of 10% and 12.7%, in the cultivars Kim Yuyén and TB14, respectively. While no direct effect of S nutrient could be observed, some of the yield enhancement may be attributed to facilitated N uptake and metabolism. Polysulphate demonstrated the ability to supply plant Ca and Mg requirements and maintain soil fertility, while supporting greater biomass production, compared to the alternative fertilization programs.


Tea plantations in Vietnam. Photos by Nguyen Duy Phuong.

References

Erturk, Y., S. Ercisli, M. Sengul, Z. Eser, A. Haznedar, and M. Turan. 2010. Seasonal Variation of Total Phenolic, Antioxidant Activity and Minerals in Fresh Tea Shoots (*Camellia sinensis* var. sinensis). Pakistan Journal of Pharmaceutical Science, 23(1):69-74.

Ferrara, L., D. Montesano, and A. Senatore. 2001. The Distribution of Minerals and Flavonoids in the Tea Plant (*Camellia sinensis*). Il farmaco 56(5):397-401.

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

Hong, N.B., and M. Yabe. 2015. Resource Use Efficiency of Tea Production in Vietnam: Using Translog SFA Model. J. Agric. Sci. 7:160-172.

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.

Khoi, N.V., C.H. Lan, and T.L. Huong. 2015. Vietnam Tea Industry-An Analysis from Value Chain Approach. International Journal of Managing Value and Supply Chains 6 September 2015 (DOI: 10.5121/ijmvsc.2015.6301).

Lam Dong Portal. 2016. Lam Dong Tea in Vietnamese Tea Culture. http://www.lamdong.gov.vn/en-US/home/news/hotnews/Pages/Lam-Dong-Tea-in-Vietnamese-Tea-Culture.aspx.

Namita, P., R. Mukesh, and K.J. Vijay. 2012. *Camellia Sinensis* (Green Tea): A review. Global Journal of Pharmacology 6(2):52-59.

Ruan, J., J. Gerendás, R. Härdter, and B. Sattelmacher. 2007. Effect of Nitrogen Form and Root-Zone pH on Growth and Nitrogen Uptake of Tea (*Camellia sinensis*) Plants. Annals of Botany 99(2):301-310.

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

Wang, Y., D. Fu, L. Pan, L. Sun, and Z. Ding. 2016. The Coupling Effect of Water and Fertilizer on the Growth of Tea Plants [*Camellia sinensis* (L.) O. Kuntz]. J. Plant Nutr. 39:620-627.

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

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.

Zoysa, A.K.N., P. Loganathan, M.J. Hedley. 1999. Phosphorus Utilisation Efficiency and Depletion of Phosphate Fractions in the Rhizosphere of Three Tea (*Camellia sinensis* L.) Clones. Nutrient Cycling in Agroecosystems 53(2):189-201.

The paper "Polyhalite Application Improves Tea (*Camillia sinensis*) Yield and Quality in Vietnam" also appears on the IPI website at:

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