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Optimizing Crop Nutrition

Editorial

Dear readers,

Fertilizer consumption in many parts of the world is keeping steady, even while production is increasing, demonstrating that in these regions, nutrient use efficiency is increasing. At the same time, in places such as sub-Saharan Africa, fertilizer application is just a few kilograms per hectare and crop productivity is significantly impaired.

There is no doubt among scientists working in sub-Saharan Africa that fertilizer use must significantly increase to at least a level of 50 kg (total nutrients) per hectare. These fertilizers will need to be supplied both by domestic production and imports and, given the large quantities required, functioning ports, roads, railways and warehouses will be vital in order for them to reach the field. Currently, farmers' low purchase ability and lack of financial tools are also limiting the use of fertilizers, and these are other challenges that need to be addressed.

During the coming years, as countries of sub-Saharan Africa strive to increase their crop production in response to a fast growing population and an improving diet, we will see a significant increase in fertilizer use in this vast region. This will bring fertilizer use to the required level and closer to the level used in many other regions, including North America, East and South Asia and Europe. I have no doubt that, through increased use of fertilizer, Africa will be able to feed itself.

I wish you a good read.

Hillel Magen
Director

Photo cover page:
Response of bread wheat (variety *Dand'aa*) to fertilizer treatment (NPSZnB) with and without KCl on Vertisols in Woyra Amba Kebele, North Shoa Zone, Moret and Jiru Woreda, Ethiopia (Farmer's name: Eshetu Ezawdres. Lady in the picture: Yenealem Atlaw of MoA, Soil Fertility Directorate). 1 August 2014. Photo by Prof. Tekalign Mamo, Ministry of Agriculture, Ethiopia.

Research Findings

Photo 1. Symptoms of K deficiency on potato plant development in the field. Photo by W. Grzebisz.

Potassium as a Factor Driving Nitrogen Use Efficiency - The Case for Potatoes Cultivated on Light Soil

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Abstract

Potassium (K) is generally considered as a nutrient which significantly affects nitrogen use efficiency (NUE). This relationship was tested in a field experiment with rain-fed potatoes cultivated on a light soil. The experiment consisted of four K doses: 0, 80, 160, or 240 kg K_2O ha^{-1} and two N doses: 120 or 160 kg N ha^{-1}. The effect of residual K was tested against the background of 90 kg K_2O ha^{-1} applied to winter wheat sown consecutively. Potato yields responded positively to increasing K dose, especially in 2013, a year characterized by mild water stress in the summer months. A positive impact of K application on tuber yields was obtained in relation to the increased N dose. The harvested tuber yield showed a linear response to increasing N uptake but curvilinear to increasing K uptake, with an optimum at

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170 kg K ha^{-1}. Thus, potato fertilized with 160 K_2O ha^{-1} and with 160 kg N ha^{-1} reached highest productivity. However, the most efficient use of applied nutrients, as demonstrated by analyses of the agronomic index of NUE, was a fertilizer combination of 160 K_2O ha^{-1} and 120 kg N ha^{-1}. Elevated amounts of K fertilizer resulted in some increase of the soil K available pool. This pool in 2013, following the 2012 potato crop, was high enough to significantly increase the productivity of the consecutive winter wheat, but a similar effect did not occur in the winter of 2014.

Introduction

Potassium (K) is one of the seventeen mineral nutrients essential for growth and reproduction of all higher plants and is required in especially large amounts by crop plants. There are at least three levels of evaluation of K impact on plant growth. The first focuses on its pure physiological functions, which includes its importance in mitigating abiotic and biotic stresses. Potassium can now be considered as a primary mineral nutrient controlling crop plant response to various environmental stresses (Rengel and Damon, 2008; Zörb *et al.*, 2014). The second level of K evaluation in crop production is its impact on yield development during plant growth. Shortage of K, as has been recently been reported by Grzebisz *et al.* (2013), reduces the physiological sink size in crop plants. Supplying crop plants with adequate K, covering their needs during critical stages of yield formation, can at least partially overcome water shortage. The third level of K importance in crop production relates to its management in the soil-crop system. Since K mobility may vary among different soils, budgeting for K needs should be considered against the background of crop rotation (Grzebisz and Diatta, 2012).

Potassium, despite its importance for the cultivation of crop plants, is frequently omitted by farmers in their fertilizing plans, without considering the current soil K status. At the same time and too often, the dose of applied nitrogenous fertilizers is not adjusted, resulting in a widening N:K ratio in the soil. Such fertilizing policy has brought about serious unfavorable economic consequences not only at the farm level, but also within regional and countrywide systems. A classic example of this was in the Central European countries, which underwent an economic revolution during the last decade of the 20th Century, when the shift to the free-market economy resulted in an upsurge of production costs, with an emphasis on fertilizer price. Consequently, consumption of all fertilizers decreased drastically, particularly that of K and P. As a result, the N:K ratio of fertilizer application widened rapidly from 1:0.8 to 1:0.3. In some countries, like Poland and Hungary, this negative trend came to a halt at this level, but in others, it decreased even further to a ratio of 1:0.1 (Grzebisz *et al.*, 2010).

In crop cultivation oriented to high yields, K supply to growing plants plays a decisive role in productivity. The first consequence of low K supply is a decreasing rate of nitrate-nitrogen uptake, which in turn reduces plant growth. In addition, the dynamics of N uptake is not synchronized with crop growth. Consequently, its imbalanced supply depresses the basic yield components. Potassium shortage during the key stages of yield development leads to a decreased number of ears in cereals and/or number of grains per ear (Grzebisz *et al.*, 2013). In potatoes, it results in low stem biomass, reduced tuber number, and/or a low rate of tuber growth, and even tuber cracking (Photos 1 and 2).

Potato is one of the most important staple food crops throughout the world, also including warm areas. As a starch crop, potato needs to be adequately supplied with water and K. Therefore, highest yields are harvested on well fertilized and irrigated fields, almost complying with the tuber yield potentials. Under rain-fed conditions, typical to North and Central European countries, meeting the yield potential becomes complex. Here, tuber yields depend on three major factors: climate, soil fertility, and quality of crop management. Thus, the potential yield of potatoes in Ireland (wet Atlantic climate) is assessed at the level of 72.4 Mg ha^{-1} (Supit *et al.*, 2010). For Germany, which lies at the borderline between the wet Atlantic and humid continental climate, potato potential is estimated at the level of 60.9 Mg ha^{-1}. In countries

Photo 2. Symptoms of K deficiency on tuber development and quality (cracked vs. normal tubers). Photo by W. Grzebisz.

east of Germany, such as Poland and Bulgaria, potential yields are much lower, amounting to 39.7 and 31.6 Mg ha^{-1}, respectively, mainly due to their continental climate. Practically, however, tuber yields tend to be significantly lower than the potential (Table 1). Excluding the climatic factor, the differences between potential and practical yields, as well as between countries, can be attributed to soil quality and imbalanced nutrient management (Grzebisz and Diatta, 2012).

Table 1. Statistical characteristics of potato yield in Central-Eastern European countries, Mg ha^{-1}, mean for 2003-2012.

Characteristics	Czech R.	Germany	Hungary	Poland	Romania
Mean	25.57	41.78	24.24	18.35	14.15
SD[1]	2.94	3.68	2.88	3.84	1.72
CV[2] (%)	11.5	8.8	11.9	20.9	12.1

Note: [1]SD: Standard deviation; [2]CV: Coefficient of variation.

The key objective of this study was to demonstrate, using experimental findings, that optimizing fertilizer K and N rates can be an important factor increasing nitrogen use efficiency (NUE) and, at the same time, improving yields of potato grown on sandy soils. The secondary objective was to evaluate the residual effect of K fertilizer, remaining in the soil following a potato crop, on consecutive winter wheat productivity.

Materials and methods

The impact of K fertilization, as considered against the background of N supply and NUE, was investigated and evaluated in potato over two consecutive growing seasons: 2012 and 2013 for potato, and 2012/13 and 2013/14 for the residual K effect on winter wheat productivity. These studies were carried out on a private farm at Donatowo (52°05 N 16°52 E), 50 km west of Poznan, Poland. The field experiment was established on a soil originating from loamy sand underlined by sandy loam and classified as an Albic Luvisol. Soil K fertility level, as indicated by analysis for soil available K, was measured as satisfactory for producing a high yield of tubers (186 mg K_2O kg^{-1} soil in 2012 and 154 mg K_2O kg^{-1} soil in 2013). The content of available P was very high in both years and magnesium was very high in 2012 and high in 2013.

A factorial experiment was set up consisting of eight treatments with four doses of K_2O application (0, 80, 160, or 240 kg K_2O ha^{-1} and two doses of N application (120 or 160 kg N ha^{-1}), and an absolute control (without N and K application). Each of the treatments was replicated four times. The two tested crops were cultivated in rotation: potato (variety Bellarosa), followed by winter wheat (variety Muszelka). An individual plot size for potato was 100 m^2. Before planting, N in the form of ammonium nitrate - NH_4NO_3 (34% N) and K as potassium chloride (KCl) were applied to the soil. Phosphorus was applied as di-ammonium phosphate (DAP) according to soil analysis. The potato seed-tubers were sown during the third week of April. Harvest took place during the third week of September, from harvest sampling plots of 14 m^2. After the potato harvest, the plots were divided into two sub-plots of 37.5 m^2, treated with or without freshly applied K fertilizer as KCl at a rate of 90 kg K_2O ha^{-1}. Phosphorus was applied as DAP, according to soil analysis.

The winter wheat crop was sown during the first week of October, just after the potato harvest. Nitrogen in the form of NH_4NO_3 (34% N) was applied at a rate of 180 kg N ha^{-1}, split into three dressings and applied at i) spring regrowth (50%); ii) the beginning of shooting (25%); and, iii) at heading (25%). The crop was harvested at the end of July. Harvest sampling was exercised from 15 m^2 plots using a plot combine harvester. Total seed yield was adjusted to 14% moisture content.

Nitrogen concentration in plant samples was determined by the standard macro-Kjeldahl procedure on dried then finely ground plant material. Potassium concentrations in the dried and ground plant tissues were determined by flame photometry, following ashing of the dried plant material in a muffle furnace at 640°C, then releasing the K into solution using 33% nitric acid (HNO_3). Results are expressed on a dry matter basis. Amounts of nutrients in plant organs and entire plants were calculated by multiplication of tissue concentration and respective biomass. Measurement of residual available K in soil following the potato harvest was carried out using the Egner Rheim method: soil samples were extracted with 0.04M calcium lactate at a pH of 3.5-3.7 using hydrocloric acid (HCl). This method is particularly suitable for relatively acidic soils.

Nitrogen fertilizer use efficiency indices were expressed using the following equations:

- Agronomic N use efficiency (kg tubers kg^{-1} N):
  $AEN = (Y_{Ni} - Y_0)/N_d$
- Apparent N recovery (%):
  $NR = (NU_{Ni} - NU_0)/N_d \cdot 100$
- Physiological N use efficiency (kg tubers kg^{-1} N):
  $PhEN = (Y_{Ni} - Y_0)/(NU_{Ni} - NU_0)$

Unit potassium uptake (UKU) and unit nitrogen uptake (UNU) were calculated using the formula:

$UKU = KU_i/Y_{Ni}$ (kg K Mg^{-1} tubers);

$UNU = NU_i/Y_{Ni}$ (kg N Mg^{-1} tubers).

Where:

Y_{Ni}: Yield of tubers harvested from determined doses of N (kg ha^{-1})

Y_0: Yield of tubers harvested from the absolute control (kg ha^{-1})

N_d: Nitrogen fertilizer dose (kg N ha^{-1})

KU_i: Potassium uptake by crop from determined doses of K (kg ha^{-1})

NU_i: Nitrogen uptake by crop from determined doses of N (kg ha^{-1})

KU_0: Potassium uptake by the crop in the absolute control (kg ha^{-1})

NU_0: Nitrogen uptake by the crop in the absolute control (kg ha^{-1})

The experimentally obtained data were subjected to the conventional analysis of variance using computer program STATISTICA 10. The differences between treatments were evaluated with Tukey's test.

Results and discussion

Yield of tubers

The course of weather conditions during potato vegetation is generally considered as the decisive factor for plant growth and tuber production (Supit *et al.*, 2010). During the study, 2012 (the first year) can be considered as wet. In three consecutive months, i.e., June, July and August, the total sum of precipitation was 312 mm. It was higher by 110 mm than the long-term average. In 2013, the course of weather was different; a wet June with 90 mm of precipitation was followed by two semi-dry months with a total sum of about 100 mm. In spite of the relatively adequate amount of precipitation during the season, its distribution was only moderately suitable for potato growth. In the summer months, the amount of precipitation was below the long-term averages and inadequate to cover water requirements of this crop during critical stages of tuber growth.

In both years, tuber yield was significantly affected by interaction between the P and N doses of application. In 2012, a year with ample water supply to plants during tuber growth, yield harvested in the absolute control treatment (no fertilizer application) amounted to 31 Mg ha^{-1} (Fig. 1). This level of yield implicitly indicates preliminary high soil fertility and very suitable conditions for potato growth. For comparison, the country average yield of potatoes during this year only amounted to 24.4 Mg ha^{-1}, which was the highest in the last decade (FAOSTAT, 2014).

Nevertheless, the contribution of fertilizer application at this basal situation was obvious; application of N alone, at 120 or 160 kg ha^{-1}, brought tuber yield above 40 Mg ha^{-1} (Fig. 1). Potassium (K_2O) application at 80 kg ha^{-1} resulted in a small addition in the tuber yield only at the higher N level. Further

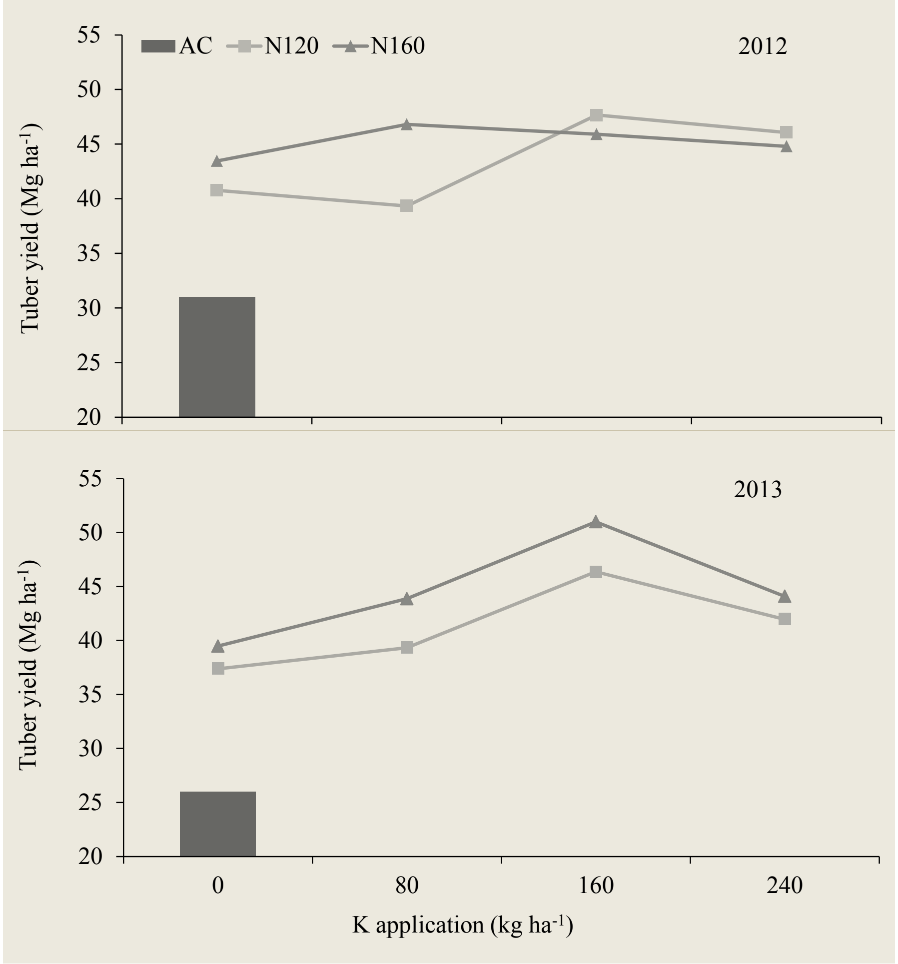

Fig. 1. Effect of K and N application on potato tuber yields in 2012 and 2013. AC: absolute control; N120 and N160: nitrogen application levels, kg N ha^{-1}.

increase of K application to 160 kg ha^{-1} elevated tuber yields to more than 45 Mg ha^{-1} at both N levels. Further increase of K application produced no further response. A detailed analysis of tuber fractions showed a dominance of large tubers, which contributed from 77% at the K control to 86% at the 240 K_2O ha^{-1} dose, when fertilized with 160 kg N ha^{-1}.

The second year of the study was less favorable for potato production. Yields harvested in the absolute control amounted to 27 Mg ha^{-1} (Fig. 1), compared to the country average yield of only 21.4 Mg ha^{-1} (FAOSTAT, 2014). However, tuber yield showed a significant response to fertilizer treatments. The harvested tuber yield gradually increased to a maximum (45 and 50 Mg ha^{-1}, at 120 and 160 kg N ha^{-1}, respectively) at 160 kg K_2O ha^{-1}, but declined significantly with further increase of fertilizer inputs. The significant impact shown here for N application at 160 kg ha^{-1} may be considered as optimal for high-yielding potato, regardless of the field location, as reported by Jamaati-e-Somarin *et al.* (2010) for Iran, Mustonen *et al.* (2010) for Finland and Tein *et al.* (2014) for Estonia.

The results presented here clearly explain controversies concerning impact of K fertilizing systems on potato tuber yields. In this study, experiments were conducted on light soil, but quite rich with available K. Thus, in the year with ample water supply during tuber growth and development (2012), yield positively responded to N application, which appeared the restrictive element. Contribution of K fertilizer was seldom significant (Fig. 1). An adequate supply of water and N was sufficient to exploit yield potential of the tested variety, assessed at the high level of 48 Mg ha^{-1}. Therefore, under favorable climatic conditions and satisfactory K soil availability, in agreement with reports for this crop in Great Britain (Allison *et al.*, 2001) and in Ethiopia (Ayalew and Beyene, 2011), further K application appears unnecessary. The same is also true with irrigated systems of potato production, as has been broadly documented by Hochmuth and Hanlon (2000).

On the contrary, for potatoes produced on sandy soils under unstable rain-fed conditions in 2013, where dependence on external supply of both fertilizers was obvious. A mild water stress in summer months implicitly underlined the impact of N application on tuber yield. However, an adequate administration of K fertilizer was required to fulfill the potential contribution of N availability. The same type of potato interactive response to K and N application has been observed by Sing and Lal (2012) in India. In that case, the optimum rates of N and K required to produce 40 Mg ha^{-1} of tubers were 225 kg N ha^{-1} and 150 kg K_2O ha^{-1}.

Nutritional status of plants at the stage of tubering

The stage of tubering is decisive for potato yields, as cardinal physiological factors, such as carbon source-sink relations and plant nutritional status, become deeply involved and interact. At this stage, N concentration in the whole plant was unaffected by either K or N application levels, in both years (Table 2), excluding a significant rise above the absolute control solely in 2012. The whole plant K concentration increased significantly in 2012 in response to the rising K (but not N) application level, but remained indifferent in 2013. Interestingly, mean N concentration in the whole plant was significantly smaller in 2012 (4.21%) than in 2013 (5.55%). On the contrary, mean K concentration in the whole plant was significantly greater in 2012 than in 2013, 4.86% vs. 3.60%, respectively.

Assuming adequate P availability, N:K ratio may serve as an indicator for the nutritional status of potato plants, with an optimum of around 0.88 (Haddock, 1961). During the wet 2012 summer, N:K ratio decreased from about 1 in plants that had received no K application to about 0.75 in plants with the higher level of K application (Table 2). The optimum ratio was obtained already at the low K application (80 K_2O ha^{-1}), indicating that optimal water status coincides with optimal nutritional status, and that nutritional requirements are at a minimum. Under the mild water stress during the 2013 summer, N:K ratio was stable and higher, 1.54, but still within the optimum range (Rosen,

Table 2. Nutrient concentration in the whole potato plant at tubering, % of DM.

K application	N application	2012			2013		
		N	K	N:K	N	K	N:K
kg K_2O ha^{-1}	*kg N ha^{-1}*	----------%----------			----------%----------		
0	120	4.23	4.00^{a}	1.06	5.33	3.52	1.51
	160	4.30	3.88^{a}	1.11	5.76	3.50	1.65
80	120	4.03	4.91^{ab}	0.82	5.47	3.62	1.51
	160	4.49	4.81^{ab}	0.93	5.57	3.68	1.51
160	120	4.12	5.46^{b}	0.75	5.33	3.59	1.48
	160	4.46	5.55^{b}	0.80	5.68	3.70	1.54
240	120	4.15	5.61^{b}	0.74	5.35	3.82	1.40
	160	4.35	5.69^{b}	0.76	6.11	3.79	1.61
Absolute control		3.72	3.87^{a}	0.96	5.37	3.21	1.67
Means		4.21	4.86	0.88	5.55	3.60	1.54

Note: ^{a,b}: The same letter means a lack of significant difference between level of the treatment.

2001). The relatively high N:K ratio may indicate that under such circumstances, N uptake by potato plants was favored, while K acquisition encountered difficulties. Even though, there was a positive plant response to increasing K and N doses, finally leading to yield increase.

Nutrient accumulation in tubers

Nitrogen uptake significantly increased in response to N application (Fig. 2). This was clearly demonstrated in both years by the upsurge of N uptake to 75-120 kg N ha^{-1}) in plants fertilized solely with N, as compared with the absolute control (60-70 kg N ha^{-1}). In this respect, the interactions between K and N levels in N fertilized plants were less significant. In 2012, N uptake ranged at a narrow band between 95 to 120 kg N ha^{-1}; at the lower N application, N uptake gradually increased with the increasing K application, reaching a maximum at the highest K level. Nevertheless, at the higher N level, N uptake remained quite stable along the K application doses. In 2013, N uptake fluctuated a lot, particularly at the higher N application level. A significant peak was recorded, however, at K dose of 160 kg ha^{-1}. Nitrogen accumulated in the potato crop at harvest was linearly correlated with tuber yield (Fig. 2C). This relationship implicitly indicates that N, irrespective of year-to-year variability, was a factor limiting potato growth and yield.

On average, the total amount of K accumulated in potato was higher as compared to N (Fig. 3). Here, as well, the initial contribution of N fertilization was most significant for K uptake, as demonstrated by the absolute control. In both years, the higher N application level seemed to interrupt P uptake at the two upper levels of K application. The response of K uptake to its application level was unequivocal up to application level of 80 kg K ha^{-1}. The maximum K uptake in both years occurred at the combination of 120 and 160 kg ha^{-1}, N and K application levels, respectively, and thereafter it tended to decrease. The results obtained here clearly indicate a yield forming K effect. This effect was especially pronounced in 2013, which was less favorable for potato cultivation, as compared to 2012. The relationship

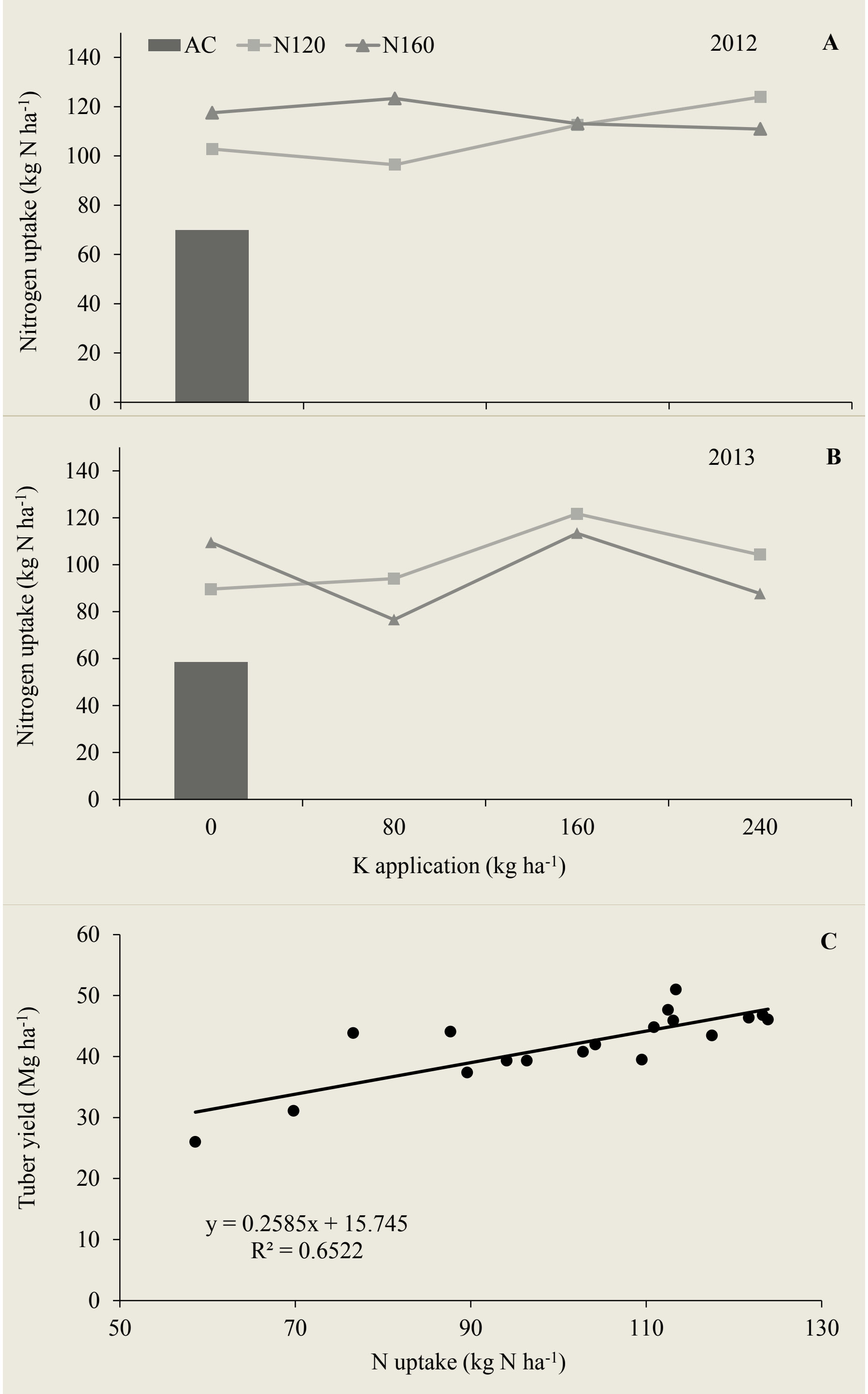

Fig. 2. Effects of K and N application on N uptake by potato crop in 2012 (A) and 2013 (B). Effect of N uptake (N_u) on tuber yields, irrespective of year and K application (C).

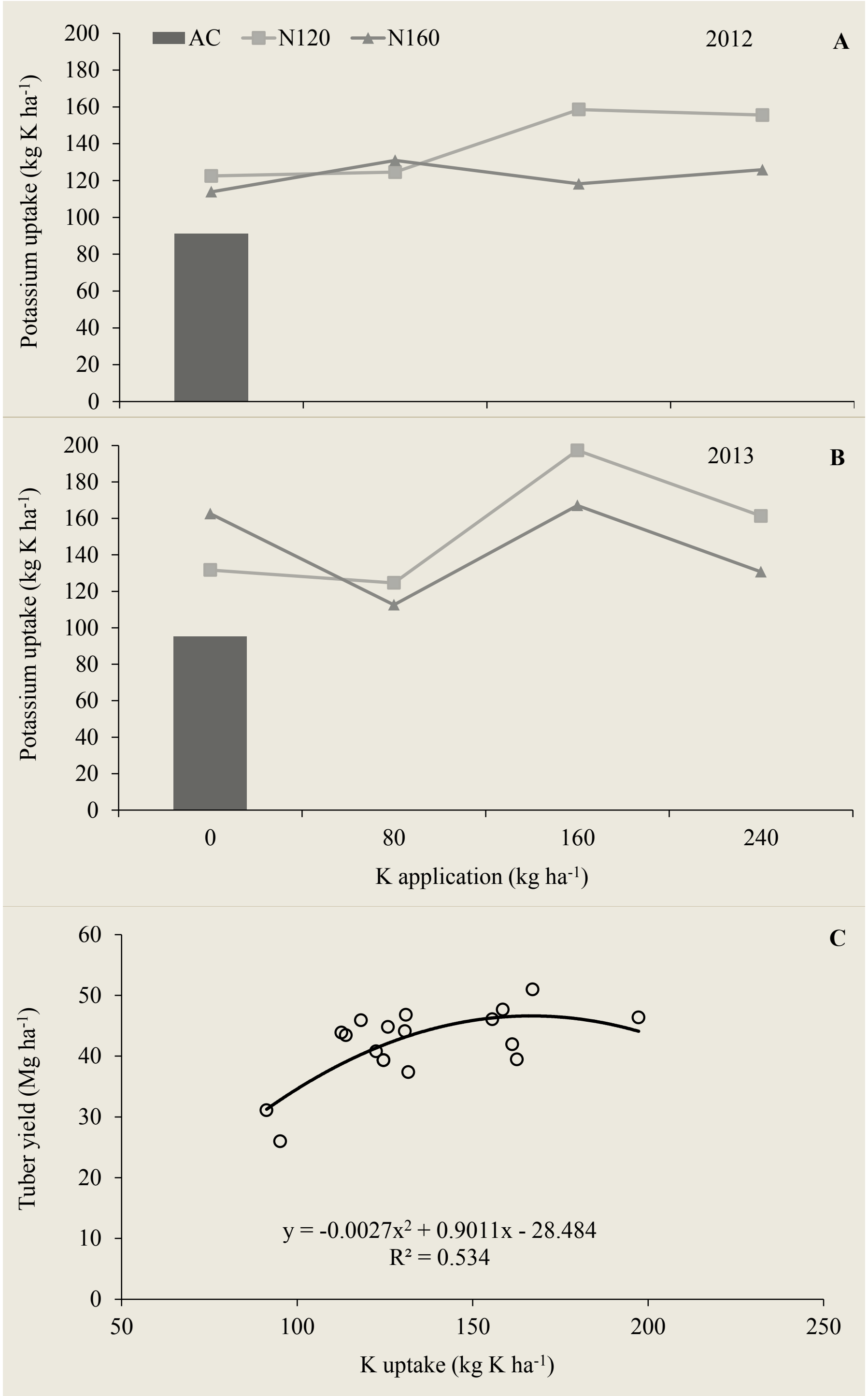

Fig. 3. Effects of K and N application on K uptake by potato crop in 2012 (A) and 2013 (B). Effect of K uptake (K_u) on tuber yields, irrespective of year and N application (C).

between the K amount accumulated by the potato crop at harvest and tuber yield was curvilinear, indicating for an optimum at 170 kg K ha^{-1} (Fig. 3C), beyond which tuber yield might decrease.

NUE indices

In agronomic practice, an important indicator of crop K requirement is the index known as Unit Nutrient Uptake (UNU). This describes the amount of a given nutrient per unit in the main product and additional amount in its by-product. For British conditions, as reported by Allison *et al.* (2001), the unit potassium uptake (UKU) value for high-yielding potato crop varies from 2.6 to 5.7 with the average of 4.2 kg K Mg^{-1} tubers. In the present study, UKU was much lower and year specific. In 2012, it varied from 2.6 to 3.4 kg K Mg^{-1} tubers. As shown in Fig. 4, slightly lower values were recorded in treatments fertilized with 160 kg N ha^{-1}. In 2013, the value of this parameter ranged from 2.6 to 4.1 kg K Mg^{-1} tubers. The higher N rate, except for the K control, resulted in an index decrease. The second index, unit nitrogen uptake (UNU), showed a year-to-year variability (Fig. 5). However, the index for the absolute control was at the same level for both years, amounting to 2.25 kg N Mg^{-1} tubers. The UNU indices in 2012 were slightly above this value, without any response to fertilizing treatments. A quite different situation was observed in 2013, when plants fertilized with 160 kg N ha^{-1} and K_2O obtained significantly smaller values.

Nitrogen use efficiency (NUE) is the most important indicator evaluating fertilizer application. Indices of physiological efficiency of nitrogen (PhEN) allow comparison of the effect of N application against the background of K application scale, i.e., increasing rates of K applied to potato crop. As shown in Table 3, PhEN indices were slightly higher in 2013 as compared to 2012. The interactive effect of K and N on this index was the highest for the 160 K_2O ha^{-1} application level. Maximum values were obtained for 120 and 160 kg N ha^{-1}, in 2012 and 2013, respectively. The second NUE index, N recovery (NR), describes the contribution of fertilizer N in total N uptake by the crop. In general, NR values were low,

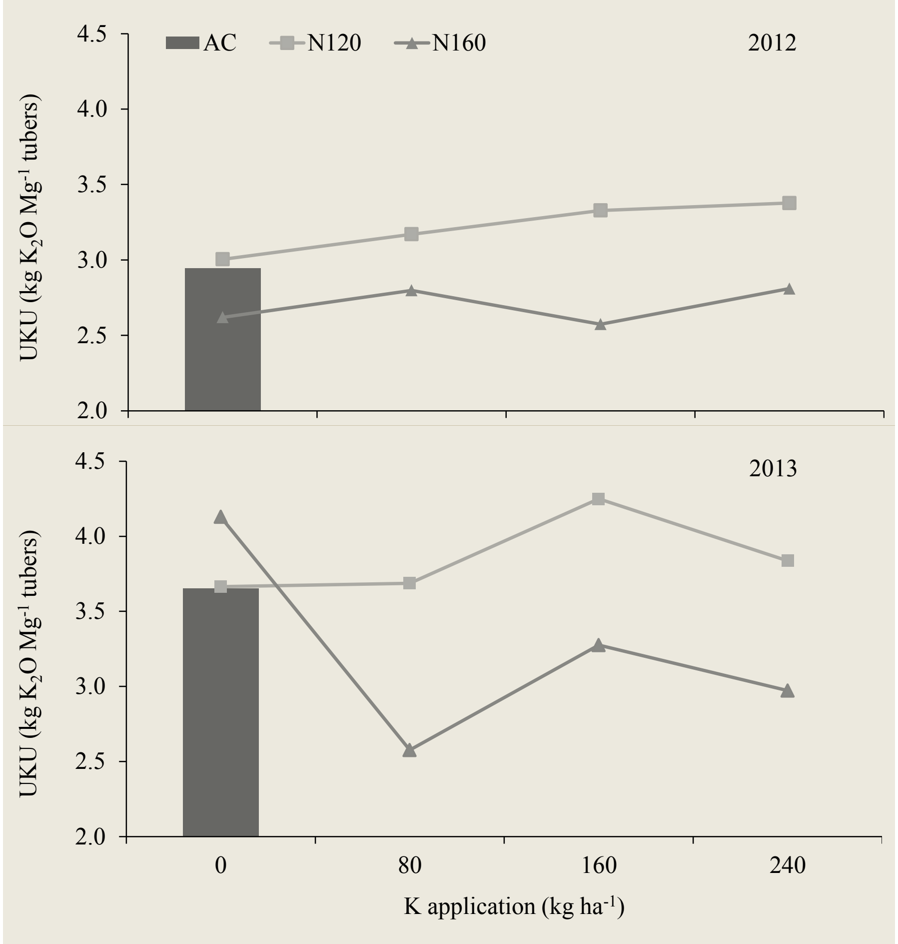

Fig. 4. Effects of K and N application on the efficiency of K uptake by potato crop in 2012 and 2013, as expressed by UKU (unit potassium uptake) (kg K_2O Mg^{-1} tubers).

Table 3. Indices of nitrogen use efficiency.

K rates	N rates	Physiological N efficiency (PhEN)		Nitrogen recovery (RN)		Agronomic N efficiency (AEN)	
		2012	2013	2012	2013	2012	2013
kg K_2O ha^{-1}	*kg N ha^{-1}*	*kg tubers $kg^{-1} N_u$*		----------%----------		*kg tubers $kg^{-1} N_d$*	
0	120	296.1	367.0	27.5	25.8	81.5	94.8
	160	261.4	229.0	29.8	36.8	77.9	84.2
80	120	313.3	376.2	22.2	29.5	69.5	111.0
	160	295.7	276.4	33.4	40.4	98.8	111.6
160	120	390.1	322.7	35.6	52.6	138.9	169.6
	160	344.3	458.7	27.1	34.1	93.2	156.2
240	120	278.4	350.1	45.1	38.0	125.6	133.0
	160	335.4	345.8	25.7	32.7	86.3	113.1
Means		314.3	340.7	30.8	36.2	96.5	121.7

Note: N_u: N uptake; N_d: N fertilizer dose.

especially in 2012. In both years, there was an obvious K x N interaction on NR; at low K inputs, NR was higher in the high N level, while the opposite occurred in the higher K inputs (Table 3). The third index, termed as agronomic use efficiency (AEN) describes the final effect of applied N fertilizer. Irrespective of the year, the highest productivity of N input occurred at the 160 K_2O ha^{-1}/ 120 kg N ha^{-1} combination. AEN values were significantly smaller at any other combination of N and K inputs.

Soil K status

It is well known that potato crop is highly sensitive to inadequate potassium supply, which is expressed mainly by a poorly developed root system. A post-harvest analysis of the soil showed some impact of the K fertilizing system on the status of available K. In general, available K slightly increased from about 16 to 26 mg K 100 g^{-1} soil, in accordance with increasing K application. Interestingly, the highest values in both years were recorded at the 160 K_2O ha^{-1}/120 kg N ha^{-1} treatments. This result may suggest that at the higher K application levels, the consecutive crop might benefit from a certain residual K, in spite of the high efficiency of potato production at that particular combination. It is notable, however, that K availability in the soil was limited to a depth of 60 cm only.

Residual effect of K fertilizer – winter wheat response

The effect of both residual and fresh applied K fertilizer was tested in winter wheat following the potato crop (Table 4). The effect of both sources of K was significant only in the first winter wheat crop, in 2013. The residual effect of K application was significant only at the highest level (240 kg ha^{-1}), contributing about 0.5 Mg wheat grains per ha. Nitrogen application regime in the 2012 potato crop seemed to have an even higher residual effect on the consecutive winter wheat crop; the difference in grain yield between 120 and 160 kg N ha^{-1} was about 1 Mg. The current K application was effective only on winter 2013, contributing about 0.5 Mg ha^{-1} to wheat grain yield (Table 4). The considerable differences between the two years may be partially explained by the efficiency of nutrient acquisition

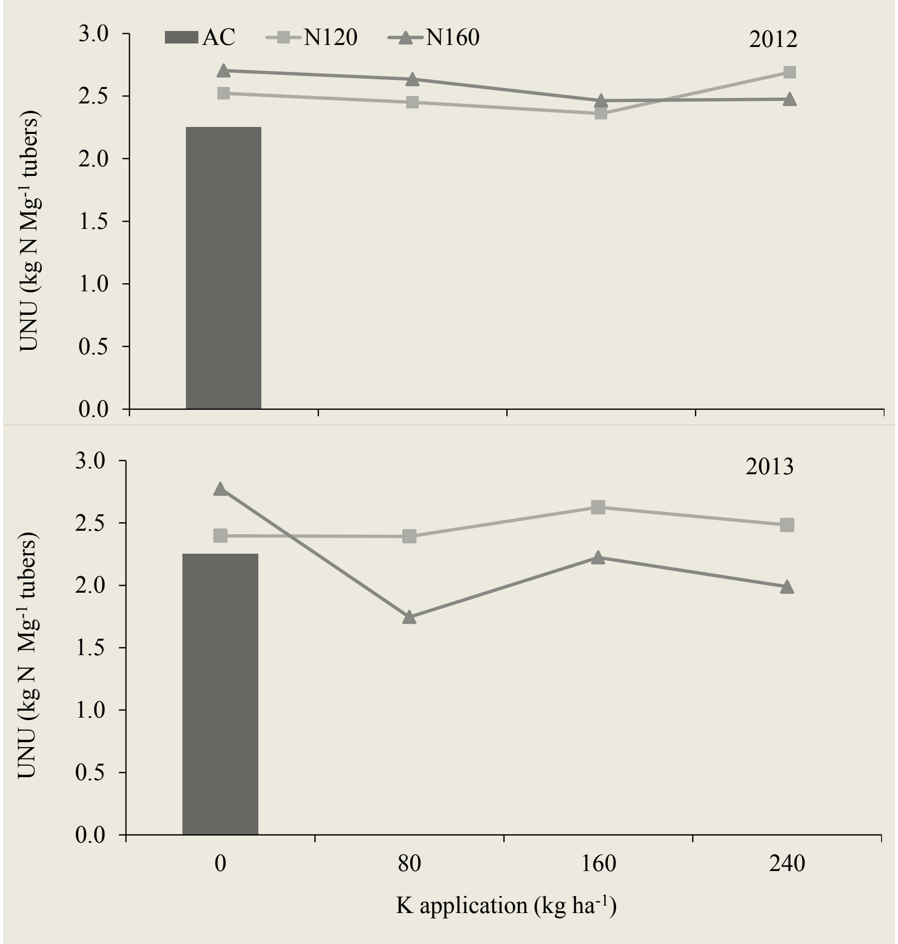

Fig. 5. Effects of K and N application on the efficiency of N uptake by potato crop in 2012 and 2013, as expressed by UNU (unit nitrogen uptake) (kg N Mg^{-1} tubers).

Table 4. Winter wheat response to the system of K fertilization, yield of grain, Mg ha^{-1}.

	2013	2014
K dose	------------------------------*kg K_2O ha^{-1}*------------------------------	
0	5,348^a	6,716
80	5,398^a	6,852
160	5,565^a	6,845
240	6,099^b	6,799
N dose	------------------------------*kg N ha^{-1}*------------------------------	
120	5,093^a	6,731
160	6,112^b	6,875
Freshly applied K dose for winter wheat	------------------------------*kg K_2O ha^{-1}*------------------------------	
0	5,355^a	6,698
90	5,851^b	6,908

Note: ^{a,b}: The same letter means a lack of significant difference between level of the treatment.

by the potato crop each year. In 2012, nutritional requirements of potato were smaller due to favorable climatic conditions, thus resulting in significant residual fertilizers in the soil. In 2013, the potato crop acquired more K than in 2012 (Fig. 4), probably leaving less residue for the consecutive crop. Nevertheless, more comprehensive evaluation of nutrients residual effects requires further consideration of other important factors, such as weather conditions during the consecutive crop.

Final conclusions

1. A comparison of yields harvested in two consecutive years, differing in weather conditions, clearly shows that the variety Bellarosa is highly sensitive to applied K fertilizer.
2. An appropriate K application may support potato crops under mild water stress.
3. Potassium and N possess significant interactions, thus careful optimization should be made with considerable adjustment to soil types in order to maximize tuber yields.
4. Excess K as well as N application may have positive residual effects on consecutive crops, depending on weather and other conditions.

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Regional activities/Central Europe

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

Tran Minh Tien(1)

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).

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).

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.

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

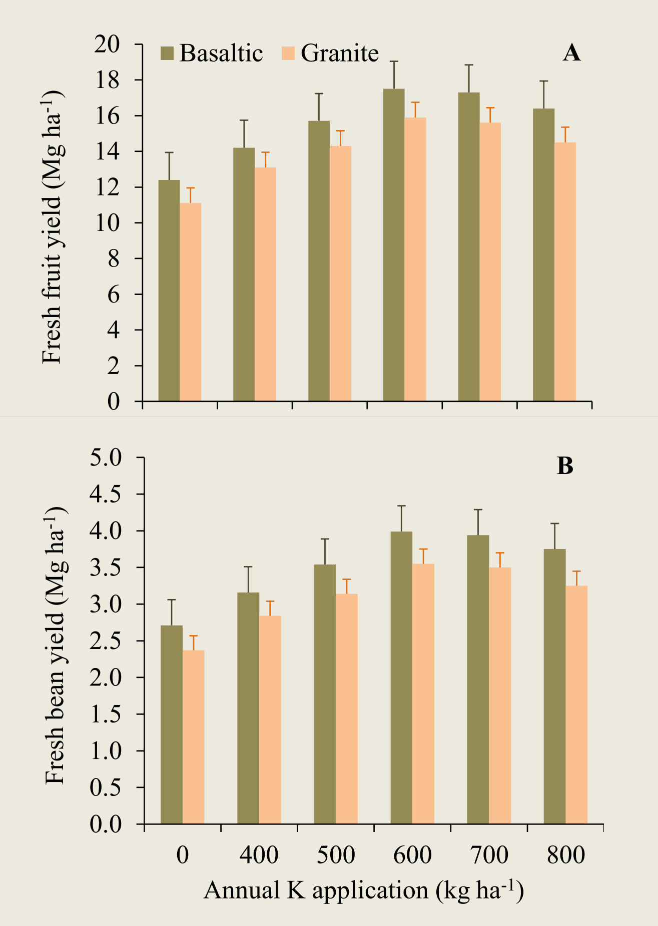

Fig. 1. Effect of annual K dosage on coffee fruit (A) and bean (B) fresh yields grown on basaltic and granite rock bed soils. Data are means of three years (2012-2014). Bars indicate LSD values at P>0.05.

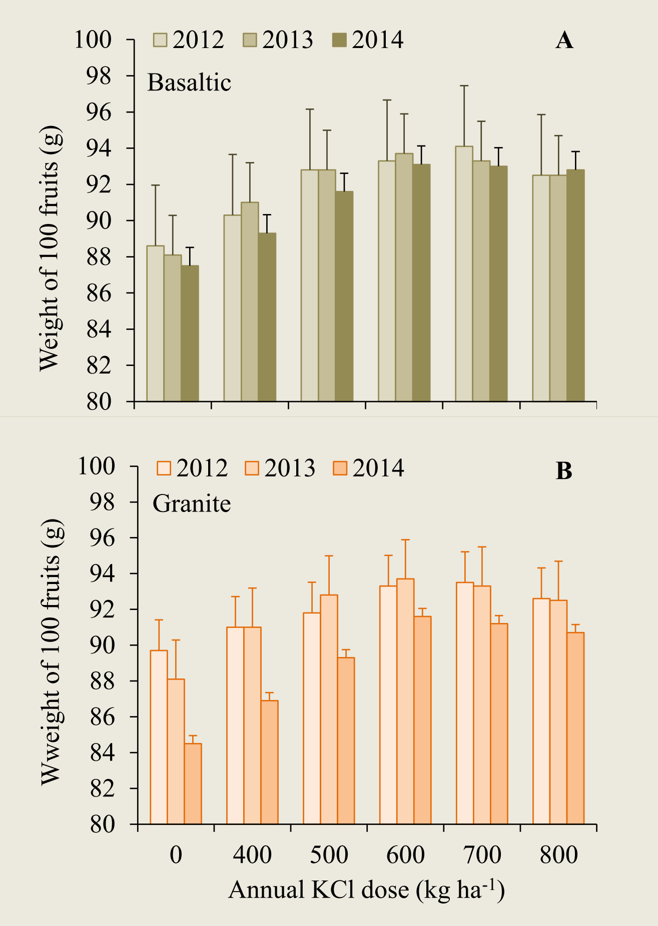

Fig. 2. Effect of K dosage on fresh fruit weight in three consecutive years in coffee plantations grown on basaltic or granite soil in Vietnam. Bars indicate LSD values at P>0.05, within each year.

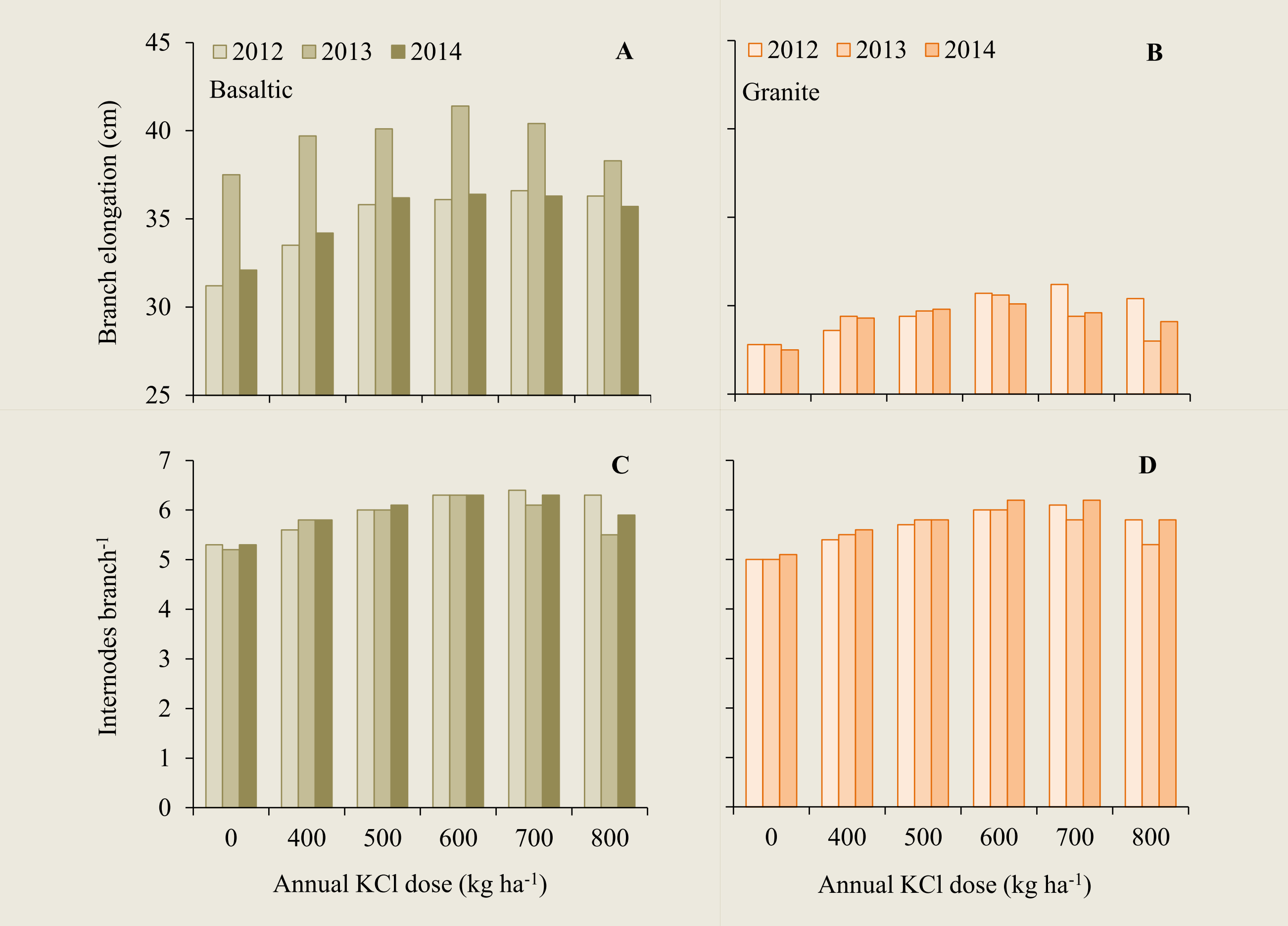

Fig. 3. Effects of K dosage on branch elongation (A and B) and internode formation (C and D) of coffee trees grown on basaltic (A and C) or granite (B and D) bed rock soil during the six wet months of three consecutive years in Vietnam.

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.

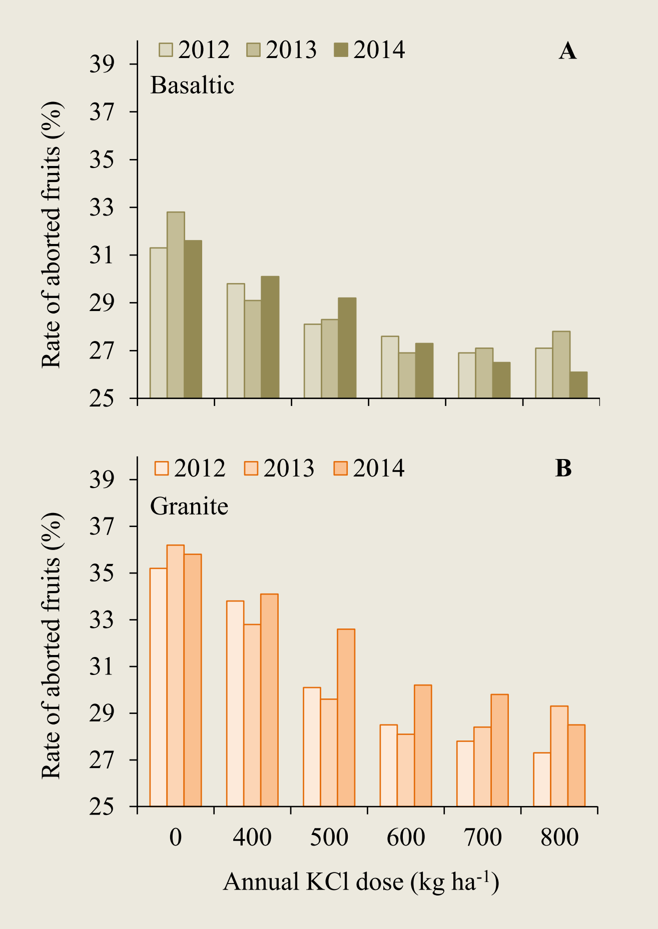

Fig. 4. Effect of K dosage on the rate of aborted fruit in three consecutive years in coffee plantations grown on basaltic or granite bed rock soils in Vietnam.

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.

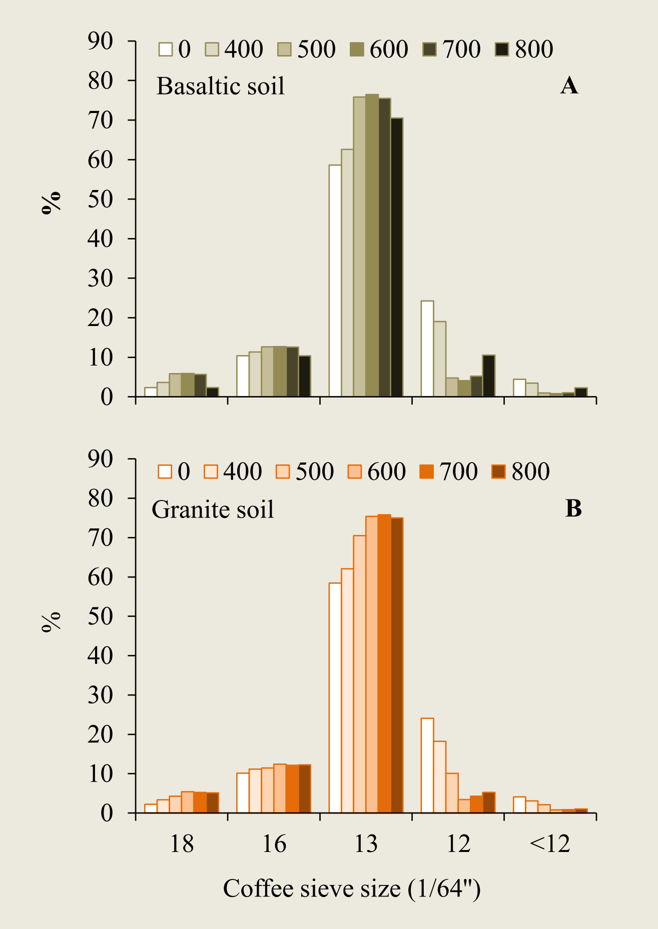

Fig. 6. Effect of KCl dosage (Legend; kg ha^{-1}) on the distribution of coffee bean size, in coffee plantations grown on basaltic and granite rock bed soils in Vietnam. Data present means over two years (2013-2014).

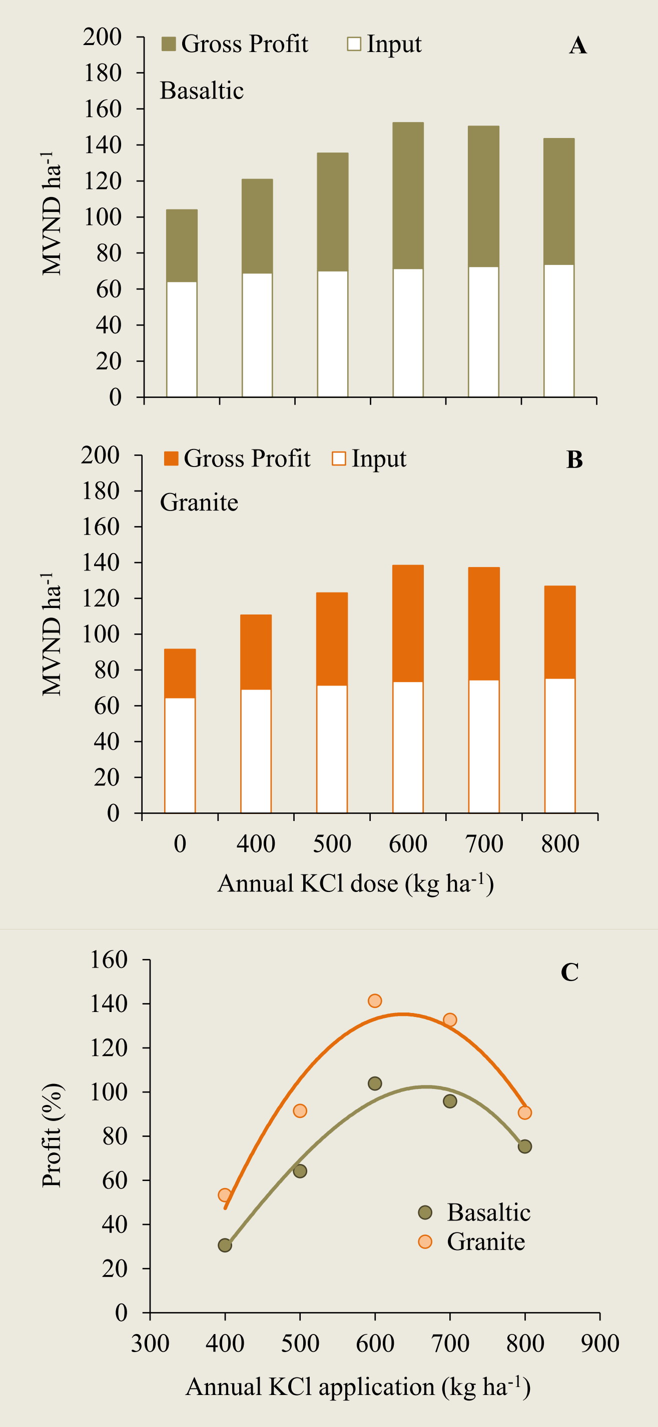

Fig. 7. Annual mean input, income, and gross profit (million VND ha^{-1}) as a function of annual K dosage in basaltic (A) and granite (B) soils in the Central Highlands of Vietnam. (C) shows the rate of profit as a function of K application.

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.

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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:

Regional activities/Southeast Asia

Research Findings

Photo by IPI.

Enhanced Potassium Application Improves Yield and Profitability of Various Vegetable Crops in Jharkhand, India

Kumar, R.[1], S. Karmakar[2], A.K. Sarkar[2], N. Kumar Awasthi[3], and H.Magen[4]

Abstract

A series of experiments were conducted in farmers' fields in different locations of Jharkhand with medium to high fertility status of available potassium (K) to study the response of selected vegetable crops viz. French bean (*Phaseolus vulgaris*), brinjal (*Solanum melongena* L.), cucumber (*Cucumis sativus*), bitter gourd (*Momordica charantia*), potato (*Solanum tuberosum*), bottle gourd (*Lagenaria siceraria*), ridge gourd (*Luffa acutangula*), green chili pepper (*Capsicum annuum* L.), and sweet pepper (*Capsicun annuum var. glossum*) to different K regimes. Five K treatments were tested: 1) K-free, farmers' fertilization practice (FFP); 2) recommended dose (100%), basal application; or, 3) split into basal and a second application at bloom; 4) enhanced (150%), basal application; or 5) enhanced, split as above. Nitrogen (N) and phosphorus (P) were uniformly

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applied according to recommendations. All nine crops displayed a significant increase (average - 31%) in yields in response to K application at recommended dose, as compared to FFP. The enhanced dose gave rise to a smaller yield increase, only 22% above the recommended dose, on average, which was also characterized by large variation between crops. Split K applications improved the yield of most crops, but to a much lesser extent. The differences among crop species regarding the linkage between crop K requirements in terms of life span and phenological phases, cropping patterns, and K and carbohydrate contents in harvested organs, are discussed. In conclusion, K application is essential, if exploiting the potential of vegetable crops and seeking to enhance the net return to farmers. For most crop species tested, recommended K dose should be revisited and upgraded. The positive response to split K dose may indicate that it is beneficial to distribute K application along the cropping season.

Map 1. Ranchi district, Jharkhand state, India. (By Joy1963. Own work, inset based on image: India Jharkhand locator map.svg. Licensed under CC BY-SA 3.0 via Wikimedia Commons. http://commons.wikimedia.org/wiki/File:JharkhandRanchi.png#/media/File:JharkhandRanchi.png).

Introduction

Soils are usually incapable of replenishing the loss of nutrients demanded by crops year after year (Mengel and Kirkby, 1987). Therefore, fertilization is essential to maintain soil productivity and fertility. Successive harvests remove large quantities of nutrients from soils; if their nutritional status is not tested regularly and sufficiently restored by balanced fertilization when found to be inadequate, soils become poor. Among the major plant nutrients (NPK), potassium (otherwise known as K or potash) requirements in vegetable crops are fairly high compared to grain crops. Potassium deficiency can bring about a drastic reduction in production and quality as well as shelf-life (Geraldson, 1985; Usherwood, 1985).

Potassium is an activator of various enzymes responsible for plant processes such as energy metabolism, starch synthesis, nitrate reduction and carbohydrate source-sink relationships and allocation. It is extremely mobile in the plant and is involved in plant water status, regulating stomatal conductance in the leaves, as well as water uptake in the roots. Potassium enhances the formation and development of fruit and tubers, and supports crop resistance against certain fungal and bacterial diseases. Soils with poor available K content usually fail to

French bean (*Phaseolus vulgaris*). Photo by IPI.

Brinjal (*Solanum melongena* L.). Photo by IPI.

Cucumber (*Cucumis sativus*). Photo by IPI.

support satisfactory crop yields (Engels *et al.*, 2012; Hawkesford *et al.*, 2012).

Jharkhand state in north-east India (Map. 1) has the potential to significantly increase its vegetable crop production by adoption of improved management practices. In general, soils in Jharkhand vary between low and medium status of available K. About 51% of the soils have medium K content and about 18% display low available K content. Thus, improving potash application practices, in context with other nutrients, would be among the first steps to further develop vegetable production in Jharkhand.

Potash application is usually carried out at the time of sowing/planting (basal application), which ensures the establishment of the crop and some subsequent K supply throughout the whole crop cycle. However, K availability in the soil is very labile; in sandy soils, it is easily leached from the root zone, while in heavy black soils, it might be fixed strongly to the soil surface. Therefore, splitting the dose along the cropping season would be a reasonable measure to ensure K availability when required by the crop.

While most of the farmers in the region tend to apply N and P, sometimes at a dosage higher than necessary, they underestimate or even ignore crop K requirements. The objectives of the present study were, therefore: 1) to quantify the yield response of various vegetable crops to doses and regimes of K application; 2) to demonstrate and thus promote the use of K fertilizer in vegetables crops in Jharkhand, India; and, 3) to initiate educated practices of K application.

Materials and methods

Field experiments were conducted during 2011 to 2014 on various major vegetable crops in farmers' fields situated at different provinces: Kanke (23°17'226"N 85°19'282"E), Pithoria (23°31'261"N 85°17'924"E), Ormanjhi (23°27'883"N 85°28'201"E), and Patratu (23°37'629"N 85°17'372"E) in Ranchi district, Jharkhand state, India (Map. 1). The soils were sandy-loam (52-63.7% sand, 20.7-28.21% silt and 15.6-18.8% clay) with organic carbon content (3.94-6.51 g kg^{-1}), pH (5.6-6.6), medium in 0.32% alkaline $KMnO_4$-oxidizable N (180-278 kg ha^{-1}), high in Bray-P1 extractable P (35-88 kg ha^{-1}) and medium to high in 1N neutral ammonium acetate extractable-K (121-480 kg ha^{-1}).

Vegetable crops examined were: French bean (*Phaseolus vulgaris* var. Arka Komal), brinjal (*Solanum melongena* L. var. Swarna Shakti), cucumber (*Cucumis sativus* var. Swarna Ageti), bitter gourd (*Momordica charantia* var. Combitore Long Green), potato (*Solanum tuberosum*) var. Pokhraj), bottle gourd (*Lagenaria siceraria* var. Victoria), ridge gourd (*Luffa acutangula* var. Swarna Manjari), green chili pepper (*Capsicum annuum* L. var. NP-46), and Shimla mirch or sweet pepper (*Capsicum annuum* L. var. California Wonder).

Farmers' fields were categorized as medium- or high-soil available K status. French bean and capsicum were grown in the medium-, while the rest of the vegetable crops were grown in the high-soil available K status. Crop seedlings were raised in a nursery/polytunnel and transplanted 15-20 days after sowing. A uniform dose of N and P was applied according to state recommendations for individual crops. Di-ammonium phosphate, urea and muriate of potash (MOP, KCl) were the sources of N, P and K, respectively.

All experiments comprised five treatments, as follows: 1) farmer fertilization practice (FFP), normally without K (K_0); 2) recommended K dose as basal ($K_{100\%}$); 3) recommended K dose split into 50% as basal, and 50% at bloom ($K_{(50+50)\%}$); 4) enhanced (150%) K dose, applied as basal ($K_{150\%}$); and, 5) enhanced (150%) K dose, split evenly into a basal application and a late one, at bloom ($K_{(75+75)\%}$). A detailed description of the fertilization regimes applied to each crop is given in Table 1. Each farmer's field was treated as a replicate. Experiments were carried out over one or two years, and the number of replicates for an experiment varied between three and six (Table 1).

Bitter gourd (*Momordica charantia*). Photo by IPI.

Potato (*Solanum tuberosum*). Photo by IPI.

Bottle gourd (*Lagenaria siceraria*). Photo by IPI.

Table 1. Detailed description of the experimental design, basic soil K availability, annual nitrogen (N) and phosphorus (P) dose, and the dose and regime of K application according to treatments and crops. Whenever split, K was applied as basal and at bloom, half and half. FFP – farmers' fertilization practice.

Crop	French bean	Brinjal	Cucumber	Bitter gourd	Potato	Bottle gourd	Ridge gourd	Green chili	Sweet pepper
Years	2	1	1	2	1	1	2	2	2
Exp. plots	3	3	3	3	3	4	3	3	3
	kg ha^{-1}								
Basal soil available K	121-258	140-225	284-480	297-416	284-416	284-417	284-322	284-416	297-258
Basal N	40	200	80	80	100	80	80	100	100
Basal P	80	150	40	40	150	40	40	60	150
Treatment	*K dosage and regime (kg ha^{-1})*								
FFP (K$_0$)	0	0	0	0	0	0	0	0	0
K$_{100\%}$	40	100	40	40	100	40	40	50	100
K$_{(50+50)\%}$	20+20	50+50	20+20	20+20	50+50	20+20	20+20	25+25	50+50
K$_{150\%}$	60	150	60	60	150	60	60	75	150
K$_{(75+75)\%}$	30+30	75+75	30+30	30+30	75+75	30+30	30+30	38+37	75+75

Results and discussion

Is K availability a factor limiting the accomplishment of high vegetable yield and quality? Indicators which answer this fundamental question may arise from several directions. The first one may be the basic fertility of the soil in terms of K availability, which indicates the potential of the soil to supply crop K requirements. Field data from the present study indicated medium to high K availability in all cases, ranging from 121 to 480 kg K ha^{-1} (Table 1). However, exploiting this soil potential depends largely on the extent to which the root system explores the relevant soil volume. Factors like water availability over dimensions of soil and time strongly restrict root expansion and function. Thus, very small portions of the theoretical soil mineral availability are practically exploited and, therefore, active fertilization should be considered also in fertile soils.

The crop response to elevated K application provides much better indications; a prompt and significant increase in yield would definitely demonstrate the dependency of crop development on K supply. This is in agreement with previous studies (Balasubramanian *et al.*, 1991; Hassan *et al.*, 1994; Patil *et al.*, 1996; Imas and Bansal, 1999; Deka *et al.*, 2000; Wuzhong, 2002; Umamaheshwarappa *et al.*, 2003; Bidari *et al.*, 2004; Thakre *et al.*, 2005; and Hari *et al.*, 2007), and was the case with all nine vegetable crops examined here, comparing the yields of K-free (K$_0$ as FFP) to those of K$_{100\%}$, where the officially recommended dosage was applied as basal fertilizer (Table 2; Fig. 1). Yield increases averaged 31%, ranging between 15% for ridge gourd, the least responsive crop, to about 51% for the most responsive one at that level - bottle gourd. The average consequent rise in net income was about 45 KRs ha^{-1}, ranging between 11 (ridge gourd) to 96 KRs ha^{-1} (brinjal). The average relative increase in net return was 49%, ranging from 18.5% (ridge gourd) up to 118% (potato) (Table 3). These results clearly express the significant contribution of basic K fertilization to farmer's income, for almost any vegetable crop tested, and in spite of the apparently good K status of the soils.

Nevertheless, there were significant differences among crops regarding the response rates (Fig. 1). Small or no response may indicate that factors other than K requirement, such as inadequate availability of water or other nutrients, or non-optimal temperature regime, might limit crop growth and development. Increased K application appears ineffective in such circumstances,

Table 2. Effect of K dose and regime on mean annual yields of nine vegetable crops grown in Ranchi district, Jharkhand state, India.

Crop	French bean	Cucumber	Bitter gourd	Ridge gourd	Chili pepper	Brinjal	Potato	Bottle gourd	Sweet pepper
Treatment	*Mg ha^{-1}*								
FFP (K$_0$)	7.3	9.4	7.5	8.0	7.1	50.6	9.2	9.2	21.8
Rec. (K$_{100\%}$)	9.6	12.4	9.2	9.2	8.5	67.1	13.3	13.9	29.1
Rec. split (K$_{(50+50)\%}$)	10.0	13.8	9.3	9.9	8.1	73.2	16.2	15.5	33.7
Enhanced (K$_{150\%}$)	10.5	15.4	10.6	10.8	10.1	76.8§	17.8	17.1	42.1
Enhanced split (K$_{(75+75)\%}$)	10.8	16.0	11.2	11.5	10.0	81.8	23.3	18.8	37.7
LSD (P=0.05)	1.88	2.19	1.74	2.22	2.06	14.9	4.81	1.58	11.1

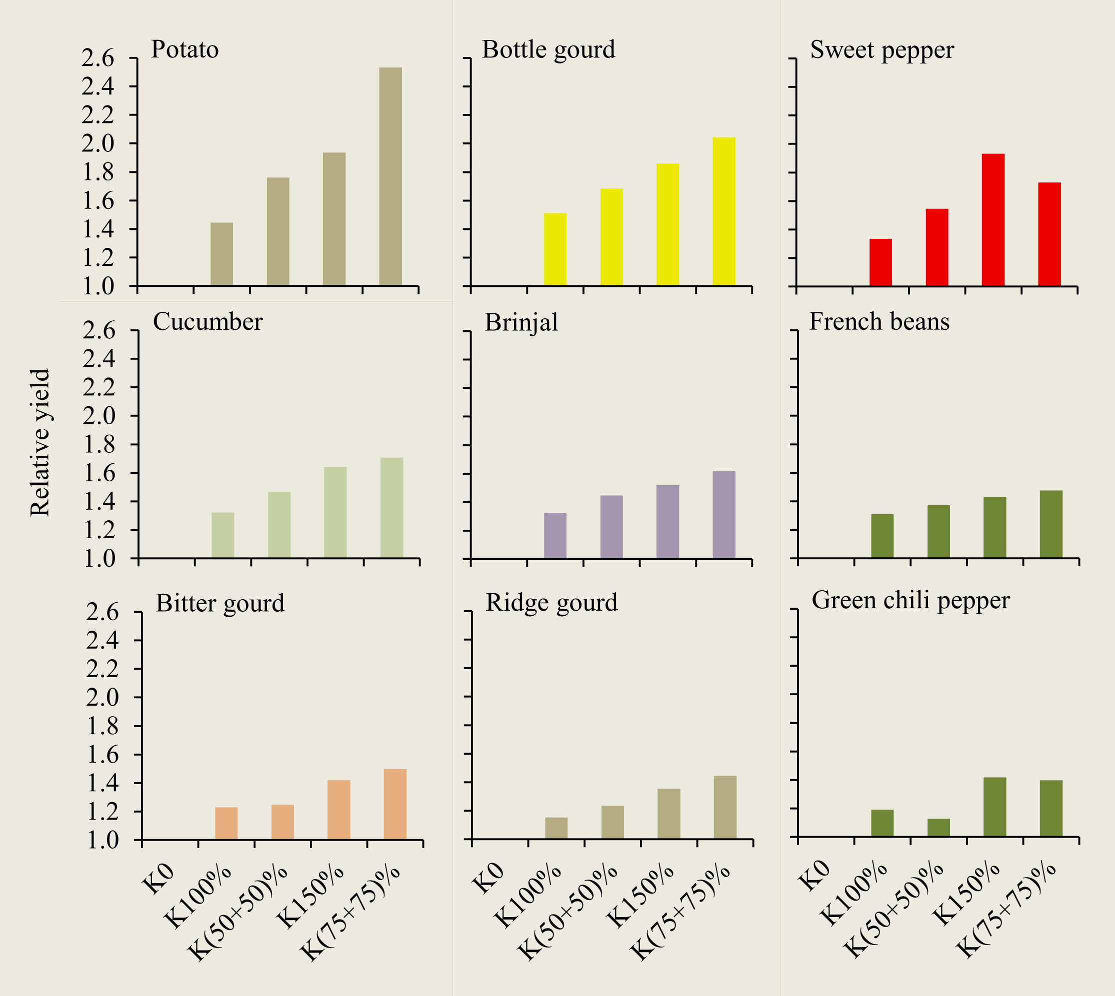

Fig. 1. Yield increment of nine vegetable crops in response to K dose and application regime. Data represent the relative yield compared to that of the K-free (K_0) farmers fertilization practice (FFP). $K_{100\%}$ = the recommended dose, applied once upon planting; $K_{(50+50)\%}$ = similar dose split into two uniform portions, applied upon planting and at bloom; $K_{150\%}$ = enhanced dose applied once upon planting; $K_{(75+75)\%}$ = enhanced dose split as described above.

Table 3. Net return to the farmer as a function of the current market price and the yield obtained by each crop species in response to K dose and regime. Data are presented by 1,000 Rs ha^{-1} (K Rs ha^{-1}).

Crop	French bean	Cucumber	Bitter gourd	Ridge gourd	Chili pepper	Brinjal	Potato	Bottle gourd	Sweet pepper
	Current market price (Rs kg^{-1})								
	15	10	15	10	20	6	15	10	12
Treatment	*Net return (K Rs ha^{-1})*								
K_0	69.2	58.6	76.3	59.5	106.2	227.6	49.7	66.2	204.3
$K_{100\%}$	101.9	87.5	100.7	70.5	131.8	323.5	108.3	111.9	288.7
$K_{(50+50)\%}$	108.6	101.3	102.8	77.0	123.0	359.8	151.8	128.6	343.9
$K_{150\%}$	114.5	116.7	121.4	85.9	163.4	380.5	174.2	143.6	443.1
$K_{(75+75)\%}$	119.1	123.0	130.1	93.1	160.6	409.9	257.3	160.1	390.3

before the active limiting problem is resolved. Alternatively, a weak response to elevated K application may indicate that K requirements are actually fulfilled. To distinguish between these two options, a rough estimate of crops' K requirements was carried out. Obviously, plant K content at harvest provides a minimum threshold estimate of K removal from the soil during crop growth and development. While this kind of measurement was beyond the scope of the present study, data regarding fruit or tuber K content is available from public web sources (USDA National Nutrient Database for Standard Reference, http://ndb.nal.usda.gov/ndb/search/list). Multiplying the yield by K content resulted in K removal by each crop and treatment (Table 4) (assuming that fruit K content is not directly affected by K soil status). Potassium is deeply involved in sugar translocation and metabolism (Engels *et al.*, 2012), which may significantly affect crop K requirements. Therefore, special attention was also paid to differences among crops in regard to carbohydrate accumulation in fruit or tubers (Table 5).

Ridge gourd provided an excellent example for a very low recovery (in the fruit) of K inputs - less than 15% (Table 4). Yield response to increased K input was positive but quite poor compared to some other crops (Fig. 1). It seems that in the case of ridge gourd, K was not the ultimate factor limiting yield improvement. French bean, cucumber, bitter gourd, chili pepper, and bottle gourd comprise a group of crops, the K removal by the fruit of which was around 50% of K inputs. Assuming a rough harvest index of 0.5, K requirements by the crop met K inputs. Together with their positive significant yield response to elevated K (Fig. 1), the availability of this nutrient seems to dominate crop development. These results support updating the recommended dosage by at least 50% or more. Brinjal, potato, and sweet pepper comprise the most interesting group of vegetable crops in the present study. Their fruit or tubers remove large quantities of K, which is sometimes more than supplied by fertilizers (Table 4), and they also accumulate significant rates of carbohydrate (Table 5). Potato and sweet pepper yields displayed the largest response to increased K input (Fig. 1), indicating a significant dependency on K availability. Potato tubers removed 60-75% of the K supplied and accumulated up to 4 Mg ha^{-1} starch. In sweet pepper, K quantities removed by fruit alone were equivalent to those applied (Table 4). Furthermore with brinjal, the heavy yields of which always removed K quantities significantly higher than applied. In addition to 3-5 Mg ha^{-1} carbohydrate accumulated in the fruit, these results strongly indicate that K availability is crucial for this crop (Hochmuth *et al.*, 1993). The relatively smaller response of brinjal yield to increased K input (Fig. 1) definitely strengthens the point that the dose range in the present study was far below real K requirements. This may be true also for potato and sweet pepper.

Splitting the recommended K dosage between basal and later application at bloom ($K_{(50+50)\%}$) brought about less significant effects on yields (Fig. 1). On average, yields increased by only 8%,

Table 4. Potassium removal from the soil by the fruit or tubers of nine vegetable crops grown under different K fertilization regimes. Seeds were not included, assuming that products are consumed as fresh vegetables, before seed maturation. In parentheses, the seasonal K dose per treatment for each crop.

Crop	French bean	Cucumber	Bitter gourd	Ridge gourd	Chili pepper	Brinjal	Potato	Bottle gourd	Sweet pepper
	----*K content in fruit or tubers (g K kg^{-1})*----								
	2.1	1.5	3.2	0.6	3.2	2.3	4.2	1.5	1.75
Treatment	----*K removal by yield (kg K ha^{-1})*----								
K_0	15.4 (0)	14.1 (0)	23.8 (0)	4.8 (0)	22.8 (0)	116.4 (0)	38.6 (0)	13.8 (0)	38.2 (0)
$K_{100\%}$	20.1 (40)	18.6 (40)	29.3 (40)	5.5 (40)	27.2 (50)	154.3 (100)	55.9 (100)	20.9 (40)	50.9 (50)
$K_{(50+50)\%}$	21.1 (40)	20.7 (40)	29.8 (40)	5.9 (40)	25.8 (50)	168.4 (100)	68.0 (100)	23.3 (40)	59.0 (50)
$K_{150\%}$	22.0 (60)	23.1 (60)	33.9 (60)	6.5 (60)	32.4 (75)	176.6 (150)	74.8 (150)	25.7 (60)	73.7 (75)
$K_{(75+75)\%}$	22.7 (60)	24.1 (60)	35.7 (60)	6.9 (60)	31.9 (75)	188.1 (150)	97.9 (150)	28.2 (60)	66.0 (75)

Table 5. Carbohydrate input in the fruit or tuber yields of nine vegetable crops grown under different K fertilization regimes. Seeds were not included, assuming that products are consumed as fresh vegetables, before seed maturation.

Crop	French bean	Cucumber	Bitter gourd	Ridge gourd	Chili pepper	Brinjal	Potato	Bottle gourd	Sweet pepper
	----*Carbohydrate content in fruit or tubers (%)*----								
	7	3.6	4.3	2	8.8	5.9	17.5	3.4	4.6
Treatment	----*Carbohydrate removal by yield (Mg ha^{-1})*----								
K_0	0.512	0.338	0.320	0.160	0.627	2.985	1.610	0.313	1.003
$K_{100\%}$	0.670	0.447	0.394	0.184	0.747	3.959	2.328	0.473	1.339
$K_{(50+50)\%}$	0.703	0.497	0.400	0.197	0.708	4.319	2.835	0.527	1.550
$K_{150\%}$	0.732	0.555	0.455	0.216	0.890	4.531	3.115	0.581	1.937
$K_{(75+75)\%}$	0.755	0.577	0.480	0.231	0.877	4.826	4.078	0.639	1.734

Ridge gourd (*Luffa acutangula*). Photo by IPI.

Chili pepper (*Capsicum annuum* L.). Photo by IPI.

Sweet pepper (*Capsicun annuum var. glossum*).Photo by IPI.

and crop response varied considerably. Chili was the sole crop where the yield declined. Yield increase of below 10% were recorded for bitter gourd, French bean, brinjal, and ridge gourd (1.5, 5%, 5%, and 7%, respectively), while more significant yield addition occurred in cucumber, bottle gourd, sweet pepper, and potato (11, 12, 16, and 22%, respectively). Splitting the enhanced K dose ($K_{(75+75)\%}$) resulted in an even smaller average increase in yield, less than 6%. Here, sweet pepper exhibited a significant yield decline; chili remained stable; French bean, brinjal, cucumber, bitter gourd, ridge gourd, and bottle gourd increased by less than 10%; while potato yield surged by 31%, in comparison to its yield at a single enhanced K application.

The idea of splitting the K dosage into several applications arises from two basic reasons: 1) the relatively high K mobility, particularly in the sandy-loam soils typical to the region of the experiment in Jharkhand; and, 2) the considerably dynamic changes in the requirements for K during plant life cycle. Successive applications of K along the growing season are assumed to ensure its availability to the plant whenever required. The results of the present study show that this assumption is generally valid. Consequently, the net return to the farmer increased in most cases (Table 3). However, K application should be adapted to an individual vegetable crop according to the altering demands through its phenological phases and to its cropping pattern. Some of the vegetable crops examined here differed significantly in these aspects.

In cucurbits, yield is a function of plant biomass at the occurrence of the first female flower, and the ratio between male and female flowers. Adequate basal N supply ensures sufficient plant biomass, whereas balanced N:K ratio (1:1-2, respectively) along the season provides optimal flower ratio, fruit set, development, and quality (Swiader *et al.*, 1994). Splitting the basal dose into two applications may be quite beneficial, as shown here for cucumber and bottle gourd. Nevertheless, additional value may emerge from dividing the same dose into several applications (Lin *et al.*, 2004). Some revision of the N and P fertilization practices might assist in improving the yields of the other cucurbit crops.

Also brinjal and French beans, which are characterized by a continuous cropping pattern, would benefit from the distribution of K application along the season, as indicated by the yield response to the split K dose. Yet, as mentioned above, the ultimate limiting factor in French beans seemed not to be to K, at least here. Brinjal requires significant upgrading of K dosage before solid conclusions can be made.

Potato, the most responsive crop in this experiment, appears to have a great potential for further improvement in yields. While significant basal N application is essential to establish sufficient vegetative biomass to support later tuber development, the application of this nutrient should be significantly reduced once tubers emerge, being replaced by considerable K application in order to sustain the massive carbohydrate translocation from leaves to tubers. Also here, the treatments with split K dose showed substantial benefits, but the whole fertilization practice should be reconsidered.

Sweet pepper and chili pepper provide an interesting comparison between two crops of the same species, *Capsicum annuum*. The difference might shed light on the role of phenology determining crop K requirements. Chili plants produce many tiny fruit that emerge and develop continuously along the plant life span. In this case, the reproductive effort displays a relatively constant but very small demand on K, hence no significant benefit in splitting the K dose could be observed. On the contrary, sweet pepper plants produce much larger fruit with considerable carbon sink demands. Fruit set displays an undulating pattern, which might influence current K requirements (Marcelis *et al.*, 2004). Therefore, splitting the K dose may have positive effects on yield, but the timing or synchronization with fruit set should be considered. This may provide an explanation for the inconsistent response of sweet pepper to the split K dose. Also here, revision of the recommended fertilization practices would benefit the farmers.

Nevertheless, before any further research is executed, farmers may consult the economic consequences of the different K application practices tested in the present study (Table 3). Considering the current market price of each crop species, even small improvements in yield may be significant for the farmers' net return.

Conclusions

1. Potassium application is essential if seeking to exploit the potential of vegetable crops.
2. For most crop species tested, the recommended K dose should be revisited, as well as the whole fertilization practice, to maintain a balanced nutrition status.
3. The positive response to split K dose may indicate that it is beneficial to distribute K application along the cropping season.

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The paper "Enhanced Potassium Application Improves Yield and Profitability of Various Vegetable Crops in Jharkhand, India" also appears on the IPI website at:

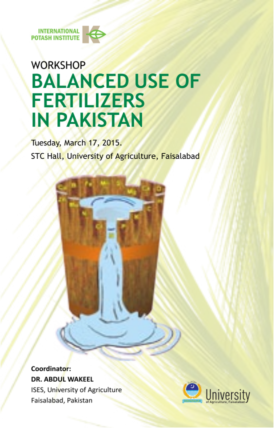
Regional activities/India

Events

IPI Events

March 2015

Workshop on "Balanced Use of Fertilizers in Pakistan" held on 17 March 2015 at the University of Agriculture, Faisalabad, Pakistan



INTERNATIONAL POTASH INSTITUTE

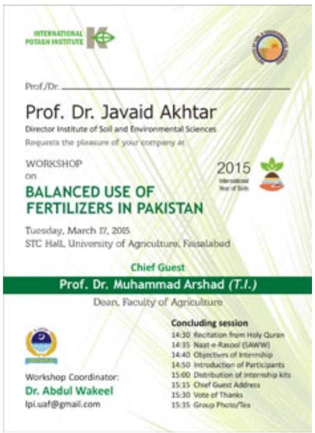
WORKSHOP

BALANCED USE OF FERTILIZERS IN PAKISTAN

Tuesday, March 17, 2015.
STC Hall, University of Agriculture, Faisalabad

Coordinator:
DR. ABDUL WAKEEL
ISES, University of Agriculture
Faisalabad, Pakistan

University of Agriculture, Faisalabad



INTERNATIONAL POTASH INSTITUTE

Prof./Dr. ____________

Prof. Dr. Javaid Akhtar
Director Institute of Soil and Environmental Sciences
Requests the pleasure of your company at

WORKSHOP
on
BALANCED USE OF FERTILIZERS IN PAKISTAN

Tuesday, March 17, 2015
STC Hall, University of Agriculture, Faisalabad

2015

Chief Guest
Prof. Dr. Muhammad Arshad *(T.I.)*
Dean, Faculty of Agriculture

Workshop Coordinator:
Dr. Abdul Wakeel
Ipi.uaf@gmail.com

Concluding session
14:30 Recitation from Holy Quran
14:35 Naat-e-Rasool (SAWW)
14:40 Objectives of Internship
14:50 Introduction of Participants
15:00 Distribution of internship kits
15:15 Chief Guest Address
15:30 Vote of Thanks
15:35 Group Photo/Tea

Imbalanced fertilization, especially the use of nitrogen, phosphorus and potassium, not only causes deterioration of natural resources but also results in low economic returns. In Pakistan, the use of chemical fertilizers (mostly nitrogen and phosphorus) started during the 1960's. Since then nitrogenous fertilizer use has been significantly higher than phosphorus, due to its better, quicker and more economic crop responses. However application of potash has been discouragingly low in most crops except potato and maize. Although Pakistani soils are developed from mica minerals containing more than 6% potassium, most of it is strongly bound to clay minerals and is not available to plants. While a few decades ago the available potassium may have been sufficient for low yielding crop varieties, recent development of high yielding varieties and intensive cropping have depleted the soils to a great extent and increased the demand for potash in order to achieve a better yield. Canal water was also considered a significant source of potassium but the decreased availability of canal water has limited this source too. There is, therefore, a dire need to promote potassium fertilization to balance the fertilizer use in Pakistan for sustainable and cost-effective agriculture.

Internship program

A comprehensive outreach program for the promotion of balanced fertilization with a special emphasis on K fertilization is planned to convey the message of balanced fertilization to farmers. The International Potash Institute in collaboration with the fertilizer industry of Pakistan support the agriculture students in the farming communities to hear their experiences and to advise on fertilizer recommendations after analyses of their fields. A combined message based on research and fertilizer industry experiences will be conveyed to farmers through these soil science and agronomy students. The objectives of this internship program are to train graduate students in field activities and interaction with farmers, and to equip farmers with an understanding of balanced fertilization, with special reference to potassium. Agriculture graduates from Punjab and Sind are selected through a transparent selection process in the presence of Engro and FFC representatives. Fourteen internees have been selected. Among these, four are from Sind province selected from Sind Agriculture University Tando Jam; three are selected from BZU, Multan; and seven are from the University of Agriculture Faisalabad.

Workshop on "Balanced Use of Fertilizers in Pakistan", 17 March 2015, University of Agriculture, Faisalabad, Pakistan. Photo by A. Wakeel.

Objectives of the workshop

The workshop was arranged to prepare the internees for field visits by providing them with enough knowledge to communicate balanced fertilizer use and the importance of potash fertilization to farmers, to get soil samples from farmers' fields for analyses; and to make recommendations for balanced fertilizer use. After this workshop Internees joined FFC and Engro teams to perform their work for three months until the middle of June 2015.

This report also appears on the IPI website at:

[Regional activities/WANA]

Events (cont.)

IPI Events

July 2015

Second Announcement of the First National Potash Symposium

Symposium theme: Potassium for sustainable crop production and food security

Paper presentations: There will be 13 papers and 3 Key Note papers. Both papers will be presented by experienced scientists around the following sub-themes:

a) Potash distribution in the soils of Tanzania
b) Role of potash for sustainable crop productivity in Tanzania
c) Trends of Potassium levels in soils of Tanzania
d) Formulation and packaging of potassium based fertilizers
e) Economics of potassium based fertilizers for sustainable crop production

Venue: Protea Hotel Court yard, Dar es Salaam, TANZANIA.

Dates: 28-29 July 2015

Organizers: African Fertilizer and Agribusiness Partnership (AFAP), Dar es Salaam, Tanzania in collaboration with International Potash Institute (IPI) based in Switzerland and Mlingano Agricultural Research Institute, Tanga Tanzania.

Significance: Potassium is an essential macronutrient for plants involved in many physiological processes. It is important for crop yield as well as for the quality of edible parts of crops, as it is also required in human nutrition. Potassium is important for agriculture because it improves water retention, yield, nutrient value, taste, and colour and disease resistance of food crops. It has wide application to fruit and vegetables, rice, wheat and other grains, sugar, corn, soybeans, palm oil and cotton, all of which benefit from the nutrient's quality enhancing properties. Likewise, potassium is essential for human and animal life, as it is involved in many body functions and is required for proper muscle development and also important for good heart function.

Participation in the Symposium: The Organizers have invited experienced scientists to be Key Note speakers and presenters of various papers in this symposium. It has also invited some participants at the costs of the organizers. Other interested participants but not invited due to limited funding are kindly required to apply to the Organizers and will be responsible for their own travel, accommodation, incidental expenditures and pay for participation fee. Organizers may assist to provide contacts of various Hotels in Dar es Salaam. The participation fee of US $ 100 should be paid in advance not later than 20th July 2015 so as logistical arrangements can be finalized. The participation fee should be deposited to: **NATIONAL SOIL SERVICES SELF HELP, ACCOUNT NUMBER 020105000207, BANK NAME: NATIONAL BANK OF COMMERCE (NBC) LTD-TANGA BRANCH, TANZANIA, SWIFT CODE: NLCBTZTX.** For privately sponsored participants, Bank pay-in slip and dully filled application form should be sent to:

Dr. Mkangwa, C.Z. Co-Chairman, Organizing Committee, National Potash Symposium, mkangwa@yahoo.co.uk +255 784 828613, ARI Mlingano, P.O. Box 5088, TANGA.

Dr. Mshindo A. Msolla (Chairman, Organizing Committee, National Potash Symposium, email: amsolla@afap-partnership.org; +255 784 849970/ +255 754 849970.

Dr. Catherine Senkoro (Secretary, Organizing Committee, National Potash Symposium, email: cathysenkoro@gmail.com; +255 754649188. ARI Mlingano, P.O. Box 5088, TANGA

Application Form:
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First National Potash Symposium on "Potassium for Sustainable Crop Production and Food Security", 28-29 July 2015, Protea Hotel Court Yard, Dar es Salaam, Tanzania, organized by the African Fertilizer and Agribusiness Partnership (AFAP), Dar es Salaam, in collaboration with the International Potash Institute (IPI), Switzerland and Mlingano Agricultural Research Institute, Tanga.

Introduction

Potassium is the third major plant and crop nutrient after nitrogen and phosphorus. Over five decades, potassium has been regarded as sufficient in most soils of Tanzania. This generalization has led to little research work regarding soil potassium status, plant nutrition and eventually fertilizer recommendations which include potassium in fertilizer formulations. Tanzania has potassium blended fertilizer recommendations for a few crops like tobacco, sisal and tea, with remaining crops depending on inherent potassium supply from the soil, which is gradually declining due to inadequate supplies. In recent years, it has been recognized that levels of potassium in some soils are lower than normally anticipated, and that its deficiency symptoms are now common in some major crops like maize, cassava, and rice. With such observed deficiencies, it is not possible to provide fertilizer recommendations which include potassium with certainty.

Significance

Potassium is an essential macronutrient for plants involved in many physiological processes. It is important for crop yield as well as for the quality of edible parts of crops, particularly as it is also required in human nutrition. Potassium is important for agriculture because it improves water retention, yield, nutrient value, taste, colour, and disease resistance of food crops. It has wide application to fruit and vegetables, rice, wheat and other grains, sugar, corn, soybeans, palm oil and cotton, all of which benefit from the nutrient's quality enhancing properties. Likewise, potassium is essential for human and animal life, as it is involved in many body functions and is required for proper muscle development and is also important for good heart function.

Objectives

This symposium is aiming at sustainably increasing agricultural productivity by inclusion of potassium in the fertilizer recommendations of various crops, hence the objectives of this symposium are:

1. Obtaining baseline information of potassium research in Tanzania,
2. Synthesize available information, and
3. Identify research gaps which will establish potassium research agenda.

Paper presentations

There will be 13 papers and 3 Key Note papers. All papers will be presented by experienced scientists around the following sub-themes:

a) Potash distribution in the soils of Tanzania,
b) Role of potash for sustainable crop productivity in Tanzania,
c) Trends of potassium levels in soils of Tanzania,
d) Formulation and packaging of potassium based fertilizers,
e) Economics of potassium based fertilizers for sustainable crop production.

For more details see information on the IPI website/Events, or contact Dr. Mkangwa, C.Z., Co-Chairman, Organizing Committee, National Potash Symposium, mkangwa@yahoo.co.uk, or Mr. Hillel Magen, IPI Director.

November 2015

2nd IPI-Ministry of Agriculture-Hawassa University-Ethiopian Agricultural Transformation Agency (ATA) joint Symposium on "The Role of Potassium in Balanced Fertilization", 24-26 November 2015, Hawassa University, Hawassa, Ethiopia.

For more details contact Mr. Eldad Sokolowski, IPI Coordinator sub-Saharan Africa or see updates and information on the IPI website/Events.

International Symposia and Conferences

July 2015

10th European Conference on Precision Agriculture, 12-16 July 2015, Volcani Center, Tel-Aviv, Israel. See more on the conference website.

October 2015

9th Symposium for the International Society of Root Research "Roots Down Under", 6-9 October 2015, Hotel Realm Canberra, Australia. See more on the symposium website.

November 2015

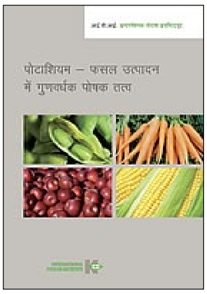
The 2nd World Congress on the Use of Biostimulants in Agriculture, 16-19 November 2015, Florence Convention Centre, Italy. For more information visit www.biostimulants2015.com.

First quarter 2016

IFA and New Ag International join forces again to organize the **4th International Conference on Slow- and Controlled-Release and Stabilized Fertilizers in China** during the first quarter of 2016. For more information go to www.newaginternational.com/index.php/news/399.

Publications

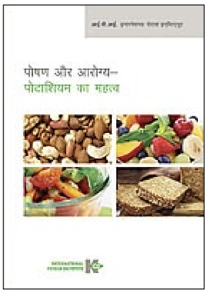
IPI Publications



पोटाशियम - फसल उत्पादन में गुणवर्धक पोषक तत्व

Potassium - the Quality Element in Crop Production

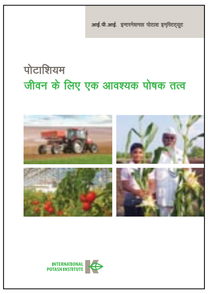
This publication is now available in *Hindi* for download on the IPI website (also available in *English*, *Portuguese* and *Ukrainian*). For hardcopies, please contact Dr. Patricia Imas, IPI Coordinator India.

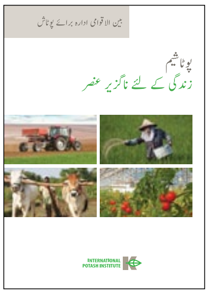


पोषण और आरोग्य-पोटाशियम का महत्व

Nutrition and Health - the Importance of Potassium

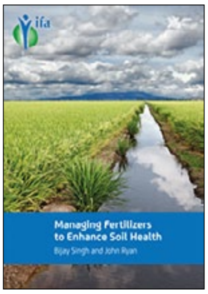
This publication is now available in *Hindi* for download on the IPI website (also available in *English* and *Portuguese*). For hardcopies, please contact Dr. Patricia Imas, IPI Coordinator India.





Potassium - a Nutrient Essential for Life. We have just published this booklet in *Chinese, Hindi and Urdu*, available on the IPI website alongside other languages (*Amharic, Arabic, English, French, Portuguese, and Ukrainian*). You can order hardcopies in *Chinese* from Dr. Tian Youguo, NATESC, Ministry of Agriculture, China; in *Hindi* from Dr. Patricia Imas, IPI Coordinators India; and in *Urdu* from Dr. Abdul Wakeel, IPI Consultant Pakistan.

Other Publications



Managing Fertilizers to Enhance Soil Health

Singh, B., and J. Ryan. First edition. May 2015. IFA, Paris, France.

The publication can be downloaded from IFA's website.

Scientific Abstracts

in the Literature

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Potassium Fertility Effects Yield Components and Seed Potassium Concentration of Determinate and Indeterminate Soybean

Md. Rasel Parvej, N.A. Slaton, L.C. Purcell, and T.L. Roberts. 2015. Agron. J. 107(3):943-950. DOI 10.2134/agronj14.0464.

Abstract: Indeterminate maturity group (MG) IV soybean [*Glycine max* (L.) Merr.] cultivars may be more susceptible to yield loss from K deficiency due to the shorter growing season and earlier onset of reproductive growth than MG V determinate soybean cultivars. Our objective was to identify whether indeterminate MG IV or determinate MG V soybean are affected differently by K deficiency. Seed yield and selected yield components were evaluated from a determinate (MG 5.3) and indeterminate (MG 4.7) soybean cultivar grown under three K fertility levels (low, medium, and high). The trial was conducted in long-term plots that receive 0, 75, or 150 kg K ha^{-1} yr^{-1}. Yield and yield components of both the determinate and indeterminate cultivars responded similarly to K deficiency. Seed yield for soybean grown with low K averaged 3.4 Mg ha^{-1} and was 13 to 15% lower than the yields of soybean grown with medium and high K fertility. The yield loss associated with K deficiency was from fewer pods (16-25%) and seeds (22-30%) $plant^{-1}$, higher seed abortion (5-7%), and lower individual seed weight (8-10%) than soybean with medium or high K fertility. Seed K concentration

increased with each increase in K fertility level averaging 15.8, 18.7, and 19.8 g K kg^{-1} for soybean grown under low, medium, and high K levels, respectively. Regardless of growth habit, the yield loss caused by K deficiency was attributed to the same primary mechanisms of reduced pod number and increased seed abortion.

Optimizing Yield and Quality of Canola Cultivars Using Various Potash Levels

Ansaar Ahmed, Fayaz Ali, Inamullah, Amjad Ali, Arif Ullah, Rubina Naz, Amanullah Mahar, Shahmir Ali Kalhoro. 2015. Amer. J. Plant Sci. 6(8):1233-1242.

Abstract: The response of several canola cultivars to different potassium (K) levels was investigated in terms of various agronomic parameters including yields, oil and protein contents in a trial conducted at The University of Agriculture, Peshawar-Pakistan in Rabi 2010-11. Three cultivars including Bulbul-98, Abaseen-95 and Dure-NIFA, with five levels of potassium i.e. 0, 30, 60, 90 and 120 kg ha^{-1} were used in Randomized Complete Block (RCB) design with four replications and factorial arrangement. A larger number of days to 50% flowering (116.6 days), plant height (203.8 cm), leaf area index (4.4), 1,000 grain weight (3.5 g), biological yield (13,189.3 kg ha^{-1}), grain yield (1,799.2 kg ha^{-1}) and harvest index (13.9%) were obtained in K applied plots than the plots where K was not applied. The highest oil (45.1%) and protein (27.7%) was obtained in plots where K was applied at the rate of 120 and 90 kg·ha^{-1}, respectively. Among cultivars, Bulbul-98 and Abaseen-95 had higher seed yield and oil percentage. Bulbul-98 had more protein content than Abaseen-95 and Durre-NIFA. On average, cultivars gave higher and at par grain yield at 60, 90 and 120 kg ha^{-1}. However, they produced higher and at par oil and protein percentage at 90 and 120 kg·ha^{-1}. Bulbul-98 and Abaseen-95 are recommended for higher grain yield and oil content for general cultivation in Peshawar valley. However, for higher protein content, Bulbul-98 is better. Potassium applied at 60 kg ha^{-1} is recommended for higher grain yield, however, for higher oil and protein content, K at 90 kg ha^{-1} is recommended.

Evaluation of Two Methods for Optimising Nitrogen Fertilisation of Field Crops

Maltas, A., R. Charles, D. Pellet, B. Dupuis, L. Levy, A. Baux, B. Jeangros, and S. Sinaj. 2015. Recherche Agronomique Suisse 6(3):84-93.

Abstract: Two methods are used in Switzerland to optimise the nitrogen fertilisation of field crops: the «corrected norms» method and the Nmin method. Each of the methods suggests a different approach: the «corrected norms» method takes into account field characteristics influencing nitrogen availability, while the Nmin method is based on the measurement of mineral nitrogen present in the soil during periods that are crucial for the plants growth. In this article, both methods are evaluated using nitrogen fertilisation experiments performed by Agroscope for a wide range of arable crops and pedoclimatic conditions. The advantages and limits of each method are presented, and ways for improvement are suggested.

Read on

Investigation and Synthesis of Sweet Sorghum Crop Responses to Nitrogen and Potassium Fertilization

Adams, C.B., J.E. Erickson, and M.P. Singh. 2015. Science Direct. Field Crops Research 178:1-7. DOI 10.1016/j.fcr.2015.03.014.

Nutrient Deficiency Limits Population Development, Yield Formation, and Nutrient Uptake of Direct Sown Winter Oilseed Rape

Wang, Y., T. Liu, X.K. Li, T. Ren, R.H. Cong, and J.W. Lu. 2015. Science Direct. J. Integrative Agriculture 14(4):670-680. DOI 10.1016/S2095-3119(14)60798-X.

High Ca^{2+} Reverts the Repression of High-Affinity K^+ Uptake Produced by Na^+ in *Solanum lycopersycum* L. (var. Microtom) Plants

Hayet Bacha, H. , R. Ródenas, E. López-Gómez, M.F. García-Legaz, M. Nieves-Cordones, R. M. Rivero, V. Martínez, M. Ángeles Botella, and F. Rubio. 2015. Science Direct. J. Plant Physiol. 180:72-79. DOI 10.1016/j.jplph.2015.03.014.

Potassium Solubilizing Rhizobacteria (KSR): Isolation, Identification, and K-Release Dynamics from Waste Mica

Vijay Singh Meena, Bihari Ram Maurya, Jai Prakash Verma, Abhinav Aeron, Ashok Kumar, Kangmin Kim, and Vivek K. Bajpai. 2015. Science Direct. Ecological Engineering 81:340-347. DOI 10.1016/j.ecoleng.2015.04.065.

Future Productivity and Carbon Storage Limited by Terrestrial Nutrient Availability

Wieder, W.R., C.C. Cleveland, W.K. Smith, and K. Todd-Brown. 2015. Nature Geoscience 8:441-444. DOI 10.1038/ngeo2413.

Simulating Wheat Growth Response to Potassium Availability Under Field Conditions with Sandy Soils. I. Model Development

Scanlan, C.A., N.I. Huth, and R.W. Bell. 2015. Science Direct. Field Crops Research 178:109-124. DOI 10.1016/j.fcr.2015.03.022.

Simulating Wheat Growth Response to Potassium Availability Under Field Conditions in Sandy Soils. II. Effect of Subsurface Potassium on Grain Yield Response to Potassium Fertiliser

Scanlan, C.A., R.W. Bell, R.F. Brennan. 2015. Science Direct. Field Crops Research 178:125-134. DOI 10.1016/j.fcr.2015.03.019.

The Path Coefficient Analysis of Yield Components for Leaf Nutrient Concentrations in Mango (*Mangifera indica* L.) Under Rainfed Agroclimatic Conditions of North-West Himalaya

Pramod Kumar, Som Dev Sharma, and N.C. Sharma. 2015. Science Direct. Scientia Horticulturae 190:31-35. DOI 10.1016/j.scienta.2015.02.042.

Effects of Potassium Deficiency on Photosynthesis and Photoprotection Mechanisms in Soybean (*Glycine max* (L.) Merr.)

Wang, X.G., X.H. Zhao, C.J. Jiang, C.H. Li, S. Cong, D. Wu, Y.Q. Chen, H.Q. Yu, and C.Y. Wang. 2015. Science Direct. J. Integrative Agriculture 14(5):856-863. DOI 10.1016/S2095-3119(14)60848-0.

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2015. Science 348, 6235. DOI 10.1126/science.1261071.

Smallholder Farmers are the New Global Food Frontier

Locke, H. 2015. The Guardian.

Genetic Approaches for Improvement of the Crop Potassium Acquisition and Utilization Efficiency

Wang, Y., and W.H. Wu. 2015. Science Direct. Current Opinion in Plant Biology 25:46-52. DOI 10.1016/j.pbi.2015.04.007.

Potassium Application Affects Carbohydrate Metabolism in the Leaf Subtending the Cotton (*Gossypium hirsutum* L.) Boll and its Relationship with Boll Biomass

Hu, W., J. Yang, Y. Meng, Y. Wang, B. Chen, W. Zhao, D.M. Oosterhuis, and Z. Zhou. 2015. Science Direct. Field Crops Research 179:102-131. DOI 10.1016/j.fcr.2015.04.017.

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Xu, X., J. Xie, Y. Hou, P. He, M.F. Pampolino, S. Zhao, S. Qiu, A.M. Johnston, and W. Zhou. 2015. Science Direct. Field Crops Research 180:37-45. DOI 10.1016/j.fcr.2015.05.008.

Carbon and Nitrogen Allocations in Corn Grown in Central and Northeast China: Different Responses to Fertilization Treatments

Miao, H.T., J.L. Lü, M.G. Xu, W.J. Zhang, S.M. Huang, C. Peng, and L.M. Chen. 2015. Science Direct. J. Integrative Agriculture 14(6):1212-1221. DOI 10.1016/S2095-3119(14)60790-5.

Whole-Genome Identification and Expression Analysis of K^+ Efflux Antiporter (KEA) and Na^+/H^+ Antiporter (NHX) Families Under Abiotic Stress in Soybean

Chen, H.T., X. Chen, B.Y. Wu, X.X. Yuan, H.M. Zhang, X.Y. Cui, and X.Q. Liu. Science Direct. J. Integrative Agriculture 14(6):1171-1183. DOI 10.1016/S2095-3119(14)60918-7.

Effect of Water Stress and Subsequent Re-Watering on K^+ and Water Flows in Sunflower Roots. A Possible Mechanism to Tolerate Water Stress

Benlloch-González, M., J.M. Quintero, M.J. García-Mateo, J.M. Fournier, and M. Benlloch. 2015. Science Direct. Environmental and Experimental Botany 118:78-84. DOI 10.1016/j.envexpbot.2015.06.008.

Potash and Spraying Focus at Oak Park Open Day

Doyle, A. 2015. Irish Farmers Journal.

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