Research Findings

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

Effects of Annual Potassium Dosage on the Yield and Quality of *Coffea robusta* in Vietnam

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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). Current farmer custom regarding fertilizer application for coffee in the region is problematic; farmers tend to overuse fertilizers with no consideration of NPK ratio. Usually, too large amounts of nitrogen (N) and phosphorus (P) are applied, while potassium (K) is often neglected. In view of the important roles of K in plant performance, the objective of the present study was to evaluate the efficiency of K fertilizer on yield and product quality of commercial Robusta coffee in the Central Highlands of Vietnam. The goals of the project were

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to identify the optimum K application dosage for commercial Robusta coffee in the Highlands, and to demonstrate the positive effects of K fertilization on coffee yield and quality. Two parallel field experiments were conducted from 2012 to 2014, one in Dak Lak province, and the other in Kom Tum province. Six annual doses of K (MOP) application (0, 400, 500, 600, 700 and 800 kg MOP 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 shows that profit is at maximum at annual K dosage of 600 kg KCl ha^{-1}. Apparently, this K dose should be recommended to the regions farmers. Nevertheless, it is more than twice the dose regularly recommended for coffee worldwide. Further analysis and research are required regarding the interactions among soil properties, precipitation regime, and coffee requirements before solid conclusions and instructions to farmers are issued.

Introduction

Coffee is one of the leading agricultural commodities worldwide. According to FAO's statistical data in 2011, total annual yield of world coffee product was 8,284,135 Mg (ton), 63.7% of which are occupied by five countries with highest yields. Brazil led the list with 2,700,400 Mg, followed by Vietnam, Indonesia, Columbia, and India, with 1,167,900, 634,000, 468,120, and 302,000 Mg, respectively (FAO, 2012). In the Central Highland region in Vietnam, an area of about 500,000 ha is occupied by coffee plantations. Coffee is a major economic engine for the local developing agricultural sector. Therefore, much effort is made to improve the regions coffee yield and quality. Vietnam has unique achievements in developing robusta coffee (*Coffea robusta* or *canephora*) as a high yielding cash crop. This has been made possible by intensification methods, including irrigation during the dry season (Marsh, 2007). Special concern has been devoted to nutrition requirements and fertilization dosage and regime.

Coffee displays high demands for fertilizers, particularly N and K (Jessy, 2011); obtaining one Mg of coffee beans, Robusta coffee would require 30-35 kg N, 5.2-6.0 kg P_2O_5, 36.5-50.0 kg K_2O, 4 kg CaO, and 4 kg MgO, depending on tree age and soil types. A high producing hectare of coffee would require at least 135 kg N, 34 kg P_2O_5, and 145 kg K_2O (De Geus, 1973). Potassium is needed for most basic processes in plants life cycle (Engels *et al*., 2012). Potassium promotes the activity of over 60 enzymes; it takes part in the creation and translocation of carbohydrates; it is also involved in protein synthesis and other anabolic and metabolic processes in plants. Potassium assists in water uptake and is involved in drought-, cold-, and salt-resistance. In many crops, satisfying the demands for K would improve the absorption of other elements. Satisfactory K nutrition may be responsible for the reduction of young fruit abortion and also to the enhancement of plant tolerance to certain diseases.

Potassium requirements for coffee are high during the development of the berries and are at maximum during their ripening. Peaks of K uptake rate were observed immediately after bloom, prior to fruit ripening, and after harvest (Mitchell, 1988). Forestier (1969), studying Arabica coffee, showed that chronic lack of K brought about a significantly increased rate of young fruit abortion, and to degeneration of branches and consequent die-back.

Several studies on soil and fertilizer application for Robusta coffee in the commercial phase have been carried out, resulting in controversial information regarding the annual requirements of coffee in Vietnam. Ton Nu Tuan Nam (1993), in his study of combined application of NPK for Robusta coffee, concluded that reaching the maximum yield would require annual application of 385 and 250 kg ha^{-1} of N and K_2O, respectively. Le Ngoc Bau (1997), who focused on plantations with particularly high coffee beans yields (>5 Mg ha^{-1}) in the Highland provinces (Gia Lai, Dak Lak and Kon Tum), found that the annual dose of K ranged from 400-500 kg K_2O ha^{-1}, twice as much as recommended. Nevertheless, in cases where K was applied at levels 2-3 times higher than recommended, no significant effects on the yield or on the tree growth and development could be observed, as well as any positive correlation between yield and K content. Nguyen Van Sanh (2009) studied balanced fertilization in Ea Pok Coffee Cooperative (Dak Lak); the results showed that the appropriate doses are 180 N - 83 P_2O_5 - 180 K_2O. Truong Hong (1997) studied the effects of macro fertilizers on coffee yield and concluded that in the basaltic soil of Buon Ma Thuot, for coffee beans to yield higher than 2.6 Mg ha^{-1} would require annual doses of 200-240 N,

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

75-90 P_2O_5, and 250-260 K_2O. In gneiss soil in Kon Tum, these indices were 200-230 N, 130-150 P_2O_5, and 125-180 K_2O. These reports fail to advise the appropriate K requirement for coffee robusta in the region, as the annual doses displayed varied within a very wide range between 250 and 900 kg ha^{-1}, in terms of KCl equivalents.

Thus, the current situation of fertilizer application for coffee in the area still encounters significant problems. Farmers tend to overuse fertilizers and do not consider the ratio among nutrition elements (Do Thi Nga, 2012). Too large doses of N and P fertilizers are usually applied in comparison to much smaller doses of K. Insufficient fertilization often causes problems of unbalanced plant nutrition, and relatively low resistance to pests, diseases, and other kinds of stress. Many orchards suffer from chronically declined yields following a few cropping seasons and are difficult to restore.

The objective of the present study was to evaluate the efficiency of K fertilizer on yield and product quality of commercial Robusta coffee in the Central Highlands of Vietnam. The goals of the project were to identify the optimum K application dosage for commercial Robusta coffee in the Highlands, and to demonstrate the positive effects of K fertilization on coffee yield and quality. The interaction of the fertilization treatments with the local soils and their effect on soil fertility will be addressed in a future article.

Materials and methods

Experiments were carried out during three consecutive years (2012-2014) in two sites: Quang Phu town, CuMgar district, Dak Lak province (12°49.5 N 108°5.3 E, elevation: 480 m); and Dak Ha town, Dak Ha district, Kom Tum province (14°30.3 N 107°54.9 E, elevation: 600 m). The two experimental sites are located in the Central Highlands of Vietnam (Map. 1) and differ in their soil type. The soil in the Dak Lac province is a reddish-brown, derived from basic and intermediate magmatic rooks (basaltic soil), whereas the Kom Tum province is typified by a reddish-yellow soil derived from acid magmatic rooks (granite soil).

In each study site, a commercial phase plantation of Robusta coffee was used. Each experiment included six treatments at four replications, designed following the RCBD - random completed block design - method with 24 slots of 180 m^2 with 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 annual fertilizer doses of during the year is shown in Table 1.

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

Map 1. Experimental sites in Vietnam. ("Vietnamese Regions". Licensed under CC BY-SA 3.0 via Wikimedia Commons; http://commons.wikimedia.org/wiki/File:VietnameseRegions.png#/media/File:VietnameseRegions.png).

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

Fertilizer type	Time and amount of application (% of total)			
	Feb.	May - June	July - August	Sept. - Oct.
MOP	15	25	25	35
Urea	15	25	35	25
FMP	0	50	0	50

Yield was determined according to the 10 internal trees for each slot. Fruit were harvested and weighed; beans were separated from the berries, weighed and sorted with commercial coffee sieves. Coffee bean samples were chemically analyzed for the contents of caffeine, chlorogenic acid, and trigonelline.

Economic analysis was carried out to identify the optimum range of K application and to determine the point of maximum profit with regard to fertilizer input vs. the income as calculated from coffee yield and quality.

Results

An increasing level of annual K dosage brought about significant increments in fresh coffee fruit yield as well as in fresh coffee beans (Fig. 1). Annual yields significantly rose up to 17.5 and 15.9 Mg ha^{-1} (3-year average) at KCl application level of 600 kg ha^{-1}, which was 41 and 43% more than yields in the control trees, in basaltic and granite bed rock soil, respectively. Further increase in K dosage was not accompanied by any significant change in fruit yield. The annual yields of fresh coffee beans grew even further, 47 and 50% more than the control, up to 3.99 and 3.55 Mg ha^{-1}, in basaltic and granite bed rock soil, respectively.

The increase in yield is partially attributed to a significant increase in fruit weight (Fig. 2). At the KCl dosage of 600-700 kg ha^{-1}, fresh fruit weight was 4-8.4% greater than that of the control. Branch elongation was extended with the increasing K fertilization, resulting in 20% more internodes (Fig. 3). Also, elevated K application considerably reduced the rate of young fruit abortion (Fig. 4), thus contributing to the increase in coffee yields. Noteworthy is the reduction in the occurrence of mealybug damage to the coffee trees along with the increasing K dosage (Fig. 5), accompanied with a parallel decrease in the severity of the damage.

In addition to elevated yields, several parameters of coffee beans quality were significantly improved. The first was the distribution of coffee bean size (Fig. 6); higher K dosage brought

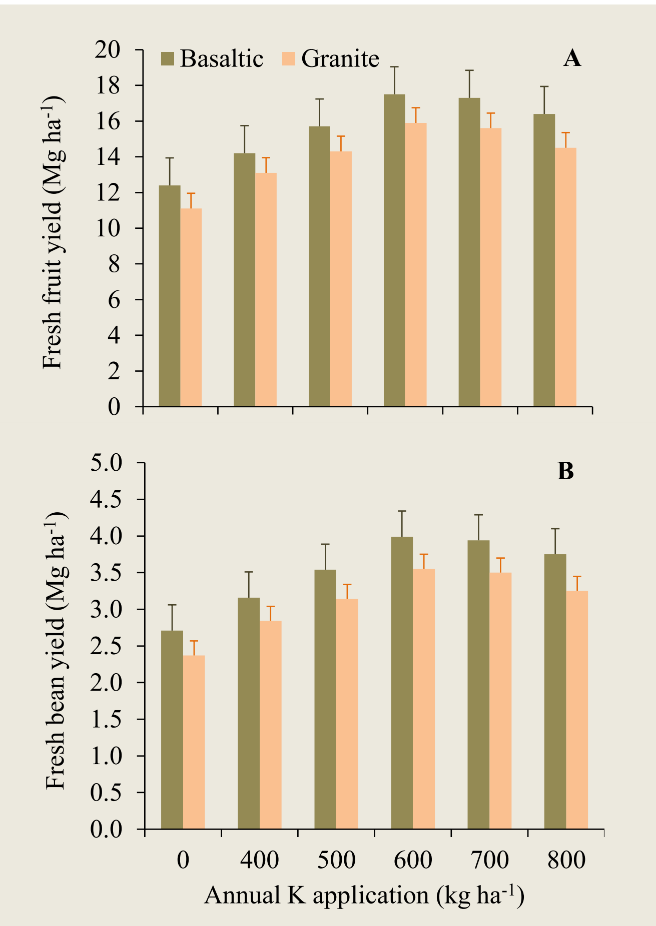

Fig. 1. Effect of annual K dosage on coffee fruit (A) and bean (B) fresh yields grown on basaltic and granite rock bed soils. Data are means of three years (2012-2014). Bars indicate LSD values at P>0.05.

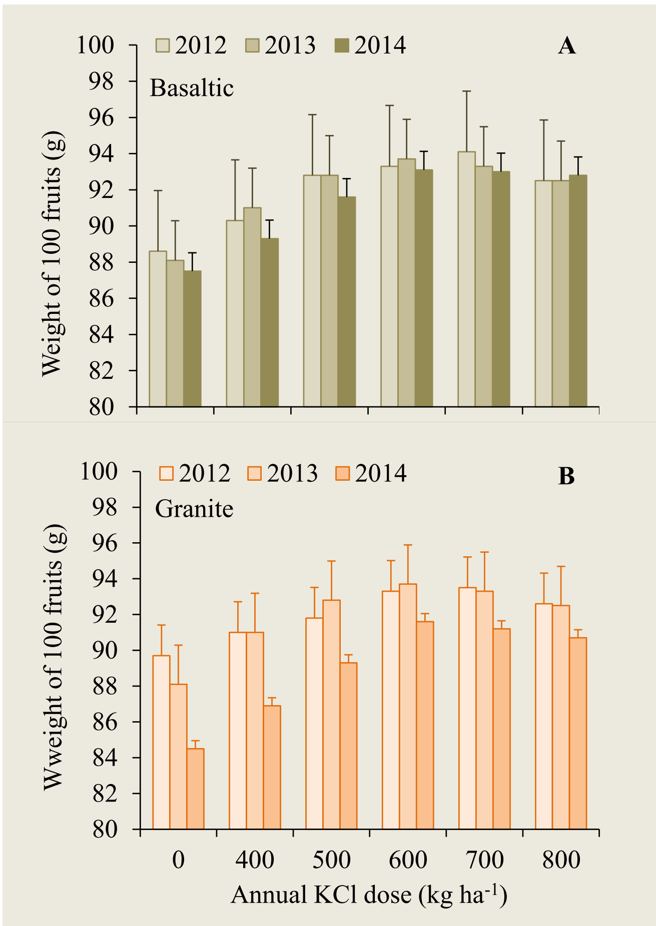

Fig. 2. Effect of K dosage on fresh fruit weight in three consecutive years in coffee plantations grown on basaltic or granite soil in Vietnam. Bars indicate LSD values at P>0.05, within each year.

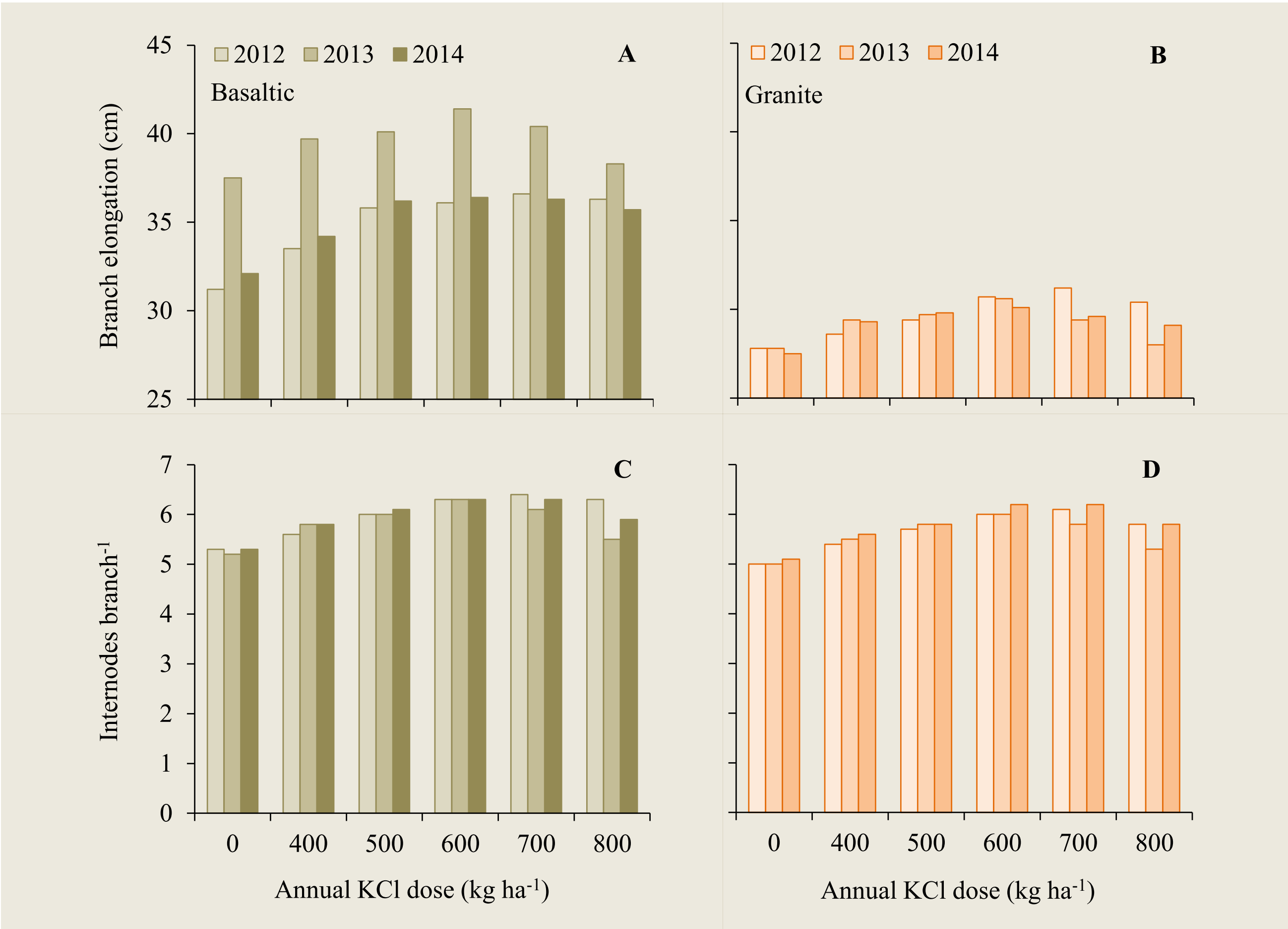

Fig. 3. Effects of K dosage on branch elongation (A and B) and internode formation (C and D) of coffee trees grown on basaltic (A and C) or granite (B and D) bed rock soil during the six wet months of three consecutive years in Vietnam.

about increased bean size, demonstrated by the movement of bean distribution from the small-size, non-commercial categories (12 and smaller) to the larger, commercial size range. The major change was the significant decline of the small-size range from almost 30% in the control trees yield to less than 5% at K dosage of 600 kg ha^{-1}. Consequently, the portion of size 13 mostly increased, from 58 to 76%, but the categories of the larger bean size, 16 and 18, also slightly rose. Accordingly, the mean weight of 100 beans increased from 14 to 15.1 g in both soil types. Other coffee quality traits positively affected by the increased K application level were the disappearance of young immature fruit, and slight reductions in the proportion of broken and brown beans. No influence was recorded regarding the key secondary metabolites in the coffee bean: caffeine (1.84%), chlorogenic acid (3.83%), and trigonelline (0.45%).

Discussion

Obviously, in comparison to zero K application, and at uniform levels of N and P application, annual doses of KCl ranging between 400 and 800 kg ha^{-1} had remarkable and stable positive influences on coffee yields and quality. In most yield parameters, maximum values were already obtained at an annual K dosage of 600 kg ha^{-1}; at the experimental conditions prevailing in the present study, any further increase of K application failed to produce significant contribution to the yield or its quality. Thus, maximum average increases of 41 and 43% were obtained in the fresh fruit yields of coffee trees grown at a KCl dosage of 600 kg ha^{-1}, on basaltic and granite bed rock soils, respectively. The increases in fresh coffee beans yield were even larger, 47 and 50%, respectively, at the same level of K application.

This upsurge in yields seemed to result from the augmented effect of many smaller, sometimes insignificant improvements of tree performance under elevated K dosage. Enhanced vegetative growth, with significant rise in the number of internodes per branch, must have increased the number of flowers and the consequent yield potential. Reduced rate of aborted young fruit and less damage due to mealybug are indicative for significantly stronger trees that can support higher yields. Another notable contribution to yield escalation was the increase in fruit size.

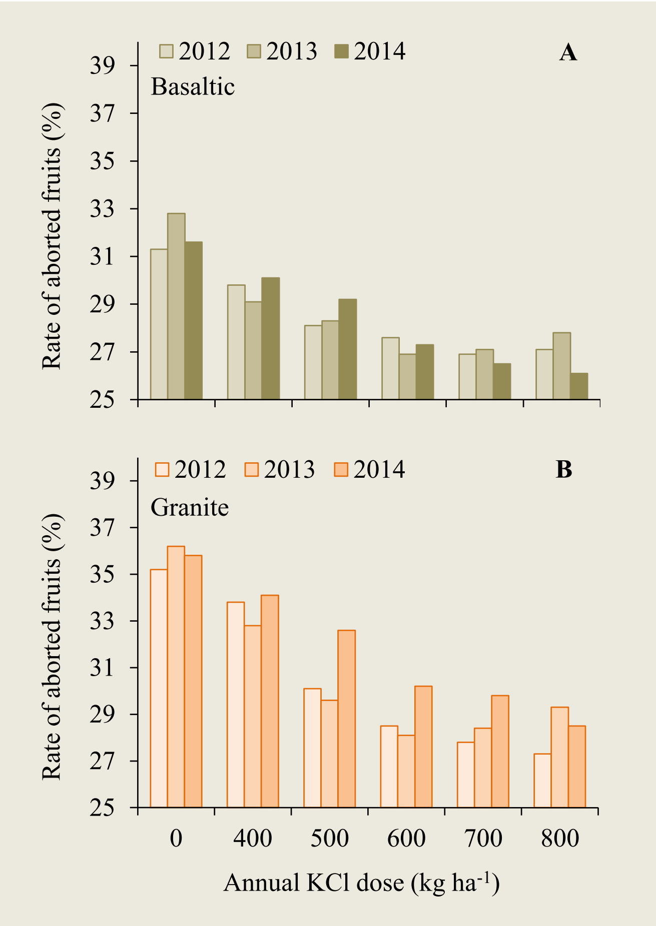

Fig. 4. Effect of K dosage on the rate of aborted fruit in three consecutive years in coffee plantations grown on basaltic or granite bed rock soils in Vietnam.

Fig. 5. Effect of K dosage on the occurrence of mealybug damage in coffee plantations on basaltic and granite soils in Vietnam.

Field meeting with farmers at Dak Ha, Kom Tum, Vietnam. Photo by Tran Minh Tien.

Field measurement in field trial at Cu Mgar, Dac Lak, Vietnam. Photo by Tran Minh Tien.

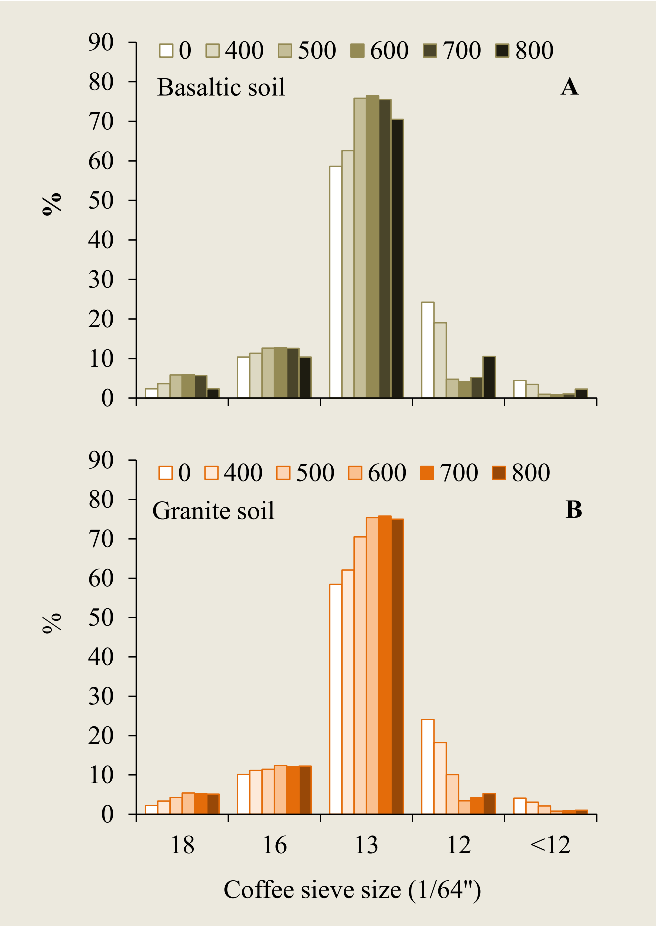

Fig. 6. Effect of KCl dosage (Legend; kg ha⁻¹) on the distribution of coffee bean size, in coffee plantations grown on basaltic and granite rock bed soils in Vietnam. Data present means over two years (2013-2014).

Furthermore, at a KCl dose of 600 kg ha^{-1}, the quality of coffee beans was significantly improved, as indicated by the diminished non-commercial category of tiny bean size, and the boost of the small but commercial bean grade. An economic analysis of the experimental results shows the significant increase of income along with enhanced K dosage up to 600 kg ha^{-1} KCl, and the reduction thereafter, with further increase of K level (Fig. 7). The function of the profit rate demonstrates a clear optimum curve, peaking around an annual K dosage of 600-700 kg K_2O ha^{-1}.

Thus, apparently, an annual dosage of 600 kg ha^{-1} would be the optimum level, satisfying the K requirements of high yielding coffee plantations in the Central Highland region of Vietnam. However, this dosage is three times greater than recommended for high yielding coffee plantations (Jessy, 2011). Furthermore, a key question in the present study is related to the tendency of coffee growers in Vietnam exaggerating fertilizers inputs, and the subsequent need to determine reasonable optimum levels. The answer largely lies in quality parameters of the local soils and on the implementation of appropriate fertilization management aimed to overcome their specific fertility problems. These issues will be considered comprehensively in a consecutive article to be published in due course.

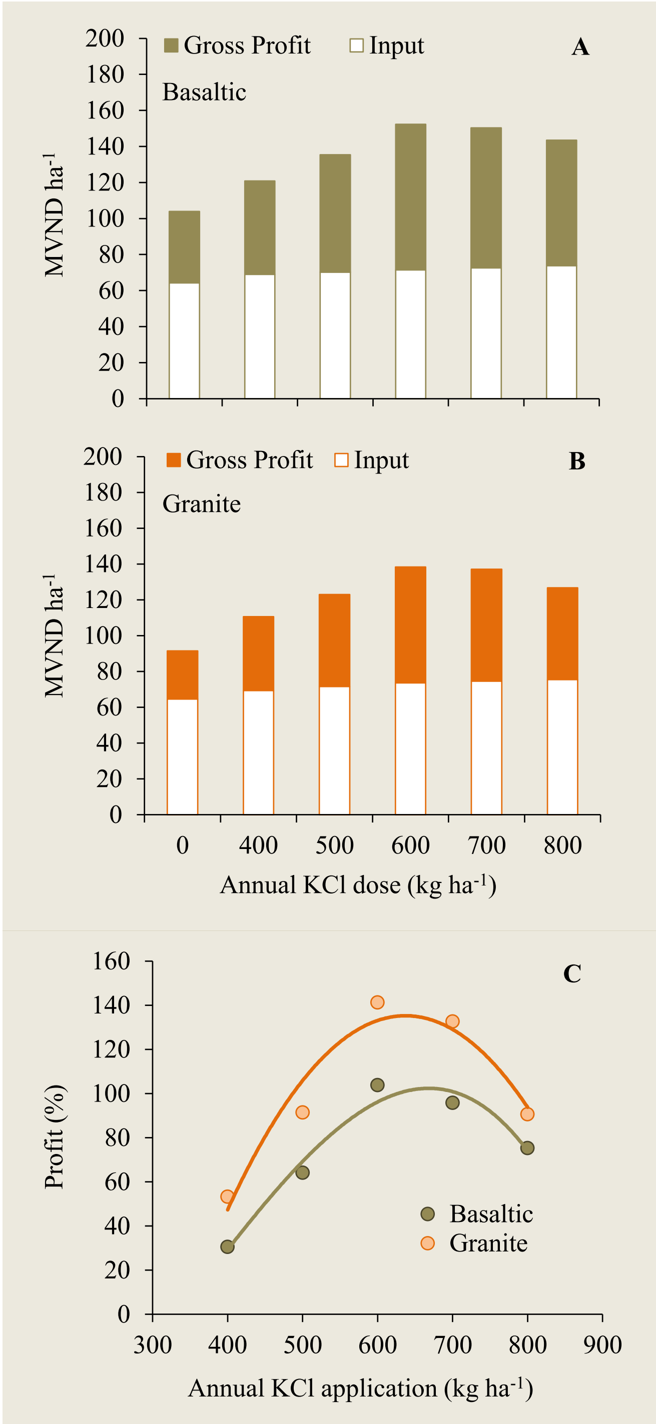

Fig. 7. Annual mean input, income, and gross profit (million VND ha⁻¹) as a function of annual K dosage in basaltic (A) and granite (B) soils in the Central Highlands of Vietnam. (C) shows the rate of profit as a function of K application.

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The paper "Effects of Annual Potassium Dosage on the Yield and Quality of *Coffea robusta* in Vietnam" also appears on the IPI website at:

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