Research Findings

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

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

Tran Minh Tien[1], Ho Cong Truc[2], and Nguyen Van Bo[3]

Abstract

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

[1]Soils and Fertilizers Research Institute (SFRI), Duc Thang, Bac Tu Liem, Hanoi, Vietnam
[2]Research Center for Highland Soils, Fertilizers & Environment; Hoa Thang, Buon Ma Thuot, Daklak, Vietnam
[3]Vietnam Academy of Agricultural Sciences; Vinh Quynh, Thanh Tri, Hanoi, Vietnam
[1a]Corresponding author: tranminhtien74@yahoo.com
Note: IPI acknowledge Mr. Alexey Shcherbakov, former IPI Coordinator for Southeast Asia, for his contribution to this project.

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

Introduction

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

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

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

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

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

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

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

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

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

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

Materials and methods

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

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

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

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

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

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

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

Results and discussion

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

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

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

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

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

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

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

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

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

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

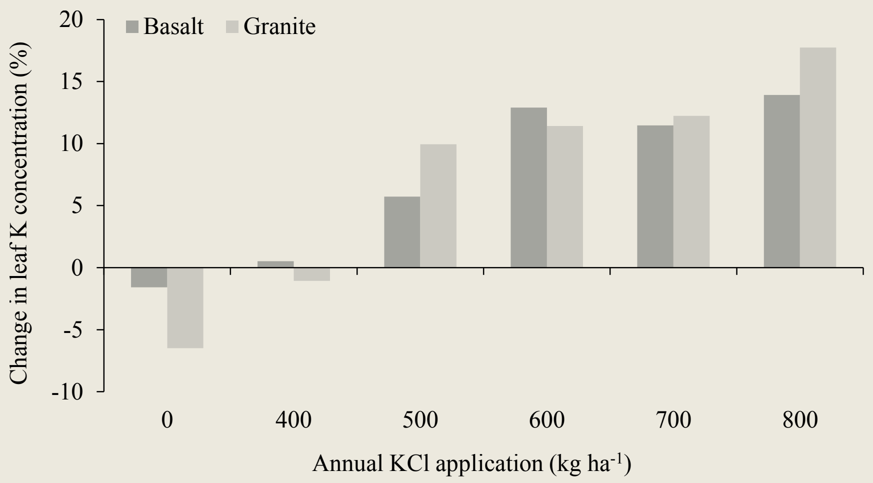

Fig. 1. The difference (%) between K leaf content in coffee trees prior to and 30 days after K application at six annual doses on basaltic and granite soils..

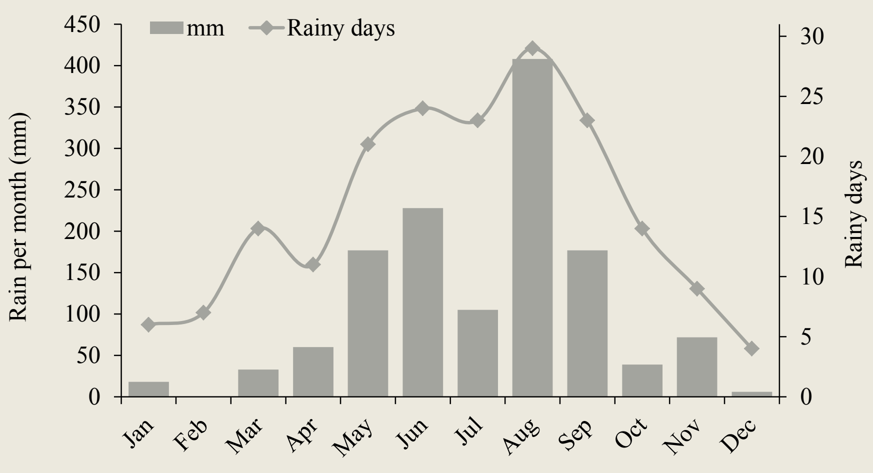

Fig. 2. Average monthly distribution of annual precipitation in Kon Tum, Central Highlands, Vietnam. *Source:* http://www.worldweatheronline.com/Kon-Tum-Ko-Nam-weather-averages/VN.aspx.

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

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

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

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

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

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

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

Conclusions

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

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.

D'haeze, D., J. Deckers, D. Raes, T.A. Phong, and N.D.M. Chanh. 2003. Over-Irrigation of *Coffea canephora* in the Central Highlands of Vietnam Revisited: Simulation of Soil Moisture Dynamics in Rhodic Ferralsols. Agricultural Water Management 63:185-202.

D'haeze, D., J. Deckers, D. Raes, T.A. Phong, and H.V. Loi. 2005. Environmental and Socio-Economic Impacts of Institutional Reforms on the Agricultural Sector of Vietnam: Land Suitability Assessment for Robusta coffee in the Dak Gan Region. Agriculture, Ecosystems and Environment 105:59-76.

Dzung, N.A., T.T. Dzung, and V.T.P. Khanh. 2013. Evaluation of Coffee Husk Compost for Improving Soil Fertility and Sustainable Coffee Production in Rural Central Highland of Vietnam. Resources and Environment 3:77-82.

FAO. 2012. CROWAT Version 8.0. Food and Agriculture Organization (FAO), Rome, Italia. Available at http://www.fao.org/nr/water/infores_databases_cropwat.html (accessed on 10 April 2012).

Forestier, F. 1969. New Problems Used Mineral Fertilizer on Coffee in the Central African Republic. The Café - Cacao 1/1969.

Giungato, P., E. Nardone, and L. Notarnicola. 2008. Environmental and Socio-Economic Effects of Intensive Agriculture: The Vietnamese case. J. Commodity Sci. Technol. Quality 47:135-151.

Ha, D.T., and G. Shively. 2005. Coffee vs. Cacao: A Case Study from the Vietnamese Central Highlands. J. Nat. Resour. Life Sci. Educ. 34:107-111.

Hoang Thanh Tiem. 1999. The Vietnamese Coffee. Agricultural Publishing House, Hanoi.

Jessy, M.D. 2011. Potassium Management in Plantation Crops with Special Reference to Tea, Coffee, and Rubber. Karnataka J. Agric. Sci. 24(1):67-74.

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.

Nguyen Tri Chiem, and Doan Trieu 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.

Nguyen Vy, and Tran Khai. 1978. Soil chemistry of Northern Vietnam. Scientific and technologic Publishing House, Hanoi.

Nguyen Van Sanh. 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.

Ton Nu Tuan Nam, and Truong 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.

Truong Hong. 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.

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

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.

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

Regional activities/Southeast Asia