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Editorial

Dear readers,

In this issue, we are celebrating "Global Fertilizer Day" which took place on 13 October 2018 and commemorates the Haber-Bosch patent on the process of making ammonia from air developed in 1908. Since this time, the use of nitrogen as a fertilizer has brought enormous benefits to agriculture, and the widespread adoption of fertilizers has lifted billions out of poverty and famine.

It is estimated that half the food grown worldwide is made possible only through the use of fertilizers. However, FAO estimate that, in order to meet global food demand in 2050, farmers will need to produce 50% more food, forage crops and biofuels compared to 2012. As available land for expanding agriculture is scarce, increased food production will come only from increasing productivity per hectare, which will require optimum and balanced fertilizer use.

At the same time, the indiscriminate use of fertilizers has implications for the environment, especially concerning the overuse of nitrogen and its loss from the soil through leaching and volatilization. To help address this issue, IPI has advocated proper nutrient management for more than 50 years, i.e. by applying potassium in a balanced proportion with nitrogen, the efficiency of nitrogen use increases and thus the risk of pollution can be significantly reduced.

In the current *e-ifc* edition, we present some ongoing examples from India, Kenya and Vietnam on how the proper use of potassium fertilizers can increase crop yields and thus, help to feed the growing populations. Demonstration plots using sugarcane in India, for instance, have proven that by effectively applying potassium along with nitrogen and phosphorus, higher yields and profits can be obtained. In Vietnam, the application of potassium - along with secondary nutrients like calcium, magnesium and sulfur - has resulted in significantly improved yields, quality and profits of black pepper. Finally, in Kenya, large-scale outreach efforts to convey the importance of balanced fertilization to farmers has led to an increase in potato yields.

We are proud that IPI is contributing to sustainable global food production in this way.

I wish you an enjoyable read.

Dr. Patricia Imas
IPI Scientific and Communications Coordinator

Photo cover page: Sugarcane demonstration plot at Bajhnathpur, India. Photo courtesy of Potash for Life, India.

Research Findings

Photo 1. Observation of black pepper (*Piper nigrum* L.) development. Photo by the authors.

Polyhalite Effects on Black Pepper (*Piper nigrum* L.) Yield and Quality in the Central Highlands of Vietnam

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Abstract

Acid soils significantly challenge the rapidly growing production of black pepper (*Piper nigrum* L.) in Vietnam. The perennial vines suffer from malnutrition, which gradually leads to plant deterioration, susceptibility to various diseases, and consequent reduction in yield and quality. While farmers already practice frequent fertilizer application, different types of fertilizers are required in order to further improve nutrient availability and to broaden nutrient range in the soil. Polyhalite is a natural mineral consisting of K_2O, SO_3, MgO, and CaO at 14, 48, 6, and 17%, respectively, and has potential as a slow-release multi-nutrient fertilizer. For this study, polyhalite was examined in combination with MOP (KCl), in equal proportions, to provide doses of 120, 240, and 360 kg K_2O ha^{-1} yr^{-1}, split into six applications during the year. These treatments were compared to doses of zero

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(control), 120, and 270 (farmers' practice) kg K_2O ha^{-1} applied solely as MOP.

The present study demonstrates the pivotal role of K application in black pepper production on acid soils. Splitting the K dose into bimonthly applications brought leaf K contents to the required range. Polyhalite application can partially replace MOP as the K source and, furthermore, polyhalite provides the crop with other essential nutrients such as Ca, Mg, and S. The supplemental nutrients strengthened the black pepper vines against mealybug attacks, supported better crop performance, and significantly improved yield and produce quality, which resulted in higher profits. The combination of 120/120 kg K_2O ha^{-1} of MOP/polyhalite, respectively, gave rise to the best crop performance and to the highest yield, produce quality, and profit. However, the exact contribution of polyhalite to the soil nutrient status requires further research.

Keywords: Acid soil; calcium; magnesium; *Piper nigrum* L.; polyhalite; potassium; *Pseudococcus citri*; sulfur.

Introduction

Black pepper (*Piper nigrum* L., Piperaceae), the 'king of spices', originated in the tropical evergreen forests of the Western Ghats of India (Sivaraman *et al.*, 1999), and is one of the oldest spices known to humankind. Global black pepper production is led by Vietnam, with 216,432 Mg yr^{-1}, followed by Indonesia, India, Brazil, and China, with 82,167; 55,000; 54,425; and 34,587 Mg yr^{-1}, respectively (FAOSTAT, 2016). In Vietnam, pepper production is concentrated on the red soils of Central Highlands and in Phu Quoc Island. The increasing prices in recent years have led to further expansion of pepper cultivation to other regions in Vietnam.

Black pepper grows successfully between 20° north to 20° south of the equator and from 0 to 1,500 m above sea level. It is a plant of the humid tropics, requiring 1,250-2,000 mm of rainfall, tropical temperatures and high relative humidity with little variation in day length throughout the year (Sivaraman *et al.*, 1999). Black pepper grows well on soils ranging from heavy clay to light sandy clays rich in humus with porous friable nature, well drained, but still with ample water retention. Soils with near neutral pH, high organic matter and high base saturation with calcium (Ca) and magnesium (Mg) were found to enhance black pepper productivity (Mathew *et al.*, 1995).

Nutrient removal and composition of black pepper vines varies with variety, age, season, soil type and management. Sim (1971) estimated the macronutrient removal by black pepper as 233, 39, 207, 30, and 105 kg ha^{-1} of nitrogen (N), phosphorus pentoxide (P_2O_5), potassium oxide (K_2O), magnesium oxide (MgO), and calcium oxide (CaO), respectively, and later estimates did not differ significantly (Sivaraman *et al.*, 1999). The critical stages of nutrient requirement for black pepper are during initiation of flower primordia and flower emergence, and during berry formation and development (Raj, 1978). Nybe *et al.* (1989) reported that phosphorus (P) and potassium (K) had greater importance than N in enhancing black pepper yields. Leaf macronutrient concentration ranges required for normal pepper development were estimated to be 3.1-3.40%; 0.16-0.18%; and 3.4-4.3% for N; P; and K, respectively. The suitable leaf concentration ranges of sulfur (S), Ca, and Mg should be 0.09-0.29%, 1.42-3.33%, and 0.40-0.69%, respectively (de Waard, 1969; Phan Huu Trinh *et al.*, 1988).

Black pepper is a surface feeder; feeding roots are concentrated in the top 50-60 cm layer of the soil. In the past, black pepper,

Photos 2. Fertilizer application and irrigation of black pepper. Photos by the authors.

as well as coffee and tea plantations were established on virgin forests after clearing the vegetation (de Geus, 1973; Chiem and Nhan, 1974; D'haeze *et al*., 2005). However, owing to heavy rains and unsustainable soil management practices, soils became poor in fertility and balanced manuring of crops became essential (de Waard, 1969). Over the course of time, sustainable traditional manuring practices were replaced with manufactured chemical fertilizers and, consequently, dieback of branches, foliar disorders, low yields and considerable reduction in life span of vines were observed (de Waard, 1969; Raj, 1978; Sivaraman *et al*., 1999; Zu *et al*., 2014).

Soil acidity is an acute problem in the humid tropics, where annual precipitation exceeds 2,000 mm or frequent heavy rainfall events take place. Under such environmental circumstances, soil acidification is a natural process; appreciable quantities of exchangeable bases (Ca^{2+}, Mg^{2+}, and K^{+}) are leached from the soil's surface layer. Subsequently, the rising relative concentrations of exchangeable hydrogen (H^{+}) and exchangeable aluminum (Al^{3+}) reduce soil pH, and hence, are responsible for soil acidification (Coulter, 1969; Pavan, 1983). The content of mobile Al in soils with pH below 5.5 is rather high, which leads to increased uptake of toxic Al by plants, root growth retardation and dysfunction (Ryan *et al*., 1993; Zu *et al*., 2014), and to consequent diminishing nutrient uptake (Duchanfour and Souchier, 1980). Where soil pH declines below 5.5, the availability of plant nutrients, particularly N, P, K, Ca, Mg, S, molybdenum (Mo), and boron (B), decrease significantly (Zu *et al*., 2014; Aloka, 2016).

Overcoming the direct and indirect effects of acid soils on crop performance requires complex simultaneous solutions. Repeated liming is useful in many cases as a practice aimed to reconstruct soil pH (Fageria and Baligar, 2008). However, liming has not always been successful due to its low solubility in water, very slow effect, unsuitable methods of application, and high cost (Liu and Hue, 2001). Gypsum ($CaSO_4 \cdot 2H_2O$) was proposed as an effective amendment for subsoil acidity (Shainberg *et al*., 1989) and, in a recent study, demonstrated significant enhancement of black pepper crop performance (Aloka, 2016). Nevertheless, along with efforts to reduce detrimental effects of acid soils, consistent nutrient availability throughout the year must be taken care of. In this respect, the microflora of black pepper rhizosphere has been recently explored (Xiong *et al*., 2015; Li *et al*., 2016), in order to influence beneficial chemical processes in the soil. However, in the absence of adequate soil fertility, and under a frequent precipitation regime, any kind of external nutrient supply should address this point. Splitting the fertilizer dose, where practical, is one promising solution. Slow-release fertilizers provide another solution; fertilizer efficiency to supply N and P significantly improved when slow-release 'nimin' (nitrification inhibitor) coated urea (Sadanandan and Hamza, 1993) and mussoorie rock phosphate (Sadanandan, 1986), respectively, were applied to black pepper. Still, more stable K fertilizers are needed, as well as long-lasting sources of Ca and Mg.

Polysulphate™ (produced by Cleveland Potash Ltd., UK) is the trade mark of the natural mineral 'polyhalite', which occurs in sedimentary marine evaporates, and consists of a hydrated sulfate of K, Ca, and Mg with the formula: $K_2Ca_2Mg(SO_4)_4 \cdot 2(H_2O)$. The deposits found in Yorkshire, in the UK, typically consist of K_2O: 14%, SO_3: 48%, MgO: 6%, CaO: 17%. As a fertilizer providing four key plant nutrients - S, K, Mg, and Ca - polyhalite may offer attractive solutions to crop nutrition. In addition, polyhalite releases the nutrients considerably slower than other K-containing fertilizers, which may also be significant for soil K availability. Once a proper application is established, polyhalite may not only provide a significant part of crop K requirements, but also supply secondary macronutrients that are essential under the present cropping environment of black pepper in Vietnam.

The objectives of the present study were to evaluate the effectiveness of polyhalite as a supplementary fertilizer on black pepper performance, yield, quality, and economic efficiency, and to offer new alternatives for black pepper fertilization under the conditions of the Central Highlands of Vietnam.

Map. 1. Location of the experiment in the Central Highlands of Vietnam.

Materials and methods

The experiment was located in the Nguyễn Văn Tứ household, H'Lốp commune, Chư Sê district, Gia Lai province of the Central Highlands of Vietnam (Map 1), and took place from January 2016 to December 2017, in a black pepper garden (cultivar Loc Ninh), planted in 2012.

The experiment was conducted on an acidic (pH_{KCl}: 4.5-4.6) reddish brown soil (Rhodic Ferralsols). Organic matter (OM) and total N contents were relatively high (OM: 3.50-3.62%; N: 0.18%). Total P was high, 0.21-0.23%, however, available P was poor (42.5 mg P_2O_5 kg^{-1}). Available K and S were moderate (102.6-103.1 and 21.9-22.5 mg kg^{-1} K_2O and SO_4, respectively). Alkaline cations, Ca^{2+} and Mg^{2+} were very low, 1.89 and 1.59 cmol kg^{-1}, respectively.

The experiment consisted of six treatments with four replications in a randomized complete block design (RCBD). Each plot included 30 pepper plants (180 m^2). A detailed description of the fertilization regime and treatments is given in Tables 1 and 2. Treatments included farmers' practice (FP) as the first control (T_1), and a second control (T_2), which received only the standard N and P fertilizers. Treatments T_3-T_6 were applied with the standard N and P fertilizers, but differed in the rate and combination of MOP and polyhalite, to provide a consistent rate of K_2O supply. Thus, T_3 and T_4 received a yearly dose of 120 kg K_2O ha^{-1}: T_3 - MOP, exclusively; and T_4 - MOP and polyhalite, 60 kg K_2O ha^{-1} each, but 100 and 429 kg fertilizer ha^{-1}, respectively. In treatments T_5 and T_6, K rates increased to 240 and 360 kg K_2O ha^{-1}, respectively, equally divided between MOP and polyhalite (Table 1). FMP (fused magnesium phosphate) was applied twice a year, during May-June and November-December. Urea, MOP, and polyhalite were applied every two months, as shown in Table 2.

Five plants per plot were monitored each year for vegetative growth at the beginning and end of the rainy season. In each plant, the length of four branches of the first order were measured and their elongation during the rainy season was calculated. Similarly, the number of lateral (second order) branches added during the rainy season to four tagged branches was counted.

Diagnostic leaves were sampled twice in July, before and 20 days after fertilizer application. The leaves (eight leaves from each of three trees $plot^{-1}$, from four different directions around the tree) were collected from non-bearing internodes of fruit-bearing branches. Leaves were heated for an hour at 105-110°C and then dried at 80°C for 8-12 hours, until a constant weight was achieved. The dry leaves were milled to fine powder, which was kept in desiccators until nutrient analyses were carried out. Leaf N content was determined using the Kjehldahl method. To determine leaf total P and K contents, the powder was extracted using H_2SO_4 + $HClO_4$, and then measured using a spectrophotometer and a flame-photometer, respectively. Leaf Ca and Mg were determined using an atomic absorption spectrometer. Leaf S content was determined using the turbidity comparison method (Tabatabai and Bremner, 1970).

Pest examinations (yellow leaf disease and mealybugs) were carried out monthly and the rate of infested plants was determined. Additionally, young fruit were counted on first order branches before the rainy season and, again towards harvest, giving rise to the fruit abscission rates. At harvest, the total yield was determined (Mg ha^{-1}). Black pepper quality traits, such as fresh/dry weight ratio, weight and volume of 1,000 acorns, and fruit density were determined. Piperine content in fruit was extracted and determined following Raman and Gaikar (2002). The evaluation of the economic efficiency included: total income (calculated according to yield); quality; current produce price in Million VND; total cost (including fertilizers); absolute profit; and, profit rate (%).

Table 1. Detailed description of fertilizer and available nutrients applied according to treatments.

Treatment	N		P		K			
	Urea	N	FMP	P_2O_5	MOP (KCl)	K_2O	Polyhalite	K_2O
	kg ha⁻¹							
T_1 (FP)	750	345	600	90	450	270	0	0
T_2 (control)	652	300	667	100	0	0	0	0
T_3	652	300	667	100	200	120	0	0
T_4	652	300	667	100	100	60	429	60
T_5	652	300	667	100	200	120	857	120
T_6	652	300	667	100	300	180	1,286	180

Note: FP = farmers' practice; FMP = fused magnesium phosphate (15% P_2O_5).

Table 2. Timing of fertilizer application during the year (% of the yearly dose).

Fertilizer	Jan-Feb	Mar-Apr	May-Jun	Jul-Aug	Sep-Oct	Nov-Dec
	%					
Urea	10	10	25	20	20	15
FMP	-	-	50	-	50	-
MOP (KCl)	10	10	15	20	20	25
Polyhalite	10	10	15	20	20	25

Note: FMP = fused magnesium phosphate.

Results and discussion

Leaf nutrient concentrations were monitored during the year, prior to and 20 days after each fertilizer application. Nitrogen and P leaf contents prior to fertilizer application in July were

2.85-2.91% and 0.13-0.14%, respectively - under the minimum threshold. Twenty days after fertilization, leaf N and P contents increased significantly to 3.16-3.21% and 0.17-0.18%, respectively, within or above the optimum range, in all treatments. Thus, the N and P fertilizer levels and the application regime practiced in the present study (300 kg N, 100 kg P_2O_5), as well as the farmers' practice (345 kg N, 90 kg P_2O_5), are quite suitable for black pepper cropping on reddish brown soil in Chu Se district, Gia Lai province.

The annual K dose was split into six applications during the year (Table 2). The effects of fertilizer treatments on leaf K contents were very similar in both years (Fig. 1). Pre-application leaf K contents were significantly lower than the minimum threshold of 3.4%. Post-application measurements revealed an obvious recovery in leaf K content in all treatments but the control, which continued to decline.

The provision of 120 kg K_2O ha^{-1} in treatments 3 and 4 considerably increased leaf K content; nevertheless, values remained below the minimum threshold for pepper. At this low K dose, no significant advantage for the 1:1 combination of KCL and polyhalite was observed. The higher K doses applied in T_1, T_5, and T_6, ranging from 240-360 kg K_2O ha^{-1}, brought post-application leaf K contents into the optimum range. Yet, even with the significant positive response to the rising K dose, leaf K contents remained substantially lower than the upper threshold of 4.3%.

The fluctuations in leaf K content, and particularly its decline below the optimum range, suggests that under the environmental circumstances in the Central Highlands of Vietnam, plants' opportunities for K uptake are too short to refill the nutrient holding capacity. This may also indicate that the agronomic efficiency of the K application regime can be further improved.

In addition to K, polyhalite is a source of S, Ca, and Mg. Prior to fertilizer application, leaf contents of these nutrients were below the minimum thresholds 0.09, 1.43, and 0.4% for S, Ca, and Mg, respectively, for all treatments (Fig. 2). Following the bimonthly fertilizer application in July, nutrient levels continued to decrease in treatments supplied solely with MOP and the unfertilized control (T_1-T_3). Whereas in plants supplied with combined MOP and polyhalite (T_4-T_6), leaf S, Ca, and Mg increased significantly, reaching but not exceeding the optimum range. Generally, the greater the polyhalite dose, the higher the corresponding nutrient content in the leaves. However, similar to the case of K, the effect seems transient and the plants possibly experience considerable fluctuations in leaf nutrient contents during the year.

Two major disorders quite often infest black pepper crops: the yellow pepper leaf (de Waard, 1986), and mealybugs (Tang Ton and Buu, 2011). The yellow leaf disease - named after its most noticeable symptom - is a multi-pathogen disease, which begins with a nematode (*Meloidogyne incognita*) attack that injures the roots, and continues with various fungi soil-borne opportunist pathogens such as *Fusarium* spp., *Phytophthora* spp., *Pythium* spp., etc. that cause root rot diseases. Once infected, the old leaves' veins turn yellow, a symptom which gradually expands to the whole pepper leaf. Consequently, infected plants shed leaves and stems, their canopy becomes scattered, and they die one to three years after infection. The disease has substantial effects on crop yield and quality as flowering, and fruit set and development, are significantly damaged. Mealybugs (*Pseudococcus citri*) attack

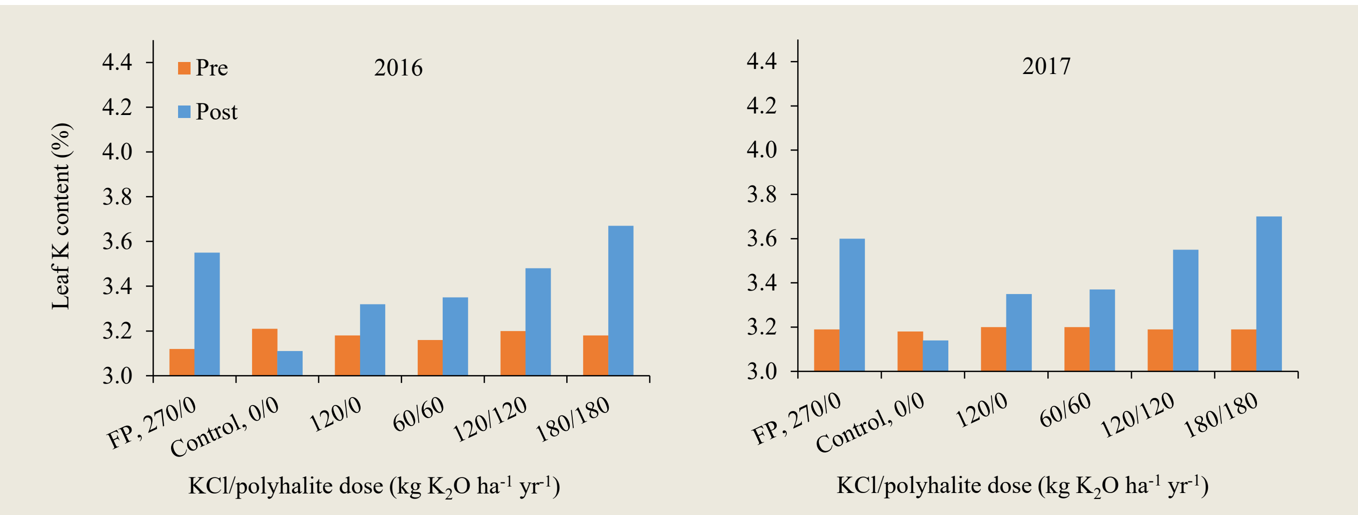

Fig. 1. Effect of KCl and polyhalite applications on pre- and post-application leaf K content in black pepper grown on acidic soil over two successive years, 2016 and 2017, in the Central Highlands of Vietnam. *Note:* FP = farmers' practice.

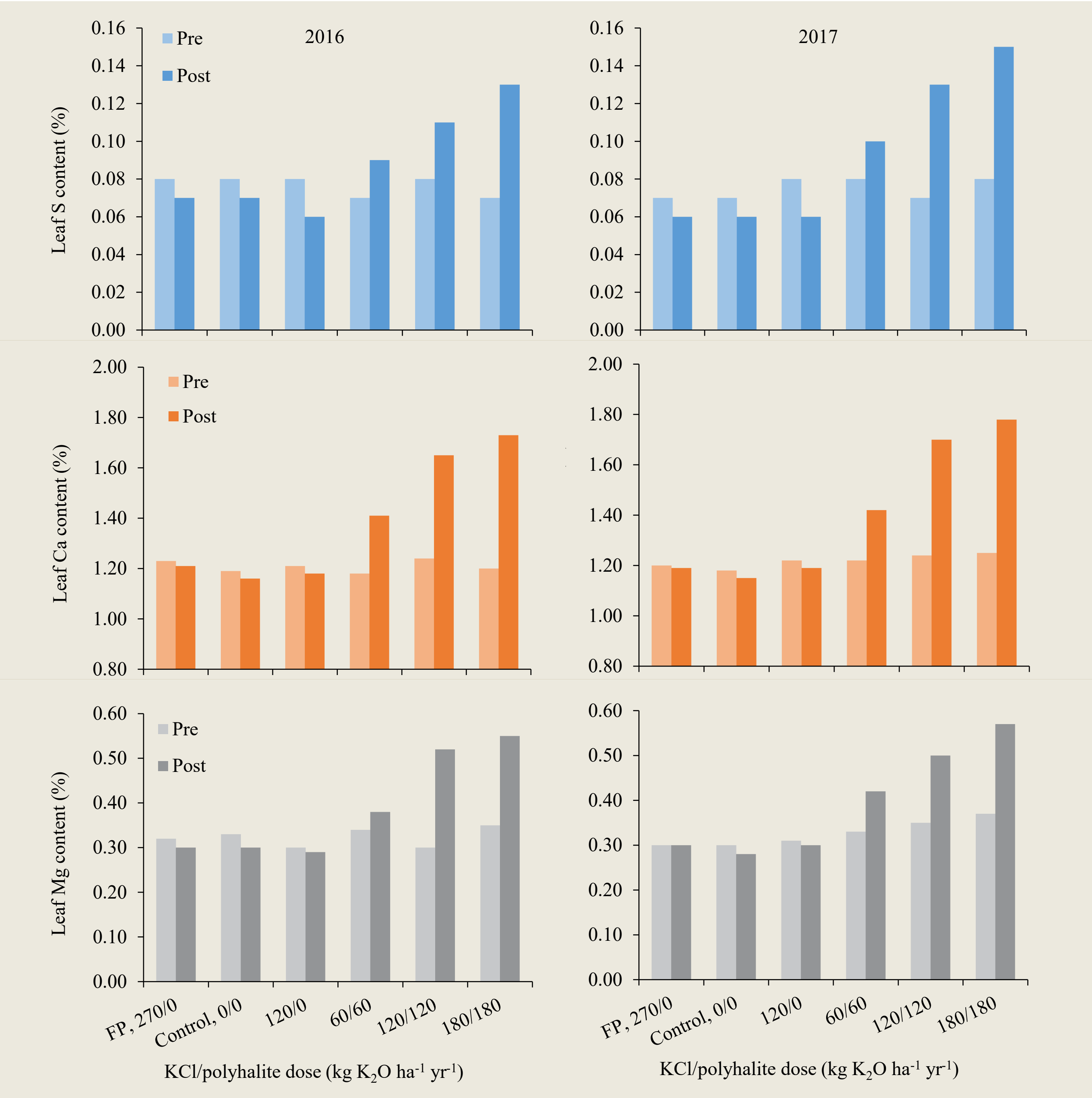

Fig. 2. Effect of KCl and polyhalite applications on pre- and post-application leaf S, Ca, and Mg contents of black pepper grown on an acidic soil over two successive years, 2016 and 2017, in the Central Highlands of Vietnam. *Note:* FP = farmers' practice.

weak plants and impact on their carbon and energy balance, and hence, reduce pepper fruit yield and quality. In addition, mealybugs are known as vectors of various plant virus diseases that negatively affect crop performance (Selvarajan *et al.*, 2016). A well-balanced crop nutrition is very efficient at preventing pests and diseases (Tang Ton and Buu, 2011).

In the present study, in both years, the basic rates of yellow pepper leaf disease were very low, leaving no room for any improvement by the fertilizer treatments (data not shown). In contrast, mealybug infestation rate in the control was 8-10% (Fig. 3). Potassium applications significantly reduced mealybug infestation rates in a dose-dependent manner. Furthermore, the results of treatments

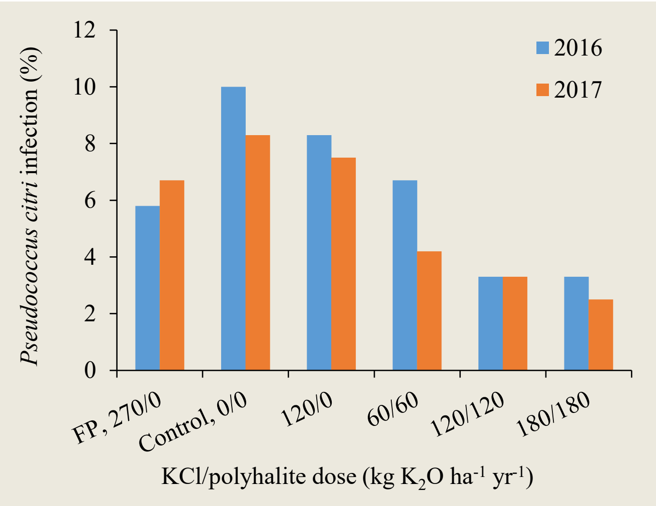

Fig. 3. Effect of KCl and polyhalite application on the rate of *P. citri* infection in black pepper plants. The experiment was conducted over two successive years, 2016 and 2017, in the Central Highlands of Vietnam. *Note:* FP = farmers' practice.

T_3 and T_4 may indicate that polyhalite application is more efficient than MOP in strengthening black pepper plants against mealybugs attack (Fig. 3). This indication is supported by recent findings demonstrating that S fertilization increases glucosinolate production in plant leaves (Bohinc *et al.*, 2012; Santos *et al.*, 2018) and subsequently, the plants' effectiveness against generalist insect pathogens rises significantly (Kos *et al.*, 2012).

Potassium applications significantly enhanced the vegetative growth of black pepper plants (Fig. 4). While the elongation of primary branches at the high K dose increased by 30%, compared to the unfertilized control, the number of secondary branches more than doubled, providing a substantially larger and stronger platform for the reproductive phase and consequently, for higher yield and better quality. Premature fruit abscission was dramatically reduced from 35% at the unfertilized control to 20% at the farmers' practice, which received 270 kg K_2O ha^{-1} yr^{-1}. Treatments T_3 and T_4, with a significantly lower K dose (120 kg K_2O ha^{-1} yr^{-1}), displayed higher fruit abscission rates, while at the higher K doses (240 and 360 kg K_2O ha^{-1} yr^{-1}), fruit shedding rates were further reduced to 16.9 and 16.2%, respectively (Table 3).

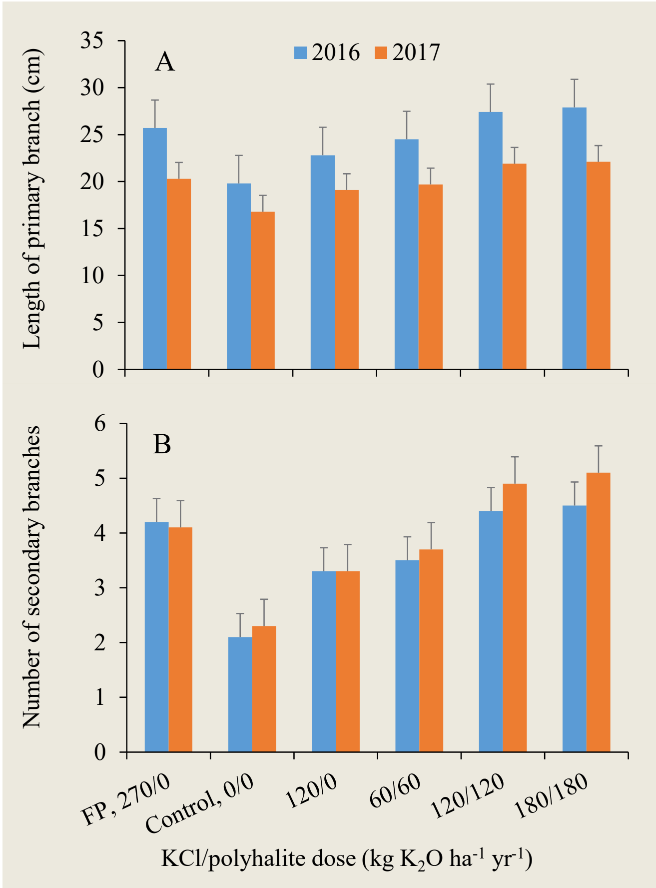

Fig. 4. Effect of KCl and polyhalite applications on the vegetative growth of black pepper plants. The experiment was conducted over two successive years, 2016 and 2017, in the Central Highlands of Vietnam. *Note:* FP = farmers' practice. Bars indicate $LSD_{0.05}$.

Black pepper yields of the unfertilized control in 2016 and 2017 were poor, 1.84 and 1.55 Mg ha^{-1}, respectively, significantly lower than in the other treatments (Fig. 5). MOP application at 120 kg

Table 3. Effects of K fertilizer type and dose on black pepper yield and quality traits.

Treatment	K-KCl	K-polyhalite	Fruit shed	Fresh/dry pepper	Fruit weight	Fruit volume	Fruit density	Piperine
	-----------*kg* K_2O *ha*$^{-1}$-----------		*%*		*g 1,000*$^{-1}$ *acorns*	*cm*^{3} *1,000*$^{-1}$ *acorns*	*g L*$^{-1}$	*%*
T_1	270	0	19.9	3.10	56.8	102.1	490	3.98
T_2	0	0	35.4	4.50	42.1	73.4	435	3.60
T_3	120	0	25.5	3.46	52.0	91.3	450	3.71
T_4	60	60	23.3	3.23	53.8	96.1	473	3.87
T_5	120	120	16.9	2.75	59.5	108.0	530	4.01
T_6	180	180	16.1	2.69	60.0	109.1	544	4.12
$LSD_{0.05}$			1.5	0.252	0.85	1.54	5.2	

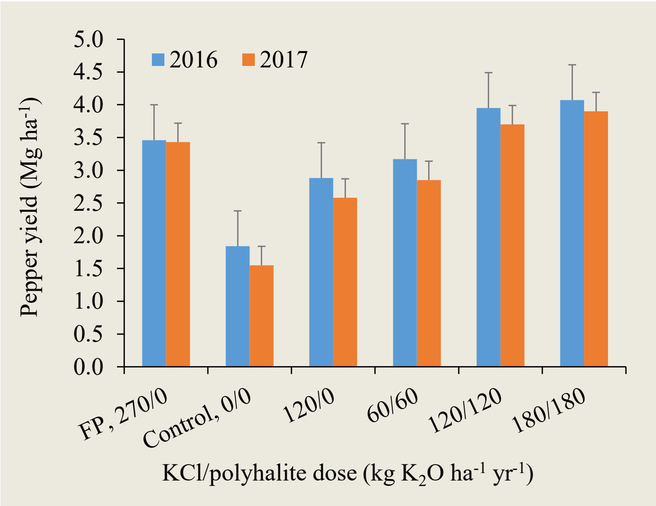

Fig. 5. Effect of KCl and polyhalite applications on black pepper yield. The experiment was conducted over two successive years, 2016 and 2017, in the Central Highlands of Vietnam. *Note:* FP = farmers' practice. Bars indicate $LSD_{0.05}$.

K_2O ha^{-1} yr^{-1} gave rise to significant yield increases of 56 and 66% more than the control, respectively. A similar dose, equally divided between MOP and polyhalite, had no further significant effects on yields. Farmers' practice, with a higher K dose of 270 kg K_2O ha^{-1} yr^{-1} applied as MOP, produced a much higher yield, averaging 3.45 Mg ha^{-1}. The greatest yields, ranging from 3.7 to 4.1 Mg ha^{-1}, were obtained at K doses of 240 and 360 kg K_2O ha^{-1} yr^{-1}, which were equally split between MOP and polyhalite (Fig. 5). There was no significant difference in yields between these two doses, suggesting that, at least under the circumstances of the present study, a yearly dose of 240 kg K_2O ha^{-1} would be sufficient. When compared to the farmers' practice, the advantage of polyhalite becomes obvious: a smaller K input of 240 kg K_2O ha^{-1}, 50% of which originated from polyhalite, resulted in 8-14% more yield than obtained at 270 kg K_2O ha^{-1} applied with MOP.

Economic analyses, based on the current costs, yield and produce quality and the consequent estimated income, showed that K application doses above 240 kg K_2O ha^{-1} provide maximum absolute and relative profits (Fig. 6). Lower K doses yielded significantly poor profits, while lack of K supply led to loss of money. A comparison between MOP alone, and in combination with polyhalite, at a relatively low K dose (120 kg K_2O ha^{-1}) indicate an advantage for combined fertilization. Furthermore, the combined MOP and polyhalite at the doubled dose (240 kg K_2O ha^{-1}) was more profitable than the farmers' practice, at 270 kg K_2O ha^{-1} (Fig. 6). These results confirm recent results obtained with other crops grown on acid soils in Vietnam (PVFCCo, 2016a; PVFCCo, 2016b; Tam *et al.*, 2016), and in Brazil (Vale and Sério, 2017; Bernardi *et al.*, 2018) that have demonstrated the agricultural and economic advantages of using polyhalite as a source of K, Ca, Mg, and S.

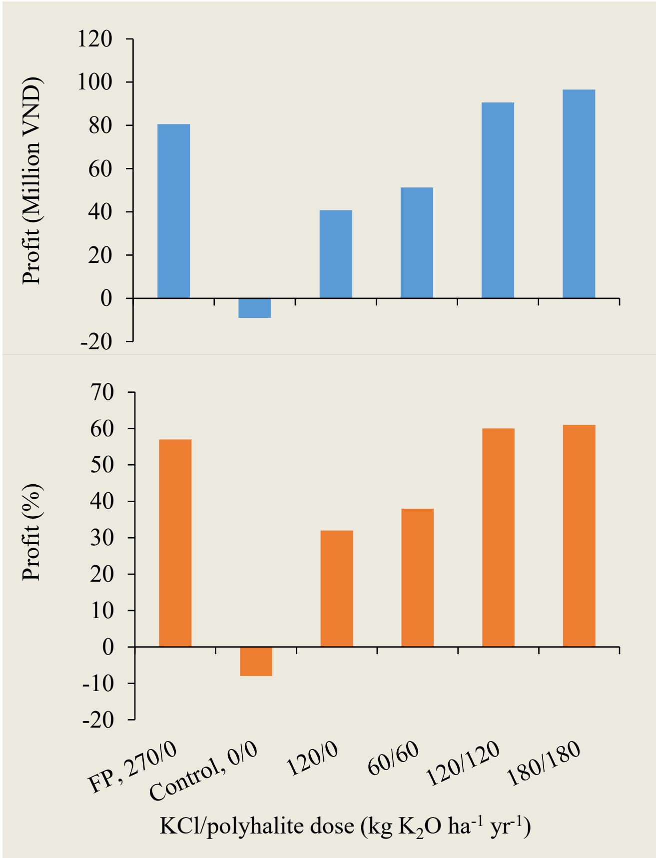

Fig. 6. Effect of KCl and polyhalite applications on the absolute and relative profit from black pepper grown on an acid soil in the Central Highlands of Vietnam, in 2017. *Note:* FP = farmers' practice.

Conclusions

The results of this study demonstrate the pivotal role of K application in black pepper cultivation on acid soils. Splitting the K dose into bimonthly applications brought leaf K contents to the required range. Polyhalite application can partially replace MOP as the K source and, furthermore, polyhalite provides the crop with other essential nutrients such as Ca, Mg, and S. The supplemental nutrients strengthened the black pepper vines against mealybug attacks, supported better crop performance, and significantly improved yield and produce quality, resulting in higher profits. However, the exact contribution of polyhalite to soil nutrient status requires further research.

Acknowledgements

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Photo 3. Measurement of black pepper development. Photo by the authors.

Photo 4. Ca and Mg deficiency in black pepper leaf. Photo by the authors.

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Regional activities/Southeast Asia

Research Findings

Photo 1. A field trip to a sugarcane demonstration plot at Kamta Maharajganj, Uttar Pradesh, India. Photo courtesy of Potash for Life, India.

The Impact of Potassium Fertilization on Sugarcane Yields: A Comprehensive Experiment of Pairwise Demonstration Plots in Uttar Pradesh, India

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Abstract

Degradation of soil fertility due to significant nutrient demands by crops and imbalanced fertilizer application is very common in the arable lands of Uttar Pradesh, India. While practices of nitrogen (N) and phosphorus (P) application have been established and disseminated, potassium (K) crop and soil requirements are almost ignored. Sugarcane (*Saccharum officinarum* L.) is among the most important cash crops grown in Uttar Pradesh, however, productivity is low compared to its well-demonstrated potential. This study aimed to evaluate and demonstrate the principal contribution of K application in increasing sugarcane yield and profitability and to raise the awareness of stakeholders and growers of the vital need to develop balanced, K-inclusive fertilization regimes for this crop. A comprehensive experiment was carried out during the seasons of 2014-2015 and 2015-2016 in seven districts of Uttar Pradesh, which included 161

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pairwise, control vs. K-applied, demonstration plot trials. The K-applied plots received a standard dose of 150 kg K_2O ha^{-1}, in addition to the common urea and di-ammonium phosphate (DAP) doses (175 and 80 kg ha^{-1} of N and P_2O_5, respectively). The additional K application resulted in a significant increase in sugarcane yield, from 62 to 71.4 Mg ha^{-1} the in control and K-applied plots, respectively. With an average yield increase of 9.35 Mg ha^{-1} (15.7%), and an average additional profit of 267,931 Rs ha^{-1}, the benefits arising from K application to the sugarcane grower are clear. However, significant differences in the control yields between eastern and western districts, and furthermore, considerable diversity in the yield response to K application in western districts highlights the significant impact that local conditions can have. While the K dose employed in the present study (150 kg K_2O ha^{-1}) can be recommended to sugarcane farmers in the short-term as a transient means to obtain higher yields and profits, further research is needed to determine appropriate K doses and application practices that ensure balanced crop nutrition, optimum fertilizer use, sufficient K availability, and sustainable soil fertility.

Keywords: K application; *Saccharum officinarum*; soil degradation; sugarcane yield.

Introduction

In India, agriculture forms the backbone of the economy, as it contributes a high proportion of the country's net domestic product (FAO, 2018). The ever-increasing demand for food, feed, and fibers, and the limitation of arable land necessitate not only novel practices of preserving, managing, and enriching natural resources, but also an up scaling of land-use-efficiency. Soil forms the basis for any crop production activity and is the most precious natural resource. Declining soil fertility is one of the primary factors that directly affects crop productivity (Prasad and Power, 1997; Pathak *et al*., 2010; Singh *et al*., 2012; Dey *et al*., 2017). Therefore, soil fertility management is crucial to ensure productivity and nutritional security, while maintaining soil health and sustainability.

Fertilizer-use is a key factor in ensuring soil fertility and productivity (Ramamurthy *et al*., 2017). Fertilizers are one of the costliest inputs in agriculture; and yet, if used correctly, they can be one of the most profitable. Imbalanced use of fertilizers not only afflicts nutrient use efficiency; it also deteriorates soil quality (Wallace, 2008). Therefore, balanced fertilizer use must be encouraged, as it is the only way to prevent soil fertility decline due to poor nutrient replenishment, or to repair soil quality deterioration caused by former excess or imbalanced nutrient application (Yadav, 2006).

India is the second largest producer of sugarcane (*Saccharum officinarum*) in the world (FAO, 2018). Thus, sugarcane is one of the most important cash crops in India, influencing the overall socio-economic development of the farming community (Nandhini and Padmavathy, 2017). Cultivation of sugarcane in India dates back to the Vedic period. The earliest mention of sugarcane cultivation is found in Indian writings dated to about 1400-1000 B.C. (Galloway, 2005). Currently, sugarcane makes up about 7% of the total agricultural output value and occupies about 2.6% of India's gross cropped area (FAO, 2005). Sugarcane also provides raw material for the second largest agro-based industry after textiles, supporting more than 500 sugar factories with a total annual sugar production capacity of about 24.2 million Mg (DSD, IMOA, 2013).

Saccharum is a monocotyledonous plant genus that belongs to the Gramineae family (Poaceae), order Glumaceae sub family Panicoidae, tribe Andripogoneae and sub tribe Saccharininea. The cultivated canes belong to two main groups: (a) thin, hardy north Indian types (*S. barberi* and *S. sinense*), and (b) thick, juicy noble canes (*S. officinarum*), which is the most economically viable. Sugarcane is a tall perennial plant growing erect up to 5-6 m and producing multiple stems. The plant is composed of four principal parts: root system, stalk, leaves and inflorescence. Sugarcane is a C_4 plant, which is highly efficient at converting and storing solar energy into sucrose. The crop's global distribution is restricted to the warm strip between 37ºN and 31ºS, extending from tropical to sub-tropical zones. Sugarcane is a long duration crop, which produces huge amounts of biomass, requiring large quantities of water, and is typically grown in loamy soils. It has essentially four phases of plant development: germination, tillering, growth, and maturation/ripening. Optimum temperature for sprouting of stem cuttings is 32° to 38°C. Higher temperatures reduce the rate of photosynthesis, increase plant respiration, and productivity sharply declines. Under 25ºC, cane growth declines significantly and sucrose accumulation is favored. Low temperatures, in the range of 12-14°C, are desirable for ripening, though the plant is susceptible to frost. Sugarcane is also vulnerable to water logging and drought.

In India, sugarcane is cultivated all over the country from latitude 8 to 33ºN, excluding cold hilly areas. Indian sugarcane production is roughly divided between tropical and sub-tropical regions, which significantly differ in crop environment, management, and consequently in yield levels. In the sub-tropical zone, Uttar Pradesh is the leading state in sugarcane production area but second for yield levels (DSD, IMOA, 2013). Sugarcane farmers in Uttar Pradesh have faced additional challenges in recent years as weather patterns, droughts, and flooding have been more extreme. For example, spring and early summer temperatures have increased high above normal thresholds, with extended drought periods. The pattern of the monsoon season has also changed, with more flooding events. In addition, frost events have become more frequent.

Despite the environmental obstacles to production, the factors that are within the farmers' control and yet limit sugarcane production seem more urgent, and furthermore, resolvable. Principles, recommendations and practices of balanced N and P fertilization have been successfully disseminated among sugarcane farmers in Uttar Pradesh. However, K is often ignored. Potassium is essential in many aspects of plant life and development (Mengel, 2016). It is particularly important in carbon assimilation, sugar production, translocation, and accumulation, as K facilitates many other biochemical and physiological processes (Geiger and Conti, 1983; Stephen, 1985; Cavalcante *et al.*, 2015).

Sugarcane is special with regard to K requirements, as its main value comes from a quality aspect – sugar content. In order to ensure a high sugar content, K must be available whenever required during crop growth and development, preventing any physiological constraints that might inhibit sugar synthesis and storage (Orlando Filho, 1985; Kwong and Pasricha, 2002; Yadav, 2006; Shukla *et al.*, 2009; Medina *et al.*, 2013). Moreover, a high soil nutrient status should be preserved to maintain future sustainable use of the land. A balanced fertilizer input, which includes a considerable K dose, can therefore be a preliminary step in achieving these vital goals.

The objective of this study was to evaluate and demonstrate the principal advantage of K application in increasing sugarcane yield and profitability, despite the considerable native environmental heterogeneity of Uttar Pradesh state.

Map 1. District map of Uttar Pradesh. The districts where sugarcane trials took place are marked with stars. *Source:* http://parachinar.info/wp-content/uploads/2018/05/districts-of-uttar-pradesh-district-map-free-download.jpg

Materials and methods

Verification trials for sugarcane response to K application took place in seven districts of Uttar Pradesh: Muzaffarnagar, Bijnor, and Meerut (western districts), and Kushinagar, Maharajganj, Gonda, and Bahraich (eastern districts) (Map 1). The trials were conducted in the fields of different farmers in each district, totaling 161 demonstration plots throughout the state (Table 1). In each field, two similar plots of 0.4 ha each, laying side-by-side, were used as control and treatment, leaving a 1 m wide path between them.

Excluding K, each pair of plots received a similar fertilizer practice of urea and DAP. The N dose was 150 and 175 kg N ha^{-1}, and the P dose was 60 and 80 kg P_2O_5 ha^{-1}, in the western and eastern districts, respectively (Table 1). In addition, farmyard manure (FYM) was applied in eastern districts at doses ranging from 2-3.5 Mg ha^{-1}. While control plots received no K fertilizer, their corresponding neighbor plots were applied with 150 kg K_2O ha^{-1} as muriate of potash (MOP).

Different improved sugarcane cultivars were used in the trial according to local recommendations in each district or location. Pest management and other routine practices were also carried out following local recommendations. Meteorological information for the relevant districts and growing seasons was extracted from https://www.worldweatheronline.com/.

Due to the large scope of the study, sugarcane yield parameters included only processable cane biomass at harvest. Economic evaluations focused on the profit gained due to K application at each site; the cost of the additional K fertilizer was subtracted from the extra revenue obtained, using local current prices.

Statistical analysis was performed using pairwise t-tests, with a confidence level of 0.95. Data analysis was conducted in one block, comparing all 161 data points in the

Table 1. Detailed description of 161 sugarcane demonstration plot trials of K application vs. control in the 2014-2015 and 2015-2016 growing seasons in seven Uttar Pradesh districts.

District	Numbers of plots	Planting	Harvest	N dose	P_2O_5 dose	K_2O dose		FYM
						Trial	Control	
		---------------*Time*---------------		---------------------------------*kg ha⁻¹*---------------------------------				
Bahraich	6	Mar 2015	Mar 2016	175	80	150	0	+
Gonda	10	Mar 2015	Mar 2016	175	80	150	0	+
Kushinagar	35	Mar 2014	Mar 2015	175	80	150	0	+
Kushinagar	15	Mar 2015	Mar 2016	175	80	150	0	+
Maharajganj	35	Mar 2014	Mar 2015	175	80	150	0	+
Bijnor	20	Mar 2015	Mar 2016	150	60	150	0	-
Meerut	20	Mar 2015	Mar 2016	150	60	150	0	-
Muzaffarnagar	20	Mar 2015	Mar 2016	150	60	150	0	-

Note: FYM = farmyard manure.

whole state. In addition, the data set was dissected according to districts to elucidate some sources of variation.

Results and discussion

Potassium, applied as MOP (KCl) at 150 kg K_2O ha^{-1} - in addition to the common fertilization practices of urea, DAP, and manure - resulted in a significant increase in sugarcane yield. While the mean sugarcane control yield was 62 Mg ha^{-1}, the corresponding K-applied plots obtained 71.4 Mg ha^{-1}, on average (Fig. 1). With an average yield increase of 9.35 Mg ha^{-1} (15.7%), and an average additional profit of 267,931 Rs ha^{-1}, the benefits arising from K application to the sugarcane grower are clear. While, sugarcane yield levels of 72 Mg ha^{-1} correspond with the average in India, they are still far below those of many sugarcane-producing countries that reach 100-130 Mg ha^{-1} (FAOSTAT, 2016). Further analyses by this study elucidates some possible explanations to this gap.

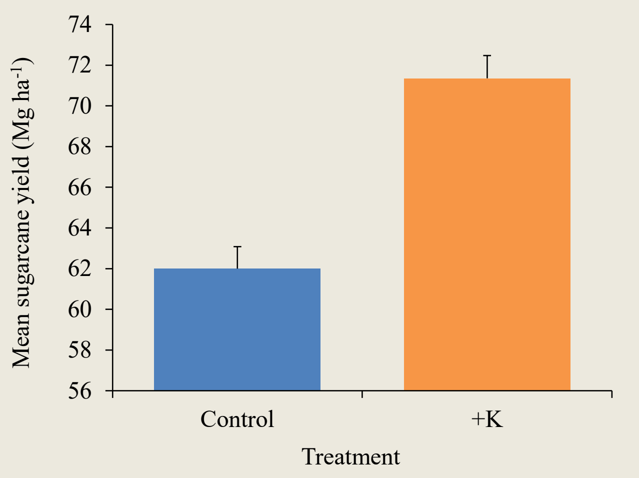

Fig. 1. Mean sugarcane control vs. K-applied yields. Values represent all 161 demonstration plots in seven districts of Uttar Pradesh. Bars indicate SE.

Yields from the control sugarcane plots that were not applied with K were clustered into two distinct groups; northeastern districts had significantly lower yields than in the northwestern districts (Table 2). This clustering pattern was less obvious in corresponding official yield averages (Table 2). The annual pattern of the daily average and extremum temperatures does not differ significantly between the western and eastern districts, where the active

Table 2. Sugarcane yields, dissected according to the Uttar Pradesh districts included in the study, and the effects of K application on the yield increase and the consequent profits.

District	Trial data				District means of annual yields*		FYM
	Control yield	Yield increase		Net profit	2013-2014	2014-2015	
	Mg ha⁻¹	*Mg ha⁻¹*	*%*	*KRs ha⁻¹*	----------------*Mg ha⁻¹*----------------		
Bahraich	51.9 ± 0.8	10.00 ± 0.56	19.3 ± 1.2	299.0 ± 16.8	56.0	57.7	+
Gonda	52.2 ± 1.4	8.71 ± 0.21	16.8 ± 0.5	260.3 ± 6.3	57.7	51.5	+
Kushinagar	53.3 ± 0.5	9.44 ± 0.32	18.5 ± 0.6	276.6 ± 9.3	59.8	60.2	+
Maharajganj	52.1 ± 0.9	8.65 ± 0.16	16.8 ± 0.5	253.5 ± 4.8	61.0	59.8	+
Bijnor	75.2 ± 1.2	7.90 ± 0.52	10.6 ± 0.7	221.2 ± 14.7	59.9	65.7	-
Meerut	79.6 ± 2.8	11.40 ± 1.14	14.4 ± 1.3	319.1 ± 31.8	71.2	78.5	-
Muzaffarnagar	76.2 ± 2.1	8.53 ± 0.72	11.3 ± 0.9	238.8 ± 20.1	72.9	71.9	-
Average	62.0 ± 1.1	9.35 ± 0.23	15.7 ± 0.4	267.9 ± 6.5	62.6	63.6	

Note: Values are means ± SE. FYM = farmyard manure. **Source:* http://upenvis.nic.in/Database/Sugarcane_Yield_1103.aspx.

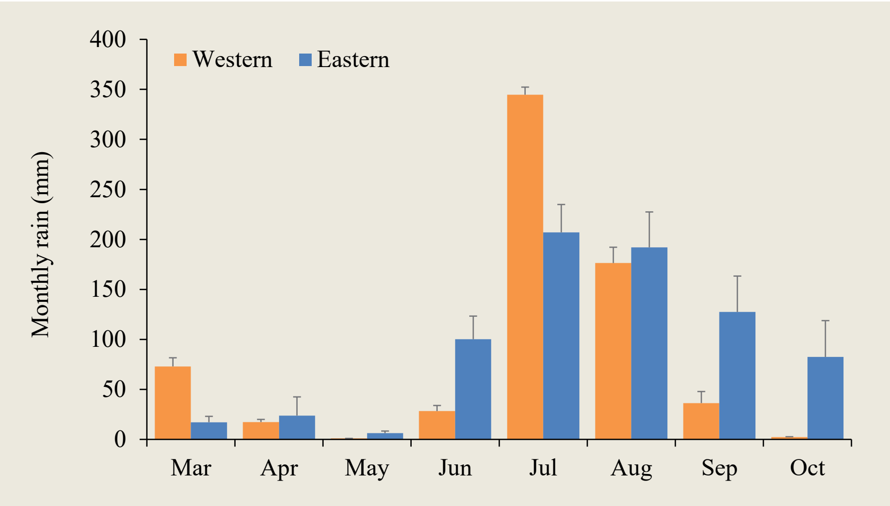

Fig. 2. Monthly rainfall in western and eastern Uttar Pradesh districts during the trial. Data extracted from https://www.worldweatheronline.com/.

sugarcane-growing season is restricted to 4-5 months only (July - November). In both regions, extremely high temperatures from April to June, significantly exceeding the optimum range of 32-38ºC for sugarcane photosynthesis and growth, probably interrupt early sugarcane developmental stages (germination, tillering, and growth). During December and January, temperatures then drop too low, quite often touching sub-zero levels (DSD, IMOA, 2013). In eastern districts, however, the monsoon period during the trial lasted two months longer than in western districts (Fig. 2). In the eastern lowlands (0-150 m above sea level), floods and water logging occur frequently during monsoon and restrict sugarcane growth (DSD, IMOA, 2013). This may provide an explanation for the lower sugarcane yields in eastern districts. Beyond this difference, it appears that sugarcane yields tend to fluctuate significantly from one year to another on a local basis, probably due to transient extreme environmental conditions during sensitive stages of crop development.

Photo 2. A visit to the sugarcane demonstration plot at Muzaffarnagar, Uttar Pradesh, India, 2017.
Photo courtesy of Potash for Life, India.

A more detailed analysis of the trial results (Fig. 3) provides interesting information regarding the effect of K application on the yield increase. The absolute yield increase was always positive, ranging from 5-25 Mg ha^{-1} (Fig. 3A) but was very stable, as indicated by the proximity of the mean and the median, 9.35 and 9.04 Mg ha^{-1}, respectively (Fig. 3C). The absolute yield increase extremes were associated most strongly with the high control yields, while the main bulk around the median was distributed more evenly between the high and low control yielding plots (Fig. 3A). On the other hand, the relative yield increase displayed a much wider distribution, from 6-35%, with 15.7 and 15.8% as the mean and median, respectively (Fig. 3B and D). As may be expected, the majority of the lower edge of the yield increase distribution was associated with the high control yields, while plots with low control yields were characterized by higher relative yield increases.

Figure 4 demonstrates the clear-cut split between the low-yielding eastern districts, and the high-yielding western districts. The control sugarcane yields ranged from 40 to 65 Mg ha^{-1} and from 65 to 110 Mg ha^{-1}, in eastern and western districts, respectively. In eastern districts, excluding very few exceptions, the yield increase in response to K application was very stable and close to the mean of 9.35 Mg ha^{-1} (Fig. 4A). Consequently, the relative yield increase dropped steadily from 25% to about 12% of the control yield as a function of the latter (Fig. 4B). In western districts, however, the yield increase scattered quite differently,

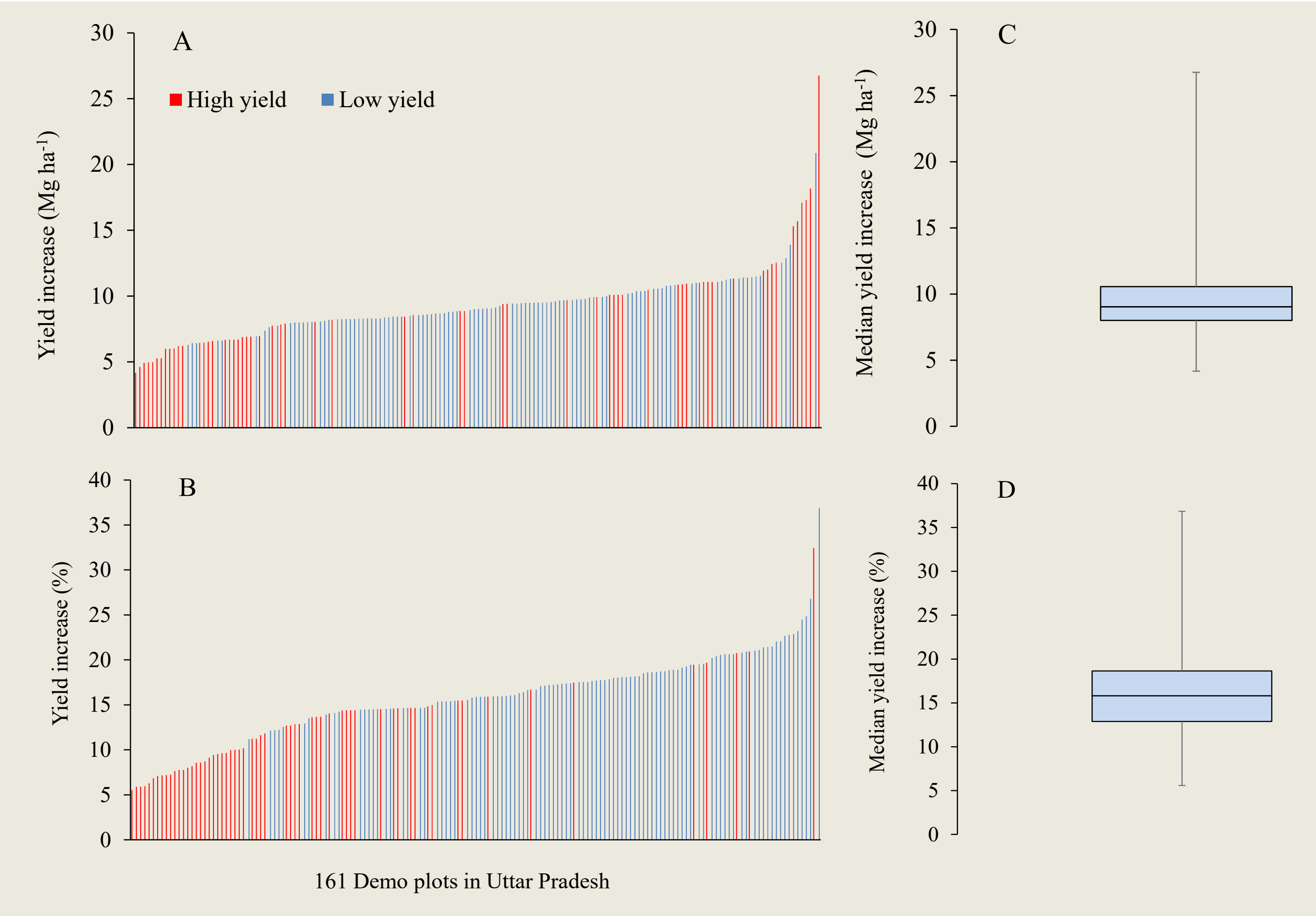

Fig. 3. Absolute (A) and relative (B) yield increase due to K application, presented in an ascending distribution among 161 demonstration trial plots in Uttar Pradesh, dissected according to high and low control yields. The corresponding statistical analyses (C and D) are presented as box plot diagrams, where the middle line represents the median, the upper and lower box edges represent the 25th and the 75th percentiles respectively, and the bars reach the maximum and minimum values.

displaying district-specific patterns (Fig. 4C). Both absolute and relative yield increases in Bijnor were the lowest (Table 2), showing a declining pattern as a function of the control yield (Fig. 4C and D). In Muzaffanagar, the yield increases split between a normal level of about 8-12 Mg ha^{-1}, which corresponded with those in eastern districts, and a lower level of about 4-7 Mg ha^{-1} that corresponded with yields in Bijnor. Meerut obtained the highest mean yield increase (Table 2), nevertheless, it resulted from extremely dispersed data, ranging from 7-27 Mg ha^{-1}, indicating the predominance of local conditions on sugarcane response to K application in this district.

The significant and straightforward effect of K application at every single site throughout the state, and in spite of considerable environmental differences, strongly demonstrates the pivotal role of this nutrient in sugarcane production. These results agree with many studies that demonstrated the significant contribution of K application to sugarcane yield and quality (Orlando Filho, 1985; Kwong and Pasricha, 2002; Yadav, 2006; Shukla *et al.*, 2009; Medina *et al.*, 2013; Kumawat *et al.*, 2016; Tran *et al.*, 2016; Ali *et al.*, 2018). The results also strongly confirm recent research highlighting the poor nutrient status of Uttar Pradesh soils, particularly regarding K availability (Singh *et al.*, 2012; Dey *et al.*, 2017; Patra *et al.*, 2017; Ramamurthy *et al.*, 2017). It is hoped that these results will lead to changes in the approach of the sugarcane industry regarding the vital need of K fertilization.

The diversity in control yields is not surprising. Considering the large scope of the study, including the geographic heterogeneity across Uttar Pradesh, different cultivars, local farmer practices, soils, seasons and year of harvest, control yield variation from 42 to 110 Mg ha^{-1} is quite normal. In contrast, the variation in the yield increase response was moderate and quite stable (Fig. 3). The relatively stable yield increase in response to fixed K application across a wide range of control yield, which occurred particularly in eastern districts (Fig. 4A), may suggest that K

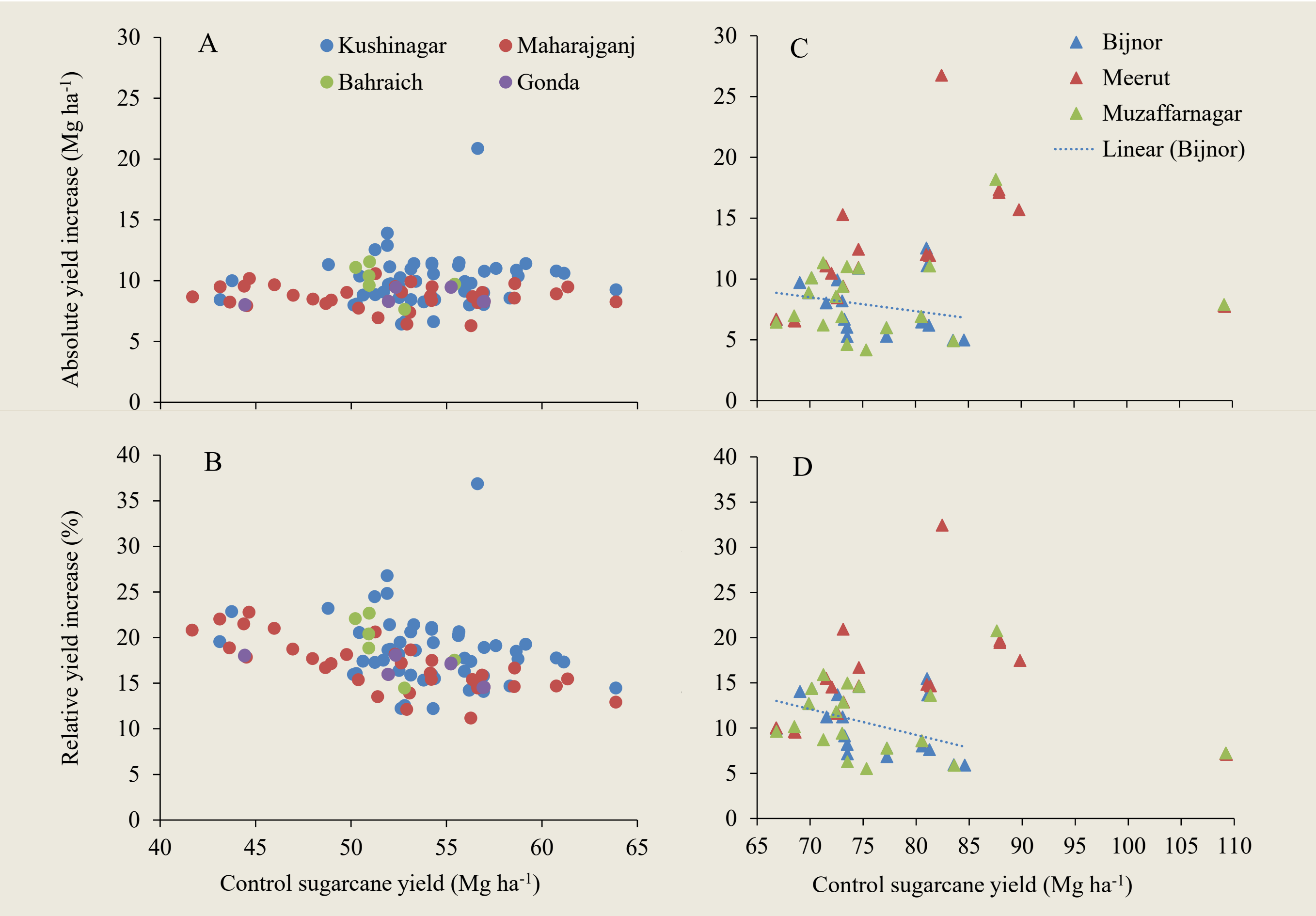

Fig. 4. The absolute (A and C) and the relative (B and D) sugarcane yield increase resulting from K application, as a function of the control yield in eastern (A and B) and western (C and D) districts of Uttar Pradesh that were included in the demonstration plot trials. The dotted line indicates the trend in Bijnor.

requirements were only partially met. A larger basal application might satisfy crop needs at earlier stages of development but completely disappear by the beginning of the monsoon season, leaving insufficient nutrient availability during the rest of the season, which is critical to sugar accumulation (Geiger and Conti, 1983; Stephen, 1985; Cavalcante *et al.*, 2015; Mengel, 2016). Therefore, further research is needed to optimize K application dose and timing, fitting it to crop requirements during the season and according to its developmental phases. The diversity in western districts was much greater (Fig. 4B), indicating significant differences between locations. In this case, the soil test yield-targeted approach (Velayutham *et al.*, 2016) could be useful in optimizing the procedure.

Conclusions

Potassium application, in addition to commonly applied N and P fertilizer, had an unequivocal effect, significantly increasing sugarcane yield over a broad scale of environmental heterogeneity throughout Uttar Pradesh. These results strongly indicate a critical need for the development of K fertilization practices aimed to increase sugarcane yield and profit in the state, as well as in neighboring sugarcane producing states. In the short-term, the K dose successfully employed in this study (150 kg K_2O ha^{-1}) can be recommended to sugarcane farmers as a transient means to obtain higher yields and profits. Nevertheless, further research is needed in order to determine appropriate K doses and application practices to ensure balanced crop nutrition, optimum fertilizer use, sufficient K availability whenever needed, and sustainable soil fertility.

Acknowledgements

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The paper "The Impact of Potassium Fertilization on Sugarcane Yields: A Comprehensive Experiment of Pairwise Demo Plots in Uttar Pradesh, India " also appears on the IPI website at:

Regional activities/India

A Short Report

Inspection of one of the Mavuno Zaidi demonstration plots. Photo courtesy of ICL Fertilizers, Kenya.

Mavuno Zaidi - Large-Scale Farmer Outreach has Increased Potato Yields in Kenya through a Focus on Balanced Fertilization

Mbuthia, L.W.[1]

Potatoes are considered to be the second most important food crop in Kenya after maize (MOA, 1998; Wang'ombe and van Dijk, 2013). However, potato yields in Kenya have remained relatively low averaging 11 to 14 Mg ha^{-1} compared to over 40 Mg ha^{-1} obtained by developed regions like North America (Wang'ombe and van Dijk, 2013). Low productivity has been attributed to several factors, including limited availability to disease free certified seeds, disease and pest infestations, low soil fertility, as well as low use of fertilizers and fungicides (Muthoni *et al.*, 2013; Wang'ombe and van Dijk, 2013; Muthoni, 2016).

With a focus on addressing some of the constraints, a large-scale farmer outreach program dubbed 'Mavuno Zaidi' - a Swhahili phrase that can be loosely translated as 'plentiful harvest' - was initiated in 2016, focusing on training farmers about good agricultural practices. The farmer outreach program was a partnership between Syngenta Kenya, a seed and agrochemical

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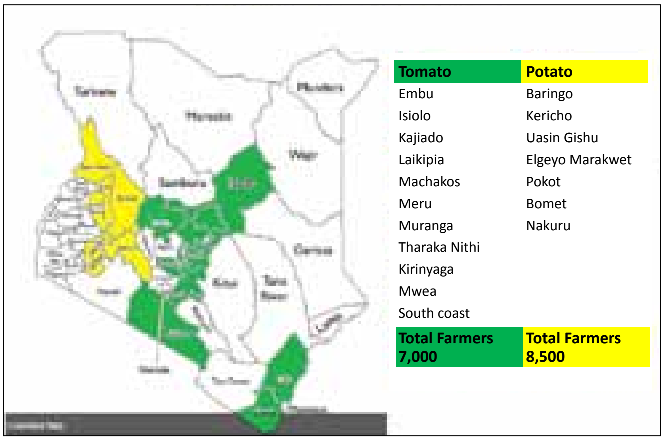

Map. 1. A map showing the different counties within Kenya covered under the 2016 Mavuno Zaidi project.

input supplier, and Israel Chemicals Ltd. (ICL), a producer and importer of fertilizers, and was implemented by Technoserve, a non-governmental organization (NGO) that serves small-scale farmers across Africa. The large-scale outreach program aimed to train up to 15,000 potato and tomato-producing small-scale farmers in 17 counties in Kenya (Map 1). Farmers were exposed to an integrated training program that encompassed business, agronomy and marketing skills. Syngenta offered agronomic expertise on seeds and crop protection, while ICL focused on soil fertility and crop nutrition, with Technoserve providing the training and implementing the project.

ICL identified unbalanced fertilization as one of the limiting factors to potato productivity in the country. In Kenya, farmers have relied on two main fertilizer products: Di-Ammonium Phosphate (DAP) which is NPK 18:46:0 and Calcium Ammonium Nitrate (CAN) which contains 26% nitrogen (N), limiting fertilization to just N and phosphorous (P). The current fertilizer recommendation for potato production is four 50 kg bags of DAP per acre which is equivalent to 500 kg ha^{-1} (KARI, 2008; Muthoni, 2016). Potassium (K) is a key nutrient for potato production but is hardly used because there is a widely-held belief that Kenyan soils are rich in K (Kanyanjua and Agaya, 2006). This has resulted in nutrient mining, and declining yields.

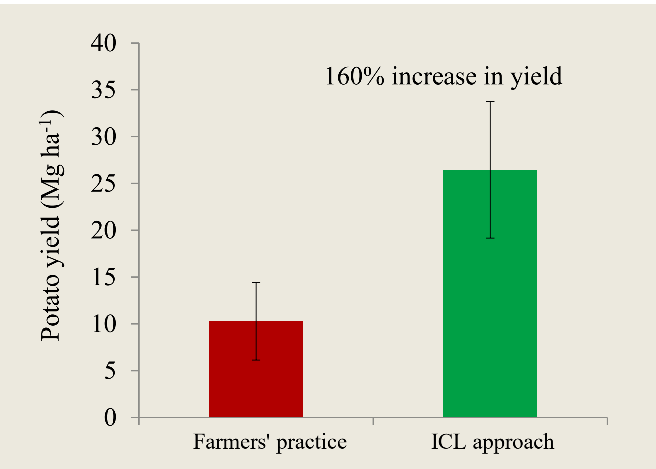

Fig. 1. A bar graph showing the difference in yield (Mg ha^{-1}) between farmers' practice (N: 150; P_2O_5: 225; K_2O: 0) and ICL's approach (N: 100; P_2O_5: 70; K_2O: 180).

While potato farmers in the region mainly use two to four 50 kg bags of DAP acre^{-1}, some farmers will also top dress with one to two 50 kg bags of CAN. This rate translates to 90-150 kg N ha^{-1} and 225 kg P_2O_5 ha^{-1}, with farmers yielding an average of 10-13 Mg ha^{-1}. Based on nutrient removals for a target yield of 30 Mg ha^{-1} using the AgPhD nutrient removal app, a balanced fertilization recommendation was developed, consisting of 90-100 kg N ha^{-1}, 60-70 kg P_2O_5 ha^{-1}, 170-180 kg K_2O ha^{-1}, 51 kg SO_3 ha^{-1} and 5 kg MgO ha^{-1}. The nitrogen fertilizer used in project demonstration plots was a control release fertilizer produced by ICL, where 30% of the N was coated with a polymer giving it a release period of two to three months. The coated fertilizer was also the source of SO_3 and MgO.

Results from 60 demonstration plots of 1,000 m^2 each, planted across seven counties in two season, yielded an average of 26 Mg ha^{-1}, varying between 20-33 Mg ha^{-1}. This compares to famers' traditional practices which on average yielded 10 Mg ha^{-1}, varying between 7-14 Mg ha^{-1} (Fig. 1). Soil analysis of the demonstration plots before planting showed that the K_2O level was above the adequate level needed for potato production, ranging between 400-840 ppm. It is therefore surprising that ICL's demonstrated practice was still able to show a good response to K. There is therefore a need to do further research on the soil analysis methods suitable for these soils, or review the limit levels for K for potato production in the region.

Conclusions

Despite the fact that the fertilizers introduced during the outreach program were more expensive than farmers normally used, a cost benefit analysis by ICL demonstrated the profitability of implementing balanced fertilization (Table 1). ICL calculated a value:cost ratio of USD 23 for every extra USD 1 spent on fertilizer under the ICL fertilizer regime. This was based on a two-fold increase in yield that resulted in farmers receiving USD 380 gross profit above their normal production (Table 1). In 2017, Syngenta approached one of the banks in Kenya to offer credit financing to farmers to enable them to purchase inputs. By October 2017, 1,200 farmers who had a farm size of 0.25 and 1 ha (a total of 770 ha) had signed up for the credit facility, enabling approximately 370 Mg of fertilizer to be distributed to them. The Mavuno Zaidi project was therefore not only successful in increasing farmers' yields but also in increasing farmers' knowledge of balanced fertilization.

Table 1. Analysis of the financial differences between farmers' practice and the ICL Mavuno Zaidi approach.

Parameter	Farmers' practice	Mavuno Zaidi (ICL approach)
Fertilizer ratio (kg ha^{-1})	N: 90-150 kg ha^{-1} P_2O_5: 225 kg ha^{-1} K_2O: 0 kg ha^{-1}	N: 90-100 kg ha^{-1} P_2O_5: 60-70 kg ha^{-1} K_2O: 170-180 kg ha^{-1} SO_3: 51 kg ha^{-1} MgO: 5 kg ha^{-1}
Fertilizer cost	USD 323-485 (15% of total outgoings)	USD 525-650 (7.5% of total outgoings)
Yield	10-14 Mg ha^{-1}	26-33 Mg ha^{-1}
Gross income	USD 2,300-3,200	USD 6,000-7,000
Value:cost ratio		USD 23 for every extra USD 1 spent on fertilizer

Photos 2. Potato demonstration plot. Photos courtesy of ICL Fertilizers, Kenya.

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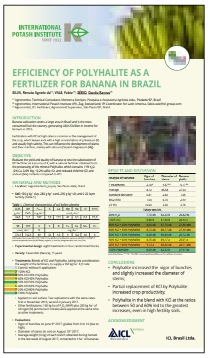
The paper "Mavuno Zaidi - Large-Scale Farmer Outreach has Increased Potato Yields in Kenya through a Focus on Balanced Fertilization" also appears on the IPI website at:

Regional activities/sub-Saharan Africa/Eastern Africa

Publications



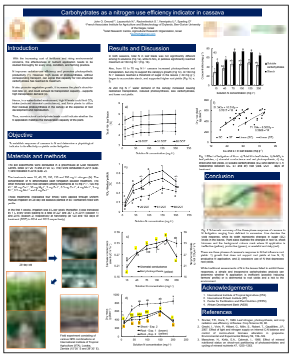
Efficiency of Polyhalite as Fertilizer to Banana Crop in Brazil

Poster by da Silva, R.A., F. Vale, and D.R. Sério

Banana cultivation covers a large area in Brazil and is the most consumed fruit in the country, generating USD 4.5 billion in income for farmers in 2016.

This poster, presented by R.A. da Silva at the "World Congress of Soil Science in Rio de Janeiro, Brazil, 12-17 August 2018", summarizes the results of an experiment to evaluate the results of substituting potash (KCl) fertilizer as a source of potassium (K), with a natural fertilizer obtained from the processing of the mineral polyhalite, which contains 14% K_2O, 12% Ca, 3.6% Mg, 19.2% sulfur (S), and reduced chlorine (Cl) and sodium (Na) contents compared to KCl.

The poster is available for download at the IPI website/Publications/Posters. For more details contact Dr. Fabio Vale, IPI Coordinator for Latin America.



Carbohydrates as a Nitrogen Use Efficiency Indicator in Cassava

Poster by Omondi, J.O., N. Lazarovitch, S. Rachmilevitch, U. Yermiyahu, and O. Sperling

With the increasing cost of fertilizers and rising environmental concerns, the effectiveness of nutrient application needs to be studied thoroughly for every crop, condition, and farming practice. This poster was presented at the "World Cassava Conference", 11-15 June 2018, in Cotonou, Benin, Africa, by J.O. Omondi.

The poster summarizes research to establish the response of cassava to nitrogen, and to determine a physiological indicator to its effectivity on yields under fertigation.

The poster is available for download at the IPI website/Publications/Posters. For more details contact Mr. Eldad Sokolowski, IPI Coordinator for China and SSA/Ethiopia.

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Nutrient Use Efficiency and Harvest Index of Cassava Decline as Fertigation Solution Concentration Increases

Omondi, J.O., N. Lazarovitch, S. Rachmilevitch, S. Boahen, P. Ntawuruhunga, E. Sokolowski, and U. Yermiyahu. 2018. J. Plant Nutr. Soil Sci. DOI: https://doi.org/10.1002/jpln.201700455.

Abstract: Response of cassava (*Manihot esculenta* Crantz) to fertigation as a form of nutrient delivery is unknown. The objectives of this study were to establish a balanced nutrition and to enhance agronomic nutrient use efficiency (ANUE) of cassava under fertigation. This study was conducted in the greenhouse and in the field. In both, the results showed a similar trend. There were six fertigation concentrations and three cassava varieties, selected for their duration of growth in the field. Shoot biomass of the long-duration variety (Nalumino) was the highest, even though its dry root yield was the lowest (10.18 t ha^{-1}) among the varieties. In contrast, the medium-duration variety (Kampolombo) produced the highest dry root yield (20.34 t ha^{-1}) and a lower shoot biomass. The highest root yield of the shortest-duration variety (Mweru) was achieved at 200 mg N, 30 mg P, and 200 mg K L^{-1} (155.0, 23.3, 155.0 kg N, P, K ha^{-1}), while Nalumino's was at 70 mg N, 7 mg P, and 70 mg K L^{-1} (54.3, 5.4, 54.3 kg N, P, K ha^{-1}). ANUE and harvest index of these varieties declined as the fertigation concentrations increased. Additionally, the correlation between concentrations of N in the youngest fully expanded leaf (YFEL) blades and dry root yields was the lowest ($R^2 = 0.5488$), whereas P and K were $R^2 = 0.7237$ and $R^2 = 0.8006$, respectively, an indication that nutrient concentrations in the leaf, especially N, cannot easily be used to predict root yield. When cassava reaches nutrient sufficiency, mainly N, its accumulation in the leaf continues without significant increase in the root yield.

Potassium may be a Key in Making Rice Plants more Tolerant to Drought

Bardhan, K. 2018. Rice Today.

Abstract: The availability of water is becoming an urgent factor in crop productivity in both developing and developed countries, particularly in drought-prone areas. One-third of the world's rice is cultivated in rainfed lowlands and 13% in upland rainfed fields where the lack of rainfall makes cropping impossible without irrigation.

In India, more than 60% of the arable land is in arid and semi-arid regions marked by a long dry season and inadequate and unpredictable rainfall. Drought can have a devastating effect on India's rice production because most farmers practice paddy culture. Therefore, identifying traits of rice that enable it to survive droughts, along with cropping management practices, that mitigate the impact of water scarcity are important research areas, particularly under the projected climate change scenarios.

Potassium: A Vital Regulator of Plant Responses and Tolerance to Abiotic Stresses

Mirza Hasanuzzaman, M.H.M. Borhannuddin Bhuyan, Kamrun Nahar, Md. Shahadat Hossain, Jubayer Al Mahmud, Md. Shahadat Hossen, Abdul Awal Chowdhury Masud, Moumita, and Masayuki Fujita. 2018. Agronomy 8(3):31. DOI:10.3390/agronomy8030031.

Abstract: Among the plant nutrients, potassium (K) is one of the vital elements required for plant growth and physiology. Potassium is not only a constituent of the plant structure but it also has a regulatory function in several biochemical processes related to protein synthesis, carbohydrate metabolism, and enzyme activation. Several physiological processes depend on K, such as stomatal regulation and photosynthesis. In recent decades, K was found to provide abiotic stress tolerance. Under salt stress, K helps to maintain ion homeostasis and to regulate the osmotic balance. Under drought stress conditions, K regulates stomatal opening and helps plants adapt to water deficits. Many reports support the notion that K enhances antioxidant defense in plants and therefore protects them from oxidative stress under various environmental adversities. In addition, this element provides some cellular signaling alone or in association with other signaling molecules and phytohormones. Although considerable progress has been made in understanding K-induced abiotic stress tolerance in plants, the exact molecular mechanisms of these protections are still under investigation. In this review, we summarized the recent literature on the biological functions of K, its uptake, its translocation, and its role in plant abiotic stress tolerance.

Importance of KUP8 for K^+ Uptake in Rooted Plantlets of *Elaeis guineensis* under K^+ Sufficient Conditions

Mohd Naqiuddin Husri, and Meilina Ong-Abdullah. 2018. South African J. Botany 118:65-75. DOI: https://doi.org/10.1016/j.sajb.2018.06.010.

Abstract: Potassium is a major nutrient essential for plant growth and development. Acquisition of this vital element and maintenance of K^+ homeostasis are complex processes, facilitated by an array of membrane transporters including carriers and channels. Key mediators of K^+ uptake are the KT/KUP/HAK family of transporters. The oil palm (*Elaeis guineensis*), is an agriculturally important crop, but the molecular mechanisms of nutrient acquisition in this plant are poorly understood. Here we report the full sequences of three KUP transporters, *EgKUP3*, *EgKUP8* and *EgKUP11*, from oil palm, obtained by a combination of database searching, PCR and 5' and 3' RACE techniques. Gene expression analysis of these three transporters was conducted on oil palm rooted plantlets at 7, 14, and 21 days after treatment with a range of KNO_3 concentrations: 0.2 mM, 10 mM and 20 mM of in root and leaf tissues. The results indicated *EgKUP8* expression is significantly upregulated in root tissues under K^+ depleted conditions (0.2 mM) at 14 and 21 days. In contrast, the expression of *EgKUP3* and *EgKUP11* was not sensitive to changes in external K^+ concentration. Functional complementation using Escherichia coli knockout strain defective in K^+ uptake systems revealed that all EgKUPs complemented growth at 50 mM K^+ concentration while EgKUP8 was also able to complement growth at 5 mM K^+ when tested at pH 7.5. In contrast, none of the EgKUPs were able to complement growth at pH 5.5 under all external K^+ concentrations tested. These observations may suggest that although EgKUP8 is less efficient at <5 mM K^+ and low pH condition (pH 5.5), at least, when expressed heterologously in *E. coli*, the escalated gene expression observed *in-planta* under similar environmental condition may be indicative of a more complex cellular role of EgKUP8 in K^+ uptake in plants. This piece of work provides the first insights into the molecular mechanisms of mineral uptake in the oil palm and provides a number of tools for further research in this area.

Growth, Physiology, and Biochemical Activities of Plant Responses with Foliar Potassium Application under Drought Stress - A Review

Zahoor Ahmad, Shazia Anjum, Ejaz Ahmad Waraich, Muhammad Ashar Ayub, Tanveer Ahmad, Rana Muhammad Sabir Tariq, Rashid Ahmad, and Muhammad Aamir Iqbal. 2018. J. Plant Nutr. 41(13):1734-1743. DOI: https://doi.org/10.1080/01904167.2018.1459688.

Abstract: Drought stress affects plant growth and ultimately yield is reduced. Potassium (K) is an essential macronutrient that is required to increase the growth and yield under drought. K plays an important role in osmotic adjustment, opening and closing of stomata, and enzymes activation. K is the component of plant structure that optimizes many physiological as well biochemical processes and ultimately improves the plant growth and yield. This review mainly covers the following topics: impact of drought on plant growth, physiological and biochemical characteristics, the role of K in plant growth, and physiology under drought stress. K is also responsible for enhancing the growth as well as yield attributes of crops under drought stress conditions by altering the physiological and biochemical process.

Effects of Nitrogen, Phosphorus, and Potassium on SPAD-502 and atLEAF Sensor Readings of *Salvia*

Dunn, B.L., H. Singh, M. Payton, and S. Kincheloe. 2018. J. Plant Nutr. 41(13):1674-1683. DOI: https://doi.org/10.1080/01904167.2018.1458874.

Abstract: There are various optical sensors in the market for precision nitrogen (N) management, which estimate leaf N status from chlorophyll content of leaves. However, readings may also be affected by the amounts of other nutrients in the plant leaves like potassium (K) and phosphorus (P), as well as sampling location within a plant or leaf. SPAD-502 and atLEAF optical sensors were used on *Salvia* 'Vista Red' plants grown with 0N-7.9P-0K, 41N-0P-0K, 0N-0P-31.6K, 0N-7.9P-0K + 41N-0P-0K, 0N-7.9P-0K + 0N-0P-31.6K, 41N-0P-0K + 0N-0P-31.6K, or 0N-7.9P-0K + 41N-0P-0K + 0N-0P-31.6K fertilizer plus a control. Both sensors were correlated with leaf N and each other. However, both sensor readings were affected by the presence or absence of P and K in the leaves, and thus these nutrients should be analyzed and reported along with leaf N values. Sensor readings were found to vary within a leaf and within leaf canopy location, so sampling needs to be consistent.

Plant Growth and Fruit Quality of Two Pepper Cultivars under Different Potassium Levels of Nutrient Solutions

Sedighe Mardanluo, Mohammad Kazem Souri, and Mohammad Ahmadi. 2018. J. Plant Nutr. 41(12):1604-1614. DOI: 10.1080/01904167.2018.1463383.

Abstract: Potassium (K) is a major nutrient element that has effects on growth, yield, and quality production of agricultural crops. In the present study, the effects of various K concentrations in a nutrient solution including 150, 235, 300, 400, or 500 mg K L^{-1} were evaluated on two pepper cultivars; chili pepper (*Capsicum annuum* Avicolare) and bell pepper (California Wonder) under greenhouse conditions. Hoagland's formula was used for preparation of nutrient solutions. The vegetative growth parameters including plant height, leaf area, SPAD value, and shoot fresh weight were significantly increased by 300 mg L^{-1} K in both cultivars. The highest yield and fruit quality parameters including fruit length/diameter ratio, fruit dry matter percentage, fruit vitamin C, total soluble solids, and titratable acidity in chili pepper and bell pepper were obtained under application of 300 and 400 mg K L^{-1} in nutrient solution, respectively. In either cultivar there was increase in leaf K, nitrogen, and zinc concentrations, while in bell pepper calcium was reduced by higher K levels in the nutrient solution. The results indicate that for better growth and quality production of pepper, higher levels of K in nutrient solutions can be beneficial.

Effect of Top-Dressed Potassium Fertilization on the Yield and Quality of Cucumber

Carla Verônica Corrêa, Aline Mendes de Sousa Gouveia, Bruno Novaes Menezes Martins, Natália de Brito Lima Lanna, Ana Emília Barbosa Tavares, Veridiana Zocoler Mendonça, Letícia Galhardo Jorge, Antonio Ismael Inácio Cardoso, and Regina Marta Evangelista. 2018. J. Plant Nutr. 41(10):1345-1350. DOI: 10.1080/01904167.2018.1447580.

Abstract: The current study aimed to evaluate the effect of top-dressed potassium (K) application on the production of hybrid cucumber "Sapphire." The experimental design was a randomized complete block, with five blocks of 0.80 × 0.40 m^2 each and eight replicate plants per block. The five fertilization rates of K used were 0, 45, 90, 135, and 180 kg K_2O ha^{-1}. Data collection consisted of the estimation of fruit diameter, fruit length, fruit fresh and dry weights, the number of fruits per plant, and the weight of fruits per plant. The number of fruits per hectare and the fruit fresh weight per hectare were calculated. Fruit tissue was analyzed for determination of macronutrient concentrations, pH, titratable acidity, soluble solids, sugar contents, and protein content. The data were statistically analyzed using regression analysis and analysis of variance (ANOVA). There was a significant effect of the fertilization rate of K on fruit diameter, fruit fresh and dry weights, macronutrients concentrations in fruits, titratable acidity, soluble solids, and reducing sugars. A quadratic equation was adjusted for the number of fruits per plant and per hectare; fruit yield per plant and per hectare, with maximum top-dressing doses, was estimated to be between 60 and 95 kg K_2O ha^{-1}. A linear increase was obtained in the pH. An increase in the K fertilization rate caused a linear decrease in the fruit length.

Cassava Yield and Economic Response to Fertilizer in Tanzania, Kenya and Ghana

Senkoro, C.J., F.M. Tetteh, C.N. Kibunja, K.W. Ndungu-Magiroi, G.W. Quansah, A.E. Marandu, G.J. Ley, T.J. Mwangi, and C.S. Wortmann. 2018. Agron. J. 110(4):1600-1606. DOI: 10.2134/agronj2018.01.0019.

Abstract: Cassava (*Manihot esculenta* Crantz) is a major food crop in Africa with little information of response to applied nutrients. Our objectives were to: determine cassava yield response to macronutrients for production areas in Ghana, Kenya and Tanzania; evaluate the effect Mg, S, Zn and B application; and determine agronomic efficiency (AE) and value cost ratio (VCR) for nutrient application. Fresh storage root yield with no fertilizer averaged 14.4 Mg ha^{-1} and mean yield increases due to 80 kg ha^{-1} N applied were 8.1, 6.5 and 9.0 Mg ha^{-1} in Ghana, Kenya and Tanzania. Storage root yield was increased 93% with P application for Aduma in Ghana and there was a curvilinear to plateau response to K at Wenchi Ghana. No other responses

to P and K rates occurred, but an N × P synergism occurred in Tanzania. There were no responses to applied Mg, S, Zn, and B. The VCR for N at all sites was >2 indicating sufficient profit opportunity to make N application attractive to many financially constrained farmers. The mean soil organic C (SOC) was 8 g kg^{-1}; the results may lose applicability with much higher SOC soils. Over all trials, application of 80 kg ha^{-1} N had, on average 8.44 Mg ha^{-1} increased yield with 105 kg kg^{-1} agronomic efficiency and 7.8 \$ $\$^{-1}$ profit to cost ratio. The results indicate that cassava is efficient in P and K uptake with restricted and little profit potential for P and K application in these countries, respectively.

Iron, Magnesium, Nitrogen and Potassium Deficiency Symptom Discrimination by Reflectance Spectroscopy in Grapevine Leaves

Rustioni, L., D. Grossi, L. Brancadoro, and O. Failla. 2018. Scientia Horticulturae 241:152-159. DOI: https://doi.org/10.1016/j.scienta.2018.06.097.

Abstract: This work aims at the identification and discrimination of mineral deficiency symptoms by reflectance spectroscopy. *Vitis vinifera* L. plants were subjected to 5 different hydroponic mineral nutrition: control and iron, magnesium, nitrogen and potassium deficiencies. Basal, young and apical leaves were studied. Spectra were collected along veins, in interveinal areas and in leaf margins. Reflectance spectroscopy appeared to be able to discriminate the mineral deficiencies, producing characteristic pigmentations and symptom distribution. These results appeared to be coherent with the physiological role of each nutrient. The most promising target in terms of leaf position and wavelengths of interest were identified for each condition. Mineral deficiencies also produced specific pigment distribution within the same plant, suggesting the possibility of symptom identifications also without the availability of well-fed control plants in field conditions. The reflectance spectral feature of the leaves could support the identification of mineral deficiencies in field conditions. These results could support further researches, including index development for symptom intensity quantifications and definition of threshold values for fertilization management. Due to the rapidity and low cost of the technique, future applications could support both technical requests and scientific researches.

Using Rootstock to Increase Watermelon Fruit Yield and Quality at Low Potassium Supply: A Comprehensive Analysis from Agronomic, Physiological and Transcriptional Perspective

Yaqin Zhong, Chen Chen, Muhammad Azher Nawaz, Yanyan Jiao, Zhuhua Zheng, Xianfeng Shi, Weiyan Xie, Yigeng Yu, Jia Guo, Shunhua Zhu, Min Xie, Qiusheng Kong, Fei Cheng, Zhilong Bie, and Yuan Huang. 2018. Scientia Horticulturae 241:144-151. DOI: https://doi.org/10.1016/j.scienta.2018.06.091.

Abstract: Grafting is a widely used technique in watermelon production. How grafting affects watermelon fruit yield and quality at low potassium supply and the mechanism remains unclear. This study addresses the question from agronomic, physiological and transcriptional perspective. Watermelon plants [*Citrullus lanatus* (Thunb.) Matsum. and Nakai, cv. Zaojia 8424], either self-grafted or grafted onto the rootstock 'Yongshi' (*Citrullus lanatus* sp.), 'Jingxinzhen No.1' (*Lagenaria siceraria* Standl.), and 'Qingyanzhen No.1' (*Cucurbita maxima* × *C. moschata*). Plants were subjected to 6.0 mM K (normal K) and 0.1 mM K (low K). Compared with plants treated with 6.0 mM K, those supplied with 0.1 mM K produced less fruit yield as indicated by the decrease in single fruit weight of all plants; however, a smaller decrease was observed in plants grafted onto 'Yongshi' (10%), 'Jingxinzhen No.1' (15%) and 'Qingyanzhen No.1' (19%) than the self-grafted watermelon (38%). The K^+ concentration of stem, leaf, fruit peel and flesh were obviously higher in the rootstock- grafted plants than in the self-grafted ones under 0.1 mM K. In addition, rootstock-grafted plants had significantly higher leaf zeatin riboside and chlorophyll content. Fruit quality, including contents of total soluble solid, sucrose, vitamin C, lycopene, β-carotene, were significantly decreased in the self-grafted plants under 0.1 mM K. However, 0.1 mM K treatment did not result in an obvious decrease in most of the measured fruit quality parameters in the rootstock-grafted plants. Fruit transcriptome analysis showed that there were 670, 27, 16 and 15 differential expressed genes (DGEs) responded to 0.1 mM K in the self- grafted, 'Yongshi', 'Jingxinzhen No.1' and 'Qingyanzhen No.1'-grafted plants, respectively, indicating that rootstock-grafting decrease the sensitivity of watermelon fruit to 0.1 mM K at the transcriptome level, GO and KEGG analysis showed that most of the DGEs were enriched in cellular metabolic process and metabolic pathways. Low K (0.1 mM K) significantly increased the gene expression of potassium channel (*Cla020934*), but decreased the gene expression of phytoene synthase (*Cla009122* - responsible for lycopene synthesis) in the fruit flesh of self-grafted watermelon. Taken together, the above results suggested that compared with self-grafted plants, watermelon grafted onto rootstock can enhance plant fruit yield, quality and decrease the sensitivity of fruit flesh transcriptome to low K. The mechanism of improved performance under low potassium is discussed.

Maintenance of Mesophyll Potassium and Regulation of Plasma Membrane H+-ATPase are Associated with Physiological Responses of Tea Plants to Drought and Subsequent Rehydration

Xianchen Zhang, Honghong Wu, Linmu Chen, Linlin Liu, and Xiaochun Wan. 2018. The Crop Journal. DOI: https://doi.org/10.1016/j.cj.2018.06.001.

Abstract: Drought stress is one of the main factors limiting yield

in tea plants. The plant cell's ability to preserve K^+ homeostasis is an important strategy for coping with drought stress. Plasma membrane H^+-ATPase in the mesophyll cell is important for maintaining membrane potential to regulate K^+ transmembrane transport. However, no research to date has investigated the possible relationship between plasma membrane H^+-ATPase and mesophyll K^+ retention in tea plants under drought and subsequent rehydration conditions. In our experiment, drought stress inhibited plasma membrane H^+-ATPase activities and induced net H^+ influx, leading to membrane potential depolarization and inducing a massive K^+ efflux in tea plant mesophyll cells. Subsequent rehydration increased plasma membrane H^+-ATPase activity and induced net H^+ efflux, leading to membrane potential hyperpolarization and thus lowering K^+ loss. A first downregulated and then upregulated plasma membrane H^+-ATPase protein expression level was also observed under drought and subsequent rehydration treatment, a finding in agreement with the change of measured plasma membrane H^+-ATPase activities. Taken together, our results suggest that maintenance of mesophyll K^+ in tea plants under drought and rehydration is associated with regulation of plasma membrane H^+-ATPase activity.

Influence of Co-Application of Nitrogen with Phosphorus, Potassium and Sulphur on the Apparent Efficiency of Nitrogen Fertiliser Use, Grain Yield and Protein Content of Wheat: Review

Duncan, E.G., C.A. O'Sullivan, M.M. Roper, J.S. Biggs, and M.B. Peoples. 2018. Field Crops Research 226:56-65. DOI: https://doi.org/10.1016/j.fcr.2018.07.010.

Abstract: The efficient capture and utilisation of fertiliser nitrogen (N) by cereals has implications for crop growth, grain yield, farm profits, the environment and human nutrition. Extensive research has evaluated many innovative ways to improve the efficiency of fertiliser N recovery (N use efficiency; NUE) by wheat (*Triticum aestivum*). This review paper, prepared as an outcome of a workshop by the Nutrient Use Efficiency in Wheat Expert Working Group of the Wheat Initiative held in Harpenden, UK in May 2017, is specifically focused on the effects of the co-application of fertiliser N with fertiliser phosphorus (P), potassium (K) and/or sulphur (S) on the efficiencies of capture and utilisation of fertiliser N and its accumulation in wheat grain, as this specific aspect of wheat nutrition was identified by the meeting as a major gap in knowledge. The contribution of P, K and S individually to grain yield has been reasonably well studied, and it is generally assumed that interactions between N and P, K and S will improve crop performance. However, a total of 32 field studies only have been published since 1963 that examine the effects of multiple nutrients on wheat yield and NUE, or changes in the apparent recovery of fertiliser N (% applied) in grain and its impact on grain protein content. The published data showed that NxP, NxK and NxS interactions led to improvements in NUE and the apparent grain recovery of fertiliser N, with the strongest effects generally coming from co-applications of N + P, followed by N + K then N + S treatments. Only five studies explored the combined or interactive effects of NxPxK, and just one considered either NxPxS or NxPxKxS. Grain yields were usually improved by applications of three (N + P + K) or four (N + P + K + S) nutrients in combination, but it was difficult to draw conclusions about effects on fertiliser N recovery and NUE because of the small number of studies, the variability in responses, and the lack of a N fertiliser alone comparative treatment. Grain protein content did not appear to be strongly increased by nutrient interactions, but it did not decrease with higher yields under N, P, K, S fertilisation suggesting that balanced nutrition may provide some protection against protein dilution as yields increase. The available literature suggested that ensuring balanced availability of P, K and S has the potential to reduce the rates of fertiliser N required by wheat because N appears to be accumulated in grain with greater efficiency. This would have both positive agronomic and environmental benefits.

Rosemary Growth and Nutrient Balance: Leachate Fertigation with Leachates Versus Conventional Fertigation

García-Caparrós, P., A. Llanderal, J.C. Rodríguez, I. Maksimovic, and M. Urrestarazu. 2018. Scientia Horticulturae 24:62-68. DOI: https://doi.org/10.1016/j.scienta.2018.07.024.

Abstract: The free discharge of drainage water from greenhouse horticultural production to the environment is a current environmental concern due to its capacity to contribute to environmental pollution. This has led to the search of sustainable alternatives for its reuse in the production of other crops. However, before the large-scale use of such horticultural leachates in ornamental plants, the effects of such fertigation treatments on ornamental plants need to be evaluated. Plants of rosemary were grown in pots with a mixture of sphagnum peatmoss and Perlite and subjected to three fertigation treatments: T_0 (a standard nutrient solution or control), T_1 (raw leachates from *Cucumis melo*) and T_2 (a mixture of raw leachates from *C. melo* and tap water 1:1 v/v), over a period of 9 weeks. At the end of the experiment, the growth parameters, color of leaves as well as water and nutrient uptake efficiencies and their losses were assessed for each fertigation treatment. The total dry weight and the water use efficiency of rosemary plants decreased under the fertigation with raw and diluted leachates. In addition, rosemary plants were shorter compared to the control but there were no differences in leaf color between the fertigation treatments. The uptake of N, P and K were affected by the applied fertigation treatments in a different manner. The use of horticultural leachates in the production of ornamental plants (as shown here for melon and rosemary) is feasible and presents a viable option to reduce water and nutrient input in plant production.

Potato Plants (*Solanum tuberosum* L.) are Chloride-Sensitive: Is this Dogma Valid?

Hütsch, B.W., K. Keipp, A.-K. Glaser, and S. Schubert. 2018. J. Science of Food and Agriculture 98(8):3161-3168. DOI: https://doi.org/10.1002/jsfa.8819.

Abstract:
BACKGROUND: Chloride sensitivity of the potato (*Solanum tuberosum* L.) cultivars Marabel and Désirée was investigated in two pot experiments (soil/sand mixture and hydroponics). It was tested whether there are differential effects of KCl and K_2SO_4 application on tuber yield and tuber quality, and whether both potato cultivars differ in their chloride sensitivity.
RESULTS: Tuber yield, dry matter percentage of the tubers, starch concentration and starch yield were not significantly affected by potassium source (K_2SO_4 or KCl). After exposure to salt stress in hydroponics (100 mmol L^{-1} NaCl, 50 mmol L^{-1} Na_2SO_4, 50 mmol L^{-1} $CaCl_2$) for 5 days, 3-week-old potato plants had significantly reduced shoot dry mass after NaCl and Na_2SO_4 application. However, $CaCl_2$ treatment did not significantly affect shoot growth, although the chloride concentration reached 65 to 74 mg Cl^- mg^{-1} dry matter, similar to the NaCl treatment. In contrast, growth reductions were closely related to sodium concentrations, thus plants suffered sodium toxicity and not chloride toxicity.
CONCLUSION: Both potato cultivars are chloride-resistant and can be fertilised with KCl instead of K_2SO_4 without the risk of depression in tuber yield or tuber quality. The statement that potatoes are chloride-sensitive and that chloride has negative effects on yield performance needs reconsideration.

Potassium Fertilization Improves Apple Fruit (*Malus domestica* Borkh. Cv. Fuji) Development by Regulating Trehalose Metabolism

Zhang, W., N.S. Zhang, J.J. Zhao, Y.P. Guo, Z.Y. Zhao, and L.X. Mei. 2017. J. Horticultural Science and Biotechnology 92(5):539-549. DOI: 10.1080/14620316.2017.1304165. DOI: https://doi.org/10.1080/14620316.2017.1304165.

Abstract: Potassium (K) fertilization and antioxidant enzymes both positively influence plant growth and development. However, it is not known whether K treatment improves fruit development via increasing soluble sugar. In this study, K-treated apple (*Malus domestica* Borkh.) fruit was harvested from 60 to 150 days after full bloom and was analyzed for ROS production and trehalose metabolism. The results show that K fertilization improved fruit firmness, increased growth according to several parameters, increased soluble sugar content, and decreased ROS production. The ascorbate metabolic pathway more effectively reduced ROS production than catalase and peroxidase (POD) did under K treatment. Trehalose-treated fruit also showed higher activity of ascorbate-related enzymes (DHAR, GR, and APX) compared with non-treated fruit. The changes of antioxidant enzyme activity in trehalose-treated fruit corresponded to those in K-treated fruit. Moreover, trehalase (TREH) activity in fruit was notably reduced by K treatment. This demonstrates that K influences ROS production via regulating trehalose content and TREH activity in fruit. This study provides new insight into the K mechanism which improves fruit development, including fruit firmness and size.

Potassium Fertilization of Timothy-Based Cut Grassland - Effects on Herbage Yield, Mineral Composition and Critical K Concentration on Soils with Different K Status

Lunnan, T., A.F. Øgaard, and T. Krogstad. 2018. Grass and Forage Science 73(2):500-509. DOI: https://doi.org/10.1111/gfs.12341.

Abstract: Herbage yield responses to K fertilizer application are variable in Norwegian grassland. Excessive K application may increase the risk of grass tetany (hypomagnesaemia) and milk fever (hypocalcaemia). We analysed a series of K fertilizer experiments on grassland with respect to their herbage yields and mineral composition. Our results show the importance of native soil K reserves when considering the need for K application. Soils with a high content of acid-soluble K showed no response to K fertilizer application. The critical K content in grass with respect to yield was estimated to be 17.7 g K/kg DM in the first cut and 20.3 kg K/DM in the second cut, while the critical K/N relationship was found to be 0.83 when a maximum yield reduction of 2.5% was used as a criterion. In these trials, soils with a high content of acid-soluble K had the greatest risk of grass tetany and the highest values of cation-anion balance. Application of potassium chloride had little effect on the cation-anion balance, and thereby the risk of milking fever, because there was a corresponding uptake of K and Cl ions.

Leaf Nutrients Ranges and Berry Yield Optimization in Response to Soil-Applied Nitrogen, Phosphorus and Potassium in Wild Blueberry (*Vaccinium angustifolium* Ait.)

Maqbool, R., D. Percival, Q. Zaman, T. Astatkie, S. Adl, and D. Buszard. 2017. Eur. J. Hortic. Sci. 82(4):166-179. DOI: 10.17660/eJHS.2017/82.4.2.

Abstract: The study examined the main and interactive effects of soil-applied fertilizers (nitrogen, phosphorus, and potassium) and optimum fertilizer rate for the vegetative and crop phases leaf nutrients and berry yields of wild blueberry (V*accinium angustifolium* Ait.). Data were collected between 2004 and 2010 from previous and ongoing nutrition studies that were laid out in a central composite design (CCD). Experimental sites were located at Kemptown and Mount Thom, Nova Scotia, and Brantville, New Brunswick (Canada). Treatments consisted of five levels of soil-

applied nitrogen (0, 12, 30, 48, and 60 kg N ha^{-1}), phosphorus (0, 18, 45, 78, and 90 kg P ha^{-1}), and potassium (0, 12, 30, 48, and 60 kg K ha^{-1}). Leaf nitrogen (N) and phosphorus (P) concentrations significantly increased with the addition of soil-applied N and P fertilizers, respectively. Leaf potassium (K) content in vegetative year had a significant quadratic response (convex shape) to soil-applied N and P. Leaf calcium (Ca) and magnesium (Mg) concentration exhibited significant concave quadratic (depression) response to soil added N, P and K. Nitrogen fertilizer significantly increased berry yields while soil-applied P and K had quadratic effects on berry yield. For commercial fields with similar soil nutrient levels, physical, biochemical and biological characteristics they recommend soil fertilizer rates of 30 kg ha^{-1} N, 40 kg ha^{-1} P, and 30 kg ha^{-1} K applied at pre-emergence of shoots in the vegetative year of production to optimize foliar nutrient levels and berry yields. They suggest new optimal vegetative year leaf nutrient ranges N (1.80-2.03%), P (0.155-0.160%), K (0.53-0.55%), Ca (0.44-0.46%), Mg (0.115-0.13%), and B (24-26 ppm) for wild blueberry fields in Atlantic Canada.

Effects of High Potassium and Low Temperature on the Growth and Magnesium Nutrition of Different Tomato Cultivars

Huixia Li, Zhujun Chen, Ting Zhou, Yan Liu, Sajjad Raza, and Jianbin Zhou. 2018. HortScience 53(5):710-714. DOI: 10.21273/HORTSCI12983-18.

Abstract: The interaction between potassium (K) and magnesium (Mg) in plants has been intensively studied. However, the responses of different tomato (*Solanum lycopersicum* L.) cultivars to high K levels at low temperatures remained unclear. Herein, a complete randomized hydroponic experiment was conducted to evaluate the effects of temperature (25°C day/18°C night vs. 15°C day/8°C night) and K concentrations (156 mg·L^{-1} vs. 468 mg·L^{-1}) on the growth and Mg nutrition of tomato cultivars Gailiangmaofen (MF) and Jinpeng No. 1 (JP). Compared with the control temperature (25°C day/18°C night), the low temperature decreased total biomass, shoot biomass, and Mg uptake in shoot by 17.3%, 24.1%, and 11.8%, respectively; however, the root/shoot ratio was increased. High K had no significant effect on plant growth or biomass compared with the control K concentration (156 mg·L^{-1}); however, Mg concentrations and uptake in shoot were significantly lower under high-K treatment. Significant difference was observed for K uptake, but not for Mg uptake, between the two cultivars. There was no significant interaction between temperature and high K on Mg uptake of tomato, so a combined stress of low temperature and high K further inhibited Mg uptake and transport. Low temperature and high K increased the risk of Mg deficiency in tomato.

Impact of Nutrient Supply on the Expression of Genetic Improvements of Cereals and Row Crops - A Case Study Using Data from a Long-Term Fertilization Experiment in Germany

Rueda-Ayala, V., H.E. Ahrends, S. Siebert, T. Gaiser, H. Hüging, and F. Ewert. 2018. Eur. J. Agron. 96:34-46. DOI: https://doi.org/10.1016/j.eja.2018.03.002.

Abstract: Impacts of nutrient supply and different cultivars (genotypes) on actual yield levels have been studied before, but the long-term response of yield trends is hardly known. We present the effects of 24 different fertilizer treatments on long-term yield trends (1953-2009) of winter wheat, winter rye, sugar beet and potato, with improved cultivars changing gradually over time. Data was obtained from the crop rotation within the long-term fertilization experiment at Dikopshof, Germany. Yield trends were derived as the slope regression estimates between adjusted yield means and polynomials of the first year of cultivation of each tested cultivar, when tested for more than two years. A linear trend fitted best all data and crops. Yields in highly fertilized treatments increased linearly, exceeding 0.08 t ha^{-1} a^{-1} for both, winter wheat and winter rye, and ≥0.30 and ≥0.20 t ha^{-1} a^{-1} for sugar beet and potato fresh matter yields. Yield trends of winter cereals and sugar beet increased over time at N rates ≥40 kg ha^{-1} a^{-1}, being 0.04-0.10 t ha^{-1} a^{-1} for cereals and 0.26-0.34 t ha^{-1} a^{-1} for sugar beet, although N rates >80 kg ha^{-1} a^{-1} produced a stronger effect. Nitrogen was the most influential nutrient for realisation of the genetic yield potential. Additional supply of P and K had an effect on yield trends for rye and sugar beet, when N fertilization was also sufficient; high K rates benefited potato yield trends. We highlight the importance of adequate nutrient supply for maintaining yield progress to actually achieve the crop genetic yield potentials. The explicit consideration of the interaction between crop fertilization and genetic progress on a long-term basis is critical for understanding past and projecting future yield trends. Long-term fertilization experiments provide a suitable data source for such studies.

Metabolite Profiling and Gene Expression of Na/K Transporter Analyses Reveal Mechanisms of the Difference in Salt Tolerance between Barley and Rice

Liangbo Fu, Qiufang Shen, Liuhui Kuang, Jiahua Yu, Dezhi Wu, and Guoping Zhang. 2018. Plant Physiology and Biochemistry 130:248-257. DOI: https://doi.org/10.1016/j.plaphy.2018.07.013.

Abstract: Barley (*Hordeum vulgare*) and rice (*Oryza sativa*) differ greatly in their salt tolerance, although both species belong to the Poaceae family. To understand the mechanisms in the difference of salt tolerance between the two species, the responses of ionome, metabolome and gene expression of Na and K transporters to the different salt treatments were analyzed using 4 barley and 4 rice genotypes differing in salt tolerance. In comparison with 4 rice

genotypes, four barley genotypes showed better plant growth, lower shoot Na concentration and higher K concentration at the 9 day after salt treatments. There was a dramatic difference in absolute expression levels of *SOS*, *HKT* and *NHX* family genes between barley and rice, which might account for their difference in Na/K homeostasis and salt tolerance. Moreover, rice leaves accumulated excess Na under salt treatments, which caused serious damages to physiological metabolisms based on metabolomic analysis, but barley leaves had lower Na concentration and small changes in the most metabolites. These results provide useful insights into the molecular mechanism in the difference of salt tolerance between rice and barley.

Read On

What are the Challenges Facing Modern Farming Around the World?

Boote, M. Global Farmer Network. 12 June 2018. Genetic Literacy Project (GLP).

Shifting the Limits in Wheat Research and Breeding Using a Fully Annotated Reference Genome

Appels, R. *et al.* 2018. The International Wheat Genome Sequencing Consortium (IWGSC), IWGSC RefSeq principal investigators. Science 361(6403), eaar7191. DOI: 10.1126/science.aar7191.

New Resource Can Help You Monitor Floriculture Nutrition

Sparks, B. 2 August 2018. Greenhouse Grower.

View On

Maize Fertilizer Application

How best to apply fertilizer on maize farm for optimum yield. Sponsored by Alliance for Green Revolution Africa (AGRA). 2018. https://youtu.be/e8cJJ8GYumA.

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