e-ifc

Electronic International Fertilizer Correspondent *(e-ifc)*
Quarterly publication from IPI

No. 48 | March 2017

INTERNATIONAL POTASH INSTITUTE
SINCE 1952

Optimizing Crop Nutrition

Editorial

Dear readers,

If only a fertilizer existed that fitted itself fully to crop's demands, farmers' lives would be so much easier. Most fertilizers sold worldwide contain only a single nutrient, or two, which are mainly those considered macroelements, nitrogen (N), phosphorus (P) and potassium (K). The NPK industry generally combines two to three macroelements to provide many different types of NPK fertilizers with various nutrient ratios.

Polyhalite, however, is quite different. This naturally occurring potash fertilizer is endowed with three additional 'secondary' nutrients - sulphur (S), magnesium (Mg) and calcium (Ca). As such, this complex fertilizer, provides a unique combination of nutrients.

Agronomists need to learn how to validate its benefits. Applying polyhalite in a field experiment poses a challenge in identifying its effect over the control, as any of the four nutrients may be affecting the crop tested, in accordance with soil and crop type. Moreover, polyhalite's unique solubility pattern allows, on the one hand, an immediate provision of nutrients and, on the other, prolonged nutrient availability compared to regular potash fertilizers. This also affects crops' response to polyhalite (e.g. peanut, *e-ifc* no. 47/Dec 2016; coffee, *e-ifc* no. 47/Dec 2016; tea, *e-ifc* no. 46/Sep 2016).

This complex fertilizer is also fascinating because polyhalite is a mineral mined from deep within the earth's crust and is available to be applied without any chemical reaction or process, providing steady and healthy nutrition to plants. The wonders of nature.

I wish you an enjoyable read.

Hillel Magen
Director

Photo cover page:
Polyhalite application in a greenhouse in Bet Ezra, Israel. Experiment on the effect of polyhalite applied as basal fertilizer in greenhouse tomatoes. Photo by ICL.

Research Findings

Soybean harvest in Brazil. Photo by ICL Brazil.

Introducing Polyhalite to Brazil: First Steps of a New Fertilizer

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Abstract

Being among the world's leading agricultural producers, Brazil imports and uses huge amounts of fertilizer, yearly. High soil acidity, adverse side-effects of liming and poor soil fertility challenge the efficacy of conventional fertilizers. Alternative options are required to overcome poor potassium (K) recovery in the soil, deprived calcium (Ca) and magnesium (Mg) mobility in the soil profile, and excess soil-chloride concentrations. Fertilizers also need to meet the crop demand for sulfate (SO_4^{2-}); soil levels of which gradually decline over time to below critical levels. An examination of polyhalite, an evaporate mineral comprised of S, Ca, Mg, and K, has revealed equivalent effectiveness in supporting the nutrient requirements of rice when compared to corresponding soluble salts. In a soybean field test, polyhalite showed enhanced Ca and Mg mobility in the soil profile, as well as equivalent effectiveness as a K-donor compared to potassium chloride (KCl). This report discusses the potential of polyhalite to contribute to the Brazilian agricultural production.

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Keywords: Acid soil; calcium; chloride; magnesium; potassium; soybean; sulfur.

Introduction

Due to continued population growth, worldwide demands for food, fibers, and energy are rapidly increasing. Therefore, agricultural resources, namely water and soil, must be rationally and carefully managed. In order to maintain or even increase the productivity of existing arable land, soil qualities should be preserved and enhanced through several elementary practices such as soil conservation management, soil amendment, crop rotation, use of crop varieties with high genetic potential, and efficient use of mineral fertilizers.

Brazil is among the leading producers of agricultural commodities (Table 1). In the recent decade (2006-2016), Brazilian agricultural production and export have displayed a consistent increasing trend, including for 'new' commodities such as wheat, potato, and peanut. This boost in production has resulted in increased fertilizer requirements. Consequently, the amount of fertilizer delivered to farmers in Brazil in 2015 reached 30.2 million tons, of which the share of potash fertilizer was considerably high at 29.2%. This figure indicates the significance of potassium (K) to crop production, but also raises questions regarding the efficacy of the common potash fertilizer, potassium chloride (KCl), when applied to most soils in Brazil.

KCl (or muriate of potash) dominates the Brazilian potash fertilizer market (ANDA, 2016) however, local KCl production comprises less than 6% of total consumption and the rest is imported. In 2015, the share of potash fertilizers other than KCl imported to Brazil was only 1%. Such alternative K sources include mainly potassium sulfate (K_2SO_4) and potassium magnesium sulfate (K-Mg-S) (SIACESP, 2016).

Potash fertilizers, other than KCl, are advantageous due to the absence of chlorine (Cl), which is suspected to negatively affect produce quality of important crops such as tobacco, potatoes, and pineapples. Furthermore, these alternative fertilizers provide additional nutrients such as sulfur (S), calcium (Ca), and magnesium (Mg) which are important to the nutritional balance of crops (Malavolta, 1980). Nevertheless, the production costs of most Cl-free potash alternatives are significantly higher than that of KCl, therefore increasing economic constraints.

Polyhalite is one of a number of evaporate minerals containing K. Polyhalite (dehydrate) is a single crystal complex, the chemical formula of which is $K_2Ca_2Mg(SO_4)_4 \cdot 2(H_2O)$, with a low impurity content (up to 5%), comprising mostly of sodium chloride. Polyhalite displays some slow-release characteristics, thus providing progressive nutrient availability to the soil. Evaluations carried out into soil columns by the University of Nottingham, UK, showed that 50-60% of polyhalite S was immediately available, while the remaining S was slowly released (Jiang *et al.*, 2016). Polyhalite mined and manufactured in the UK (Cleveland Potash Ltd.) typically consists of 14% potassium oxide (K_2O); 48% sulfur trioxide (SO_3); 6% magnesium oxide (MgO); and 17% calcium oxide (CaO). As a fertilizer comprising four key plant nutrients - S, K, Mg, and Ca - polyhalite provides a new solution to crop nutrition.

Early studies confirmed polyhalite's efficiency as a fertilizer. Polyhalite was equivalent to or better than sulfate of potash magnesia, and consistently better than KCl with or without Mg (Boratyński and Turyna, 1971). In a study by Barbarick (1989), the continuous cropping of sorghum-sudangrass in a greenhouse showed that polyhalite was as effective, or superior to, equivalent rates of soluble sources of K, Ca, Mg and S. More recent field studies demonstrated that polyhalite was as effective or better than gypsum for a number of cruciferous crops, such as rape oilseed in France (Dugast, 2015) and mustard (Tiwari *et al.*, 2015), cabbage and cauliflower in India (Satisha and Ganeshamurthy, 2016). Sesame and peanut yield and quality were improved in India (Tiwari *et al.*, 2015) and Vietnam (Tam *et al.*, 2016), respectively. Tea (PVFCCo (a), 2016) and coffee (PVFCCo (b), 2016) crops grown on acid tropical soils in Vietnam were also found to benefit from the use of polyhalite as a slow-release, multi-nutrient donating fertilizer.

The potential of polyhalite fertilizer and its relevance to Brazilian agriculture have thus far been inadequately addressed. The objectives of the present study were to: 1) assess the agronomic effectiveness of polyhalite as a nutrient donor in potted rice plants grown on Oxisol; 2) evaluate Ca and Mg mobility in the soil profile with polyhalite as the K-donor for soybean growth on no-tillage Oxisol, and; 3) discuss the possible contribution

Table 1. Agricultural production in Brazil in recent years (Data extracted from: http://www.indexmundi.com/agriculture/).

Commodity	World ranking	Production	Export	Harvested area	Year
		------------*1,000 MT*------------		---*1,000 ha*---	
Soybean oilseeds	1	102,000	58,400	33,800	2016
Green coffee	1	3,357	2,120	1,896	2017
Orange juice	1	885	885	480	2016
Sugarcane	1	739,300	24,350	9,080	2016
Corn	3	83,500	25,500	16,400	2016
Cotton	6	3,500	1,400	930	2016
Wheat	17	6,340	1,500	2,100	2016
Potato	21	3,935	-	131	2016
Peanut oilseeds	26	425	180	123	2016

of polyhalite to the nutritional solutions of important crops in Brazil.

Materials and methods

Potted rice experiment

The study was carried out in 2013 in a greenhouse located at São Paulo University in Piracicaba, Brazil. Oxisol soil, which has a very low clay content (88; 83; 829 g kg^{-1} of clay, silt and sand, respectively) and low organic matter and micronutrients content, was put into 4 dm^3 polyethylene pots. One month before fertilizer application, calcium carbonate ($CaCO_3$) and magnesium carbonate ($MgCO_3$) were added to raise soil base saturation (V%) to 50%. The trial was comprised of six treatments (Table 2) in four replications, in a completely randomized design.

Plants were harvested 78 days after fertilizer application, and the dry matter production and nutrient uptake were evaluated.

Table 2. Description of the treatments used in the potted rice experiment (after Vitti and Vale, 2013).

Treatment	K_2O	S	Ca	Mg	N + P_2O_5 + micronutrients
	-------Doses equivalent to kg ha^{-1}-------				
1. Control	-	-	-	-	+
2. No K, S, Ca, Mg	-	-	-	-	+
3. Granular polyhalite (1 g pot^{-1})	70	96	60	18	+
4. Soluble K, S, Ca, Mg salts	70	96	60	18	+
5. Granular polyhalite (2 g pot^{-1})	140	192	120	36	+
6. Polyhalite powder (1 g pot^{-1})	70	96	60	18	+

Evaluating nutrient mobility in the soil

The on-field trial was located in Sapezal, Mato Grosso state, Brazil, on Oxisol with a medium clay content (143; 72; 785 g kg^{-1} of clay, silt, and sand, respectively), and employed a completely randomized design comprising two fertilization treatments - KCl and polyhalite (Table 3). A month before soybean sowing, dolomitic limestone (2.5 Mg ha^{-1}) was applied and incorporated using a heavy harrow. On sowing, an onto furrow base fertilizer application of 200 kg ha^{-1} of mono-ammonium phosphate (MAP) was applied. KCl or polyhalite were then applied onto the top soil at V1 and V6 soybean developmental stages.

After harvest, the soil was sampled at the following depths: 0-5, 5-10, 10-15, 15-20, 20-30, and 30-40 cm, and analyzed for soil K, Ca, Mg and S contents.

Results

Potted rice experiment

Rice plants lacking the macronutrients K, S, Ca, and Mg displayed very poor development (Fig. 1). Soluble sources of these nutrients and granular or powder polyhalite application, enabled normal plant development.

Both granular and powder polyhalite displayed a similar effectiveness in supplying plants with K_2O, S, Ca, and Mg, when compared to soluble sources (Fig. 2). No toxicity or salinity problems occurred following normal or doubled polyhalite application.

Examinations of K, S, Ca, and Mg uptake in potted rice plants showed that the recovery of polyhalite-supplied K, S, and Mg was equal to that occurring in plants fertilized with the equivalent soluble sources (Fig. 3). Ca uptake by rice was significantly better under the soluble fertilizer, however, the availability of this nutrient from polyhalite was high and sufficient for normal plant development. Doubling the polyhalite dose resulted in a consequent increase in K uptake, a slight decrease in Ca uptake, and no response in rice S or Mg uptake (Fig. 3). These results, collated under greenhouse conditions, demonstrate the principal effectiveness of polyhalite as a fertilizer, even on low fertility soils.

Evaluating nutrient mobility in the soil

Limestone, applied to reduce soil acidity, enriches the shallow soil layer into which it has been incorporated with Ca and Mg. In no-tillage systems, where limestone is broadcast onto the soil surface without incorporation into the soil, Ca and Mg are concentrated in the top soil. This restricts the root system to a shallow soil layer, increasing plant susceptibility to transient water shortages and to consequent yield reduction under unstable precipitation regimes. It was interesting to compare the distribution of K, S, Ca, and Mg in the

Table 3. Description of the soybean experiment evaluating nutrient mobility in the soil (after Vale, 2016).

Treatment		Liming	Base fertilizer	Additional fertilization	
	Timing	A month before sowing	On sowing	First trifoliate (V1)	First flower (V6)
		Heavy harrow	Onto furrow	Top soil	
KCl		Dolomite limestone (2.5 Mg ha^{-1})	MAP (200 kg ha^{-1})	KCl (70 kg K_2O ha^{-1})	KCl (70 kg K_2O ha^{-1})
Polyhalite				Polyhalite (eq. to 70 kg K_2O ha^{-1})	Polyhalite (eq. to 70 kg K_2O ha^{-1})

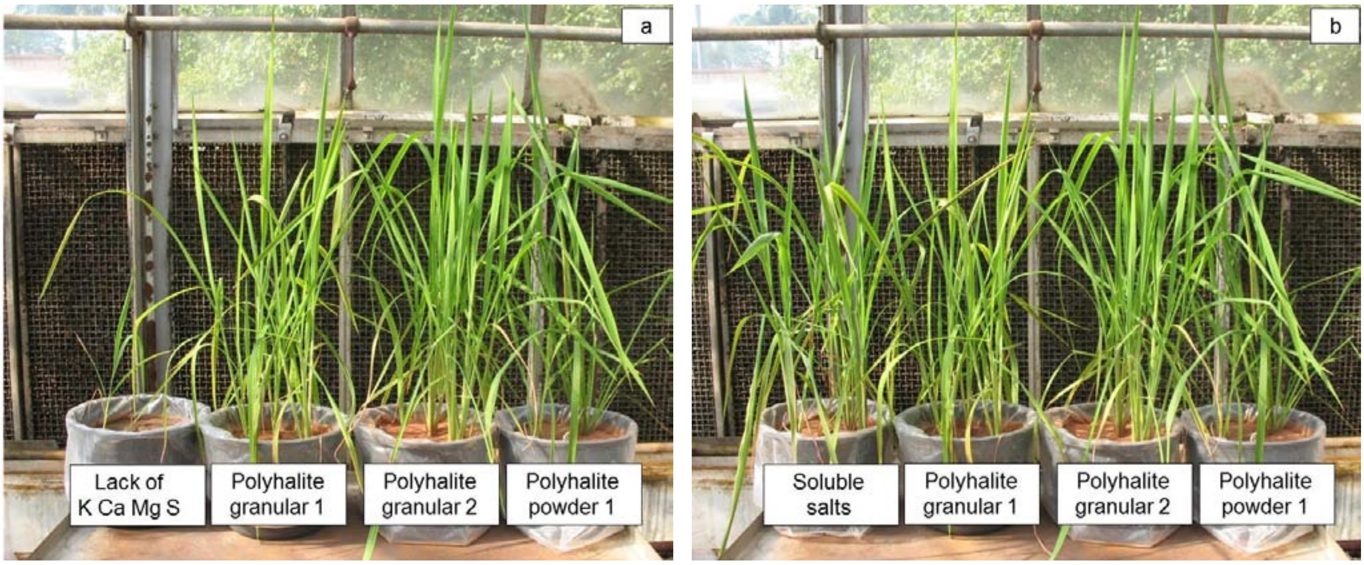

Fig. 1. Development of rice plants applied with polyhalite fertilizer in comparison with plants lacking K_2O, S, Ca and Mg (a), or with plants applied with soluble salts comprising equivalent nutrients (b).

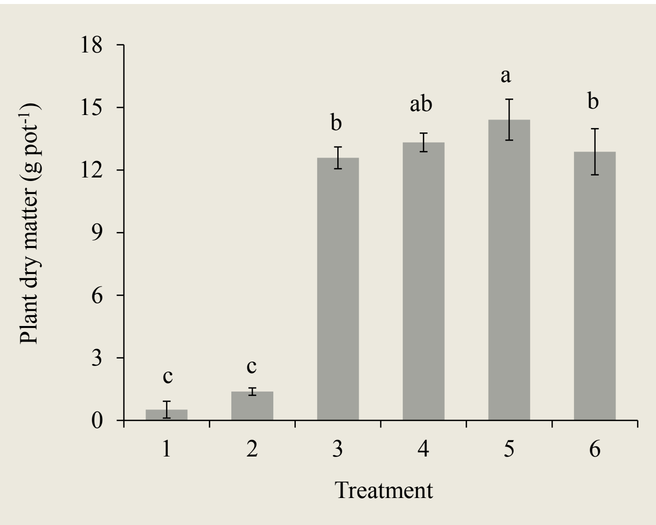

Fig. 2. Effect of fertilizer treatments on rice dry matter production. Treatments: 1. Control; 2. Lack of K, S, Ca, and Mg; 3. Granular polyhalite (1 g pot^{-1}); 4. Soluble K, S, Ca, and Mg salts; 5. Granular polyhalite (2 g pot^{-1}); 6. Powder polyhalite (1 g pot^{-1}). Different letters indicate statistically significant differences at P=0.05 (Duncan test). A detailed description of the treatments is available in Table 2.

soil profile of a soybean crop, following liming and fertilization treatments with KCl and polyhalite.

Limestone application increased Ca and Mg solely in the 0-10 cm layer, proportional to its mechanical incorporation. Compared to the KCl applied soil, polyhalite application resulted in a larger increase in Ca and Mg content throughout the soil profile; Ca content rose by 23% and 8% in the 0-20 and 20-40 cm layers, respectively, while the increments in Mg were of 25% and 17% for the same soil layers (Fig. 4).

Sulphate was the most mobile nutrient in the soil in both treatments, maintaining a narrow concentration range of 10-20 mg dm^{-3} throughout the examined soil layers (Fig. 4). While S contents were equal in the top soil layer, polyhalite significantly increased its concentrations in the deeper layers. In contrast, K content was significantly higher in the top soil, and markedly declined in soil layers deeper than 10 cm. No difference was observed in soil-K content between KCl and polyhalite applied soils (Fig. 4).

Discussion

Polyhalite potential for Brazilian agriculture

Added to the arsenal of available fertilizer, polyhalite may provide several alternative solutions to some chronic nutrition problems associated with Brazilian agriculture.

In Brazil, the current (2016/17) area of soybean, corn, wheat, and cotton crops is over 55 million hectares (CONAB, 2016). It is estimated that more than 75% of this area is cultivated under a no-tillage system in which limestone is applied superficially, without incorporation into the subsurface layers. The efficiency of surface limestone application onto no-tillage soil, particularly in the correction of soil acidity, is controversial. Studies of Brazilian soils indicate little or no limestone mobility deeper than the top soil layer (Gonzales-Erico *et al.*, 1979). Crops productivity under no-tillage systems is highly dependent on the fertility of a very shallow, 0-5 cm deep, soil layer, which is often characterized

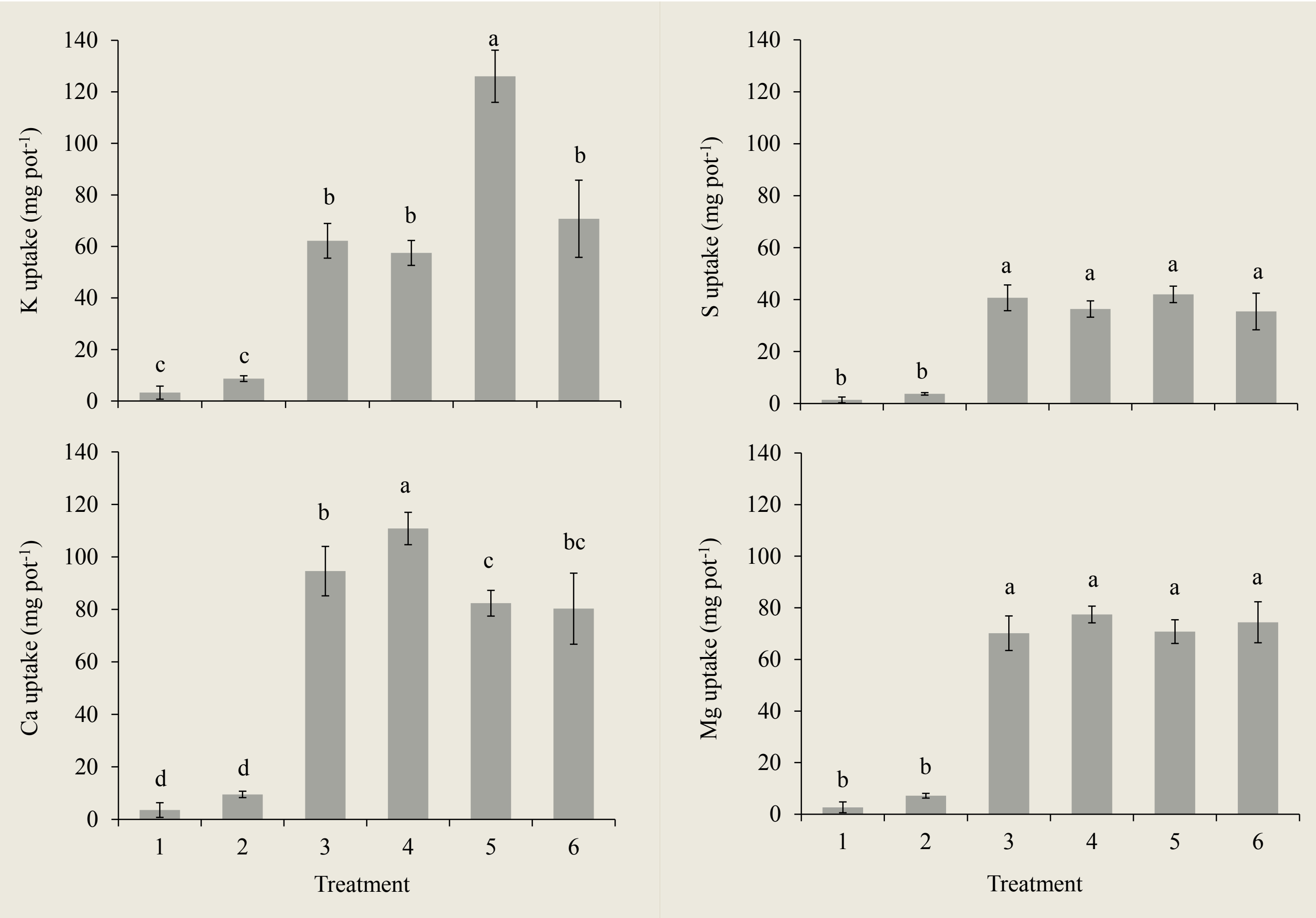

Fig. 3. K, S, Ca, and Mg uptake by potted rice plants in response to fertilization treatments on Oxisol. Treatments: 1. control; 2. lack of K, S, Ca, and Mg; 3. granular polyhalite (1 g pot^{-1}); 4. soluble K, S, Ca, and Mg salts; 5. granular polyhalite (2 g pot^{-1}); 6. powder polyhalite (1 g pot^{-1}). More details are provided in Table 2. Different letters indicate statistical significant differences at P=0.05 (Duncan test).

by a highly exchangeable Ca content base saturation, but also by high exchangeable toxic aluminum ions (Caires *et al.*, 2000). An evaluation of soybean plant development in several regions of Brazil has revealed that high grain yields, above 4.5 Mg ha^{-1}, are associated with prosperous root systems at depths below 40 cm. A thriving root system provides the plant with significantly greater access to deeper soil water and nutrient resources, thus supporting enhanced crop development and improved resistance to unfavorable weather conditions. However, such subsurface rooting is only possible with high soil fertility at a depth of 40-100 cm.

Calcium plays an important role in root growth and development. Deficiency in Ca supply at the root tip causes almost immediate disruption of its growth, followed by tissue blackening and cell death (Mengel and Kirkby, 2001). In addition, Ca is a virtually immobile element in the phloem (Marschner and Richter, 1974). Therefore, sufficient Ca availability at the root apex is crucial for crop development. Sako *et al.* (2015) found that an in-depth minimum threshold of 8 mmol$_c$ Ca dm^{-3} was required to allow the expression of high soybean productivity. The application of calcium sulfate ($CaSO_4$), suggested as the solution for the fixation of limestone to the upper soil layer, has improved Ca movement to deeper layers (Ritchie *et al.*, 1980). The soybean field trial presented here indicates that polyhalite has an adequate solubility to reach and promote the active crop rhizosphere when applied to the top soil (Fig. 4). Thus, polyhalite is a fertilizer with considerable potential to improve productivity of no-tillage systems, where soils exhibit significant Ca deficiency in the subsurface layers.

Sulfur has essential functions in plant development and crop quality, from participation in amino acid and protein formation to hormonal control, photosynthesis and plant defense mechanisms against pathogens (Vitti *et al.*, 2015). An evaluation of 8,500 soil samples in Brazil showed that 75% had low or very low S. The

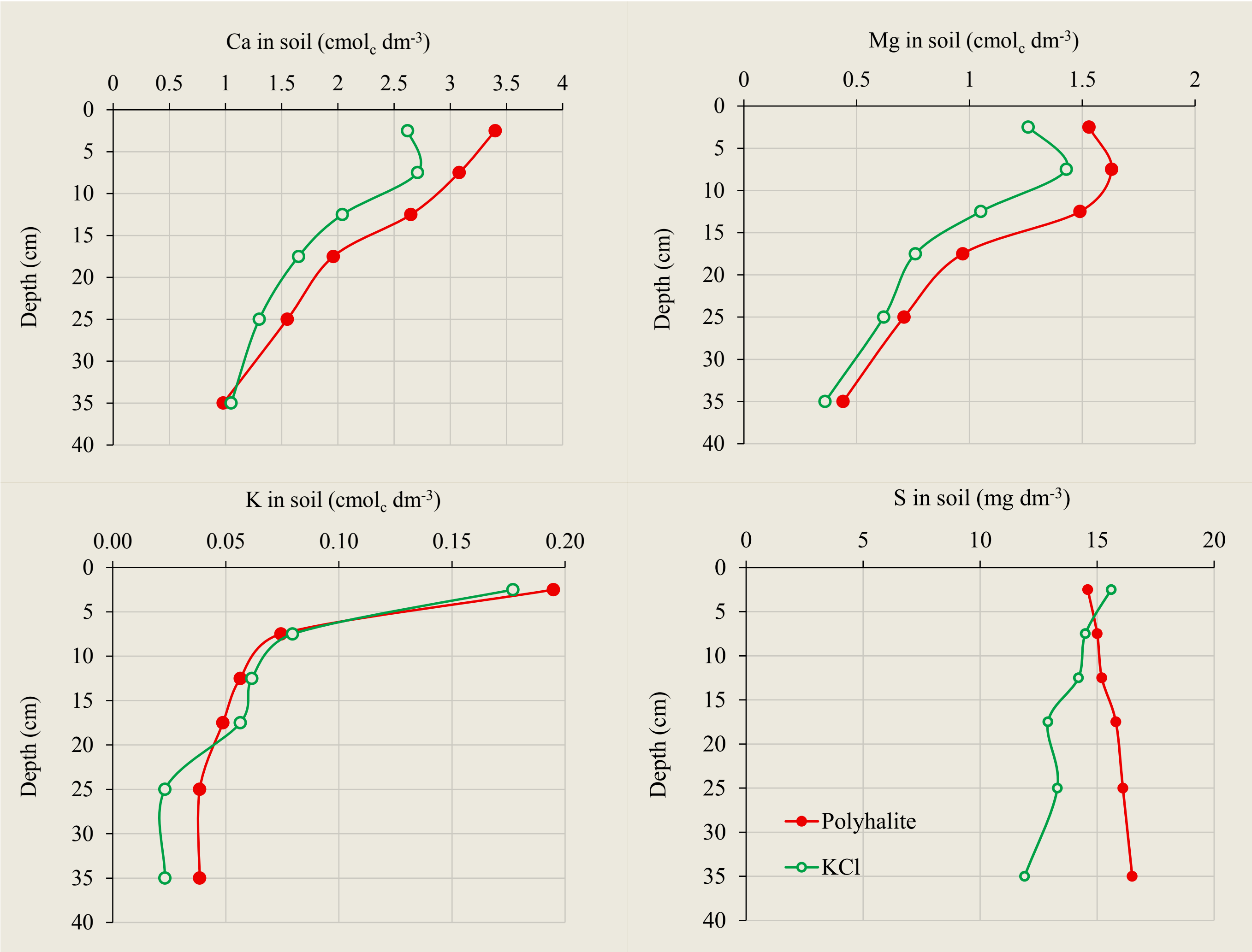

Fig. 4. Soybean soil profile contents of Ca, Mg, K, and S following liming and fertilization treatments with KCl or polyhalite on Oxisol soil.

main causes of S deficiency in tropical soils are associated with the high mobility of the sulfate ion in the soil, and the low amounts of S often found in the soil profile explored by the roots when compared to the temperate regions (Vitti, 1989). There are several reasons for the recent decline in available soil S. After more than a century of heavy-polluting industries and transportation, worldwide awareness has enforced a significant decline in sulfur dioxide emissions. Subsequently, the phenomenon of acid rain has almost vanished and S supply to the vegetation through foliar or root absorption has rapidly declined (Scherer, 2001). In addition, the considerable increase in the use of S-free pesticides and fertilizer has contributed to S deficiency in soils. Soil amendment practices that are very common in tropical acid soils, such as liming and phosphating, alter the chemical interactions between soil particles, resulting in increased leaching of the sulfate ion (SO_4^{2-}) and consequent soil S depletion (Kamprath and Till, 1983; Vitti *et al*., 2015). Thus, crop S requirements that were fully met

Soybean crop in Brazil. Photo by ICL Brazil.

Sugarcane crop in Brazil. Photo by F. Vale.

A cotton field towards harvest in Brazil. Photo by ICL Brazil.

in the past by undesired resources (pollution) are now, not being met. Among S fertilizers, polyhalite provides a potential solution to meet this demand.

Magnesium is frequently overlooked in plant nutrition and shortages adversely impact plant growth. Adequate Mg supplies are required for many essential plant functions, the most noticeable of which are root formation, chlorophyll build up, and photosynthesis. Also, many less observable biochemical reactions are dependent on an adequate supply of Mg (Cakmak and Yazici, 2010). In no-tillage systems, this nutrient tends to concentrate in the top soil, fixed in various forms of $MgCO_3$, most of which are insoluble and immobile in the soil (Ritchey *et al.*, 1980). Low Mg availability throughout the soil has become a problem in the nutrition of perennial crops, such as coffee and citrus. As a result of superficial limestone application, Mg concentrates in the shallow top soil layer, and its subsequent availability throughout the soil is very low. Under these conditions the soil's content of exchangeable Mg is sufficient, but its concentration in the soil solution - the fraction absorbed by plant roots - is too low (Juo and Uzu, 1977). The application of sulfate of potash magnesia showed promising effects on orange productivity and fruit quality; favoring greater Mg uptake, the plant nutritional balance was improved and resulted in larger fruit with higher juice content and improved sugar to acid ratio (Vale, 2010). As shown above, polyhalite also provides a soluble Mg source, and should therefore be considered as an alternative fertilizer for perennial crops in Brazil.

The very low polyhalite Cl content makes it a suitable fertilizer choice for many fruit and vegetable crops that require high K doses on the one hand, and suffer from excess Cl in the rhizosphere on the other. Chloride is often related to a deprived rooting of annual plants such as corn, wheat, cotton, and soybeans, as well as to a reduced nodulation capacity in legumes where the biological N fixation is hampered. Chloride toxicity to soybean crops increases when it is accompanied by K^+ (derived from KCl fertilizer), which particularly affects the reproductive phase and yield formation (Malavolta *et al.*, 1980). The high salinity index value of KCl (116.3) indicates possible germination delays, slow emergence or even reduced crop stand resulting from the high KCl doses applied in the roots' vicinity (Malavolta and Usherwood, 1982). Soybean crops cultivated on soils that frequently receive high KCl doses might exhibit severe toxicity symptoms due to accumulation of Cl and manganese, especially when droughts occur before flowering (Borkert *et al.*, 1994).

Potato, a rising crop in Brazil, demands high K doses during tuber development. Potassium is essential for supporting carbohydrate production and translocation to the starchy tubers (Zörb *et al.*, 2014), thus increasing their dry matter content. High dry matter content is a desired tuber quality trait, particularly when tubers are destined for processing (Reis Junior and Monnerat, 2001); it increases the palatability of French fries (potato chips), as they become crisper, tastier, and less oily (Zehler *et al.*, 1981). Excessive KCl use rapidly supplies the potato crop with available K, however the substantial chloride amounts added to the system might reduce tuber dry matter content, especially where salinity problems develop (Imas and Bansal, 1999). Replacing KCl with Cl-free potash fertilizers such as K_2SO_4 or sulfate of potash magnesia, seemed a viable alternative for potato crop nutrition management, as it improves both productivity and tuber quality (Vale and Silva, 2009). In a similar way, replacing KCl with sulfate of potash magnesia improves the produce quality of coffee due to a significant decrease in the concentration of reducing sugars in the beans (Silva *et al.*, 1999). Thus, polyhalite should be considered for crop nutrition where KCl or other Cl-rich fertilizers are unfavorable.

Concluding remarks

The results of the potted rice experiment provide convincing evidence that polyhalite, a natural complex mineral, is an effective fertilizer in supplying Ca, Mg, S, and K on Oxisol - a low nutrient sandy soil. Polyhalite was equal in supporting plant growth, development and nutrient uptake to the corresponding soluble salts (Figs. 1-3). Consequently, the Brazilian Ministry of Agriculture authorized the use of polyhalite as an agricultural fertilizer in 2015.

The soybean field trial presented here suggests that polyhalite has adequate solubility to reach and promote an active crop rhizosphere when applied to the top soil layer (Fig. 4). Thus, polyhalite is a fertilizer with considerable potential to improve production within no-tillage systems, where soils exhibit significant Ca and Mg deficiency in the subsurface layers. Moreover, polyhalite emerges as a relevant K fertilizer, with equal efficiency to KCl and without the adverse effects of chloride, making it more suitable for use on certain soils and for certain crop species. Yet, the major advantage of polyhalite is in the delivery of S, an essential nutrient which until recently, has often been overlooked. Brazil's leading crops - sugarcane (Oliveira, 2011), soybean (Gutierrez Boem *et al.*, 2007), corn (Ciampitti *et al.*, 2013), and cotton (Reiter, 2013) - require significant S inputs, as do other important crops including wheat (Zhao *et al.*, 1999) and peanut (Tam *et al.*, 2016). In accordance, new field trials have recently been launched in Brazil for soybean, corn, cotton, sugarcane, coffee, orange, banana, onion, cabbage, and potato crops, with the purpose of consolidating the potential of polyhalite as an important fertilizer for Brazilian crops.

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Regional activities/Latin America

Research Findings

Wheat plots in the vicinity of Debre Berhan, Semien Shewa zone, Amhara region, Ethiopia. Photo by E. Sokolowski.

Potash Fertilization of Teff and Wheat in the Highlands of Ethiopia

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Abstract

Arable lands in Ethiopia are seriously degraded as a result of natural and anthropogenic factors. DAP (di-ammonium phosphate) and urea have been the only fertilizers in use for the past four decades in Ethiopia, while potassium (K) fertilizers were considered unnecessary. However, recent studies have shown that Ethiopian soils undergo continuous K depletion, and that supplemented K may assist in elevating productivity of cereals. In the present study, on-farm experiments were conducted in 83 teff fields, and 150 wheat fields, in Tigray, Oromiya, and Amhara - three large states in Ethiopia. In each field, a pairwise test was carried out, comparing a common practice plot with a '+K reatment' plot, which received an additional 50 kg KCl ha^{-1}. On average, the '+K treatment' gave rise to significant yield increases of 289.4, 160.3, and 183.2 kg teff grains ha^{-1}, and 307.0, 448.5, and 170.0 kg wheat grains ha^{-1}, in Tigray, Oromiya, and Amhara, respectively. Nevertheless, an immense diversity

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occurred in the control yields of both crops, and also in the yield response to K application. Possible reasons for this yield diversity, as well as appropriate approaches aimed at raising cereals' yields while preserving the system's sustainability, are discussed.

Keywords: Eragrostis tef; potassium; soil degradation; *Triticum aestivum;* yield.

Introduction

Agriculture, characterized mainly by smallholder farming, is the dominant economic activity in Ethiopia. There are many constraints hampering Ethiopian agricultural productivity, among which the depletion of soil fertility is a key factor. Arable lands in Ethiopia are seriously degraded as a result of natural and anthropogenic factors. Along with the 'low input - low output' approach typifying the smallholder agricultural system, Ethiopian farmers still use lower fertilizer application rates compared with their counterparts in East Africa. In addition, the use of farmyard manure and crop residues is nil, or at minimum levels, subjecting soils to rapid nutrient removal. However, during recent years, the Ministry of Agriculture and Natural Resources, and the Regional Agriculture and Natural Resource Bureaus, have intensified the promotion of compost use among smallholder farmers in order to replenish soil fertility and to increase agricultural productivity.

In the framework of the 'Freedom from Hunger Campaign' during the 1960-70's (Bunch, 2007), FAO launched fertilizer demonstration trials that showed the importance of nitrogen (N) and phosphorus (P) - in this order - as the most crop-limiting nutrients in Ethiopian soils. These trials also showed that the response to potassium (K) was inconsistent or not significant enough to include it in the recommended fertilizer package. In addition, the exchangeable K content of most agricultural soils, particularly Vertisols, exceeded the universally accepted threshold set according to the ammonium acetate extraction method. Thus, until recently, the notion that "K fertilizers are not necessary" was widely adopted. Even a recent survey on the impacts of land use changes on soil fertility did not include K in the list of essential soil macronutrients (Haile *et al.*, 2014). Subsequently, DAP (di-ammonium phosphate) and urea were the only fertilizers in use for the past four decades in Ethiopia. Indeed, K fertilizer was not imported for crop production in Ethiopia until 2014.

Thus, after decades of soil-K exhaustion, indications for the increasing need to restore the soil-K status are gradually emerging (Haileselassie *et al.*, 2005; Kraaijvanger and Veldkamp, 2015). There are reports indicating sharp increases in wheat (*Triticum*) grain and straw yields in response to application of 50 kg K_2SO_4 per ha on Vertisols (Astatke *et al.*, 2004). Similar results were reported by Berhe and Gebretsadik (2010) for teff (*Eragrostis tef*) crops grown on Vertisols. In addition, farmers in the central highlands of Ethiopia often apply wood ash to their Vertisol fields, in fact enriching the soil with K (52%) and sulfur (S) (18%). It is strongly suspected that at a very low soil-K status, exchangeable K tends to undergo fixation to clay crystal lattices in Vertisols, resulting in reduced K availability. Other findings have shown that some Ethiopian acid soils are also K-deficient (Paulos, 1996; Abayneh and Birhanu, 2006).

The lack of a reliable countrywide soil fertility database is a key obstacle in realizing the government's recent plans to double agricultural production within a five-year period. In order to tackle this problem, the Ministry has designed a two-pronged approach: 1) to conduct a soil and plant nutrient survey in priority areas in order to determine key soil nutrient limitations; 2) to test different imported straight, blended or compound fertilizers against the commonly used fertilizers (DAP and urea) for their impact on crop yield in different areas and crops. In contributing to the second approach, the present study's objective was to evaluate

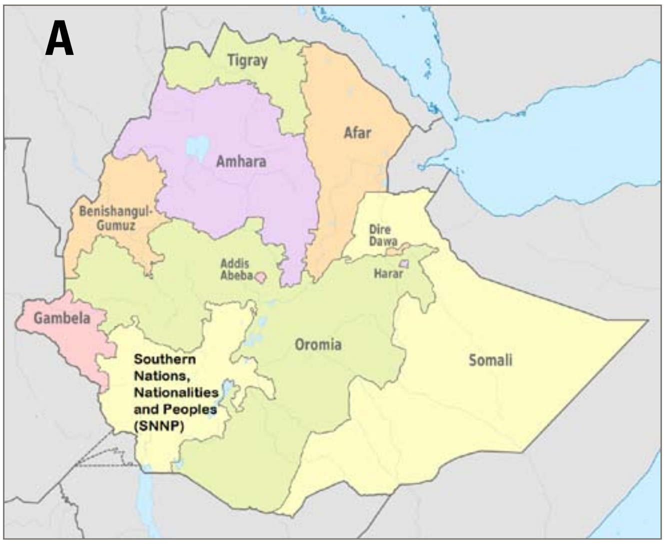
Comparison of adequate balanced fertilizer application (photo left) to half of the amount (photo right). Location: Southern Nations, Nationalities, and Peoples' Region (SNNPR), zone Wolaita, Woreda=Sodozuria, site=Kokate. Photo by E. Sokolowski.

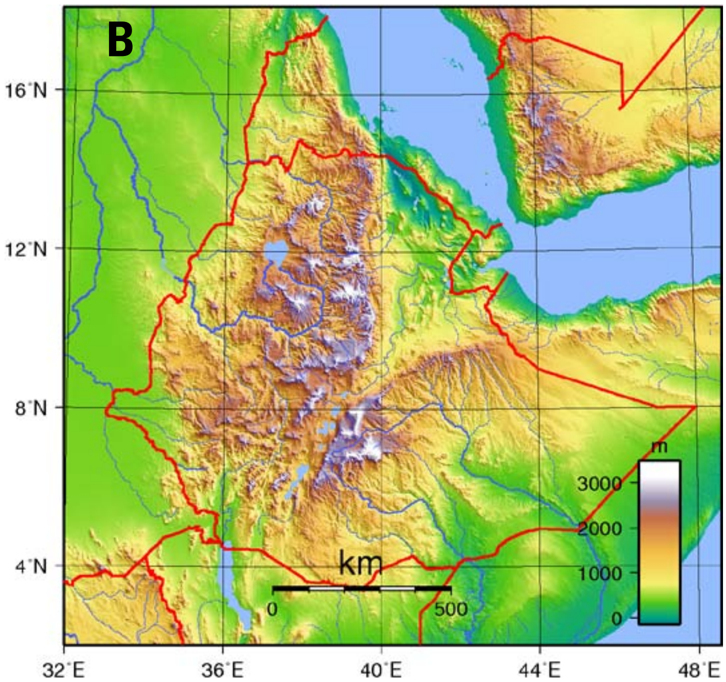
K requirements and to demonstrate the contribution of adding this nutrient to the common fertilization practice on wheat and teff yields in Tigray, Oromiya and Amhara - three Ethiopian regions (Fig. 1) where these crops dominate agricultural production.

Materials and methods

Verification trials for K response in teff and wheat were conducted in the central highlands of Ethiopia in the three states of Tigray, Oromiya and Amhara. Amhara and Oromiya are high rainfall areas while Tigray is not (Fig. 1). The dominant soil types for all states are Vertisols and Nitisol. The trial was conducted in different farmers' fields throughout the states. Each farmer grew one crop. There were two plots per farmer laying side by side: one for the control and the other for the additional K treatment, with a one meter wide path between them.

There were two treatments: 1) control, where the common fertilizer practice of urea and DAP was applied, and; 2) '+K treatment', where KCl was applied at 50 g ha^{-1}, in addition to the urea and DAP fertilizer (Table 1). No other fertilizers were applied. For each treatment, the plot size was 250 m^2 for teff, and 500 m^2 for wheat. The Kuncho variety was used for teff, while different improved varieties recommended for the areas were used for wheat. On Vertisols, wheat was planted on broad beds,





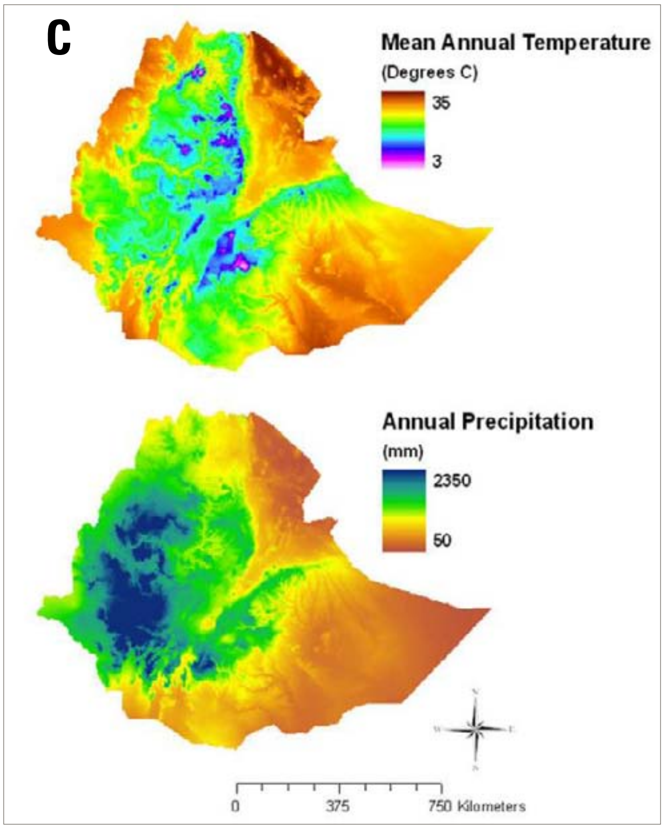


Fig. 1.
A regional map of Ethiopia, indicating the locations of Tigray, Amhara, and Oromiya, where the experimental work took place (A);
http://www.ethiovisit.com/ethiopia/images/Ethiopia_regions_english2.png.
A physical map of Ethiopia (B);
https://upload.wikimedia.org/wikipedia/commons/c/c5/Ethiopia_Topography.png.
Maps of mean temperature and precipitation in Ethiopia (C);
http://gisedu.colostate.edu/webcontent/nr505/ethiopia2009/nr505_fall09_final_Hopping_Wann/images/BaseMap2050.594.jpg.

Table 1. Fertilizer type and dose applied to the two treatments in the teff and wheat experiments in Ethiopia.

Fertilizer	Treatments	
	Control	+K treatment
	----------------*kg ha⁻¹*----------------	
Urea	100	100
DAP (di-ammonium phosphate)	100	100
KCl (potassium chloride)	0	50

constructed using a "broad bed maker" or other local tools, in order to facilitate drainage of excess water. All recommended cultural practices were followed.

The statistical analysis were performed using pairwise t-tests, with a confidence level of 0.95. Data analysis was conducted separately and independently for each region and crop, as well as for all plots regarded as a whole for each crops. Before statistical analysis, the data was trimmed in order to remove outliers.

Results

Teff

Application of 50 kg KCl ha^{-1}, added to the common fertilizer practice of urea and DAP, gave rise to average teff yield increase of 289, 160, and 183 kg ha^{-1}, in Tigray, Oromiya, and Amhara, respectively. However, the range of control teff yields and, furthermore, the response patterns to K application differed significantly between and within the regions. In Tigray, control teff yields ranged from 1,960 to 4,000 kg ha^{-1}, which were very high compared to Oromiya and Amhara, where in 78 and 68% of the plots, respectively, control yields were considerably lower than 2,000 kg ha^{-1} (Fig. 2).

The pattern of the teff relative yield added in response to a standard KCl dose of 50 kg ha^{-1} was largely affected by the control yield level. In Tigray and Oromiya, logarithmic-type functions could be roughly fitted, according to which the relative contribution of K application to yield was mostly higher at the lowest control yield levels and significantly declined as control yields increased (Fig. 3). The situation in Amhara was quite different; yield response was very low, even negative, where control yields were lower than 1,300 kg ha^{-1}. From that basic yield level, and up to about 2,500 kg ha^{-1}, teff response to K application scattered widely from 3 to 25% yield increase, with a few exceptions reaching even higher rates (Fig. 2). Nevertheless, above a control yield of 2,500 kg ha^{-1}, yield response to K application fluctuated between high and negative values. Consequently, teff response pattern to the single KCl dose in Amhara may be described roughly by a negative parabolic-type function of the control yield.

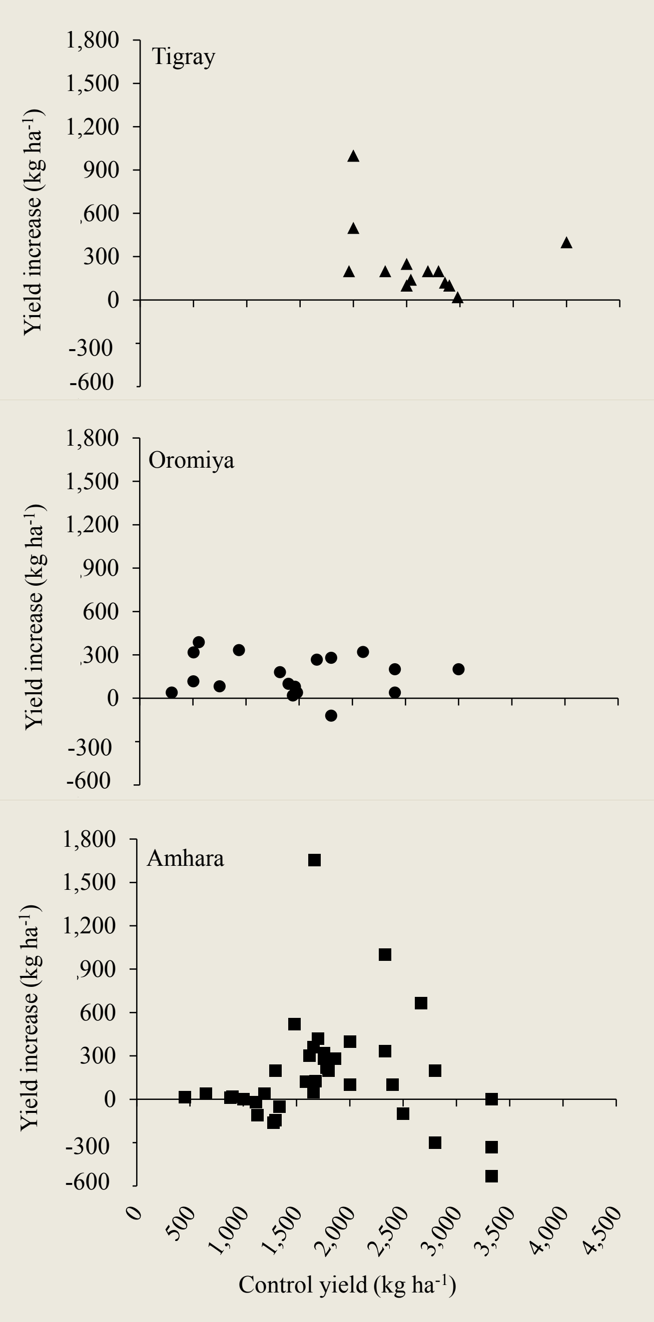


Fig. 2. Teff absolute yield increase in response to application of 50 kg KCl ha^{-1}, as a function of the control yield in three regions of Ethiopia.

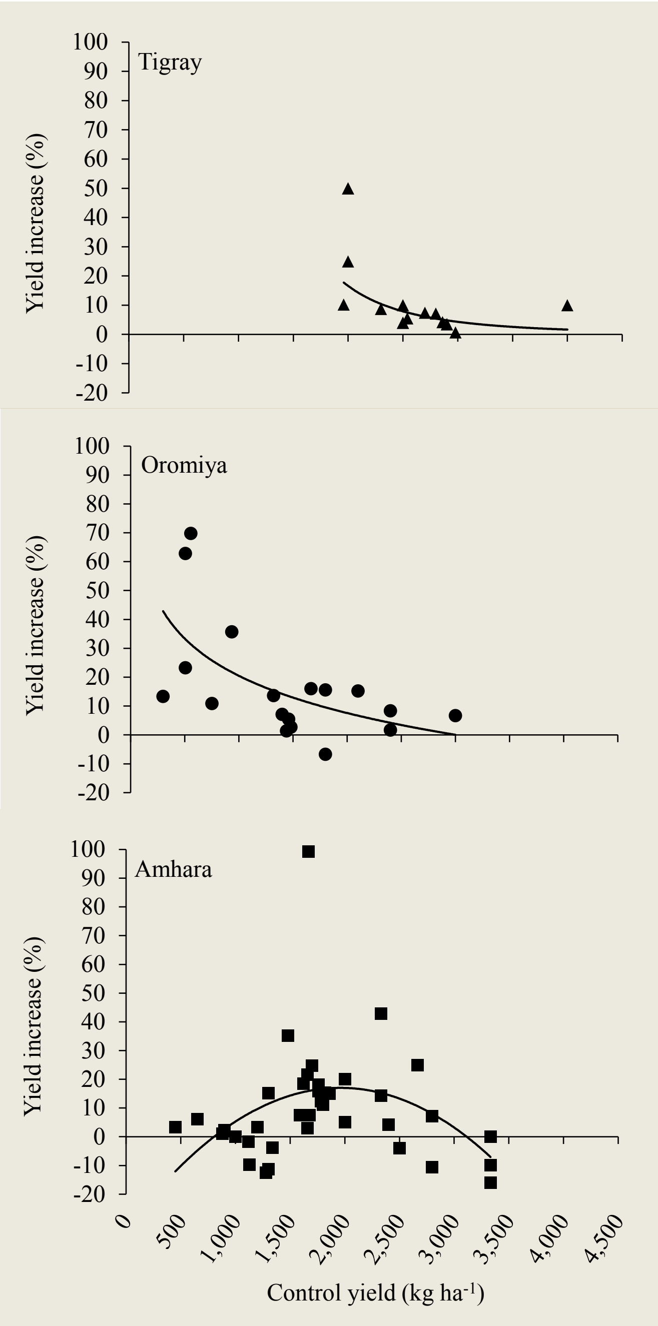


Fig. 3. Teff relative yield increase in response to application of 50 kg KCl ha^{-1}, as a function of the control yield in three regions of Ethiopia.

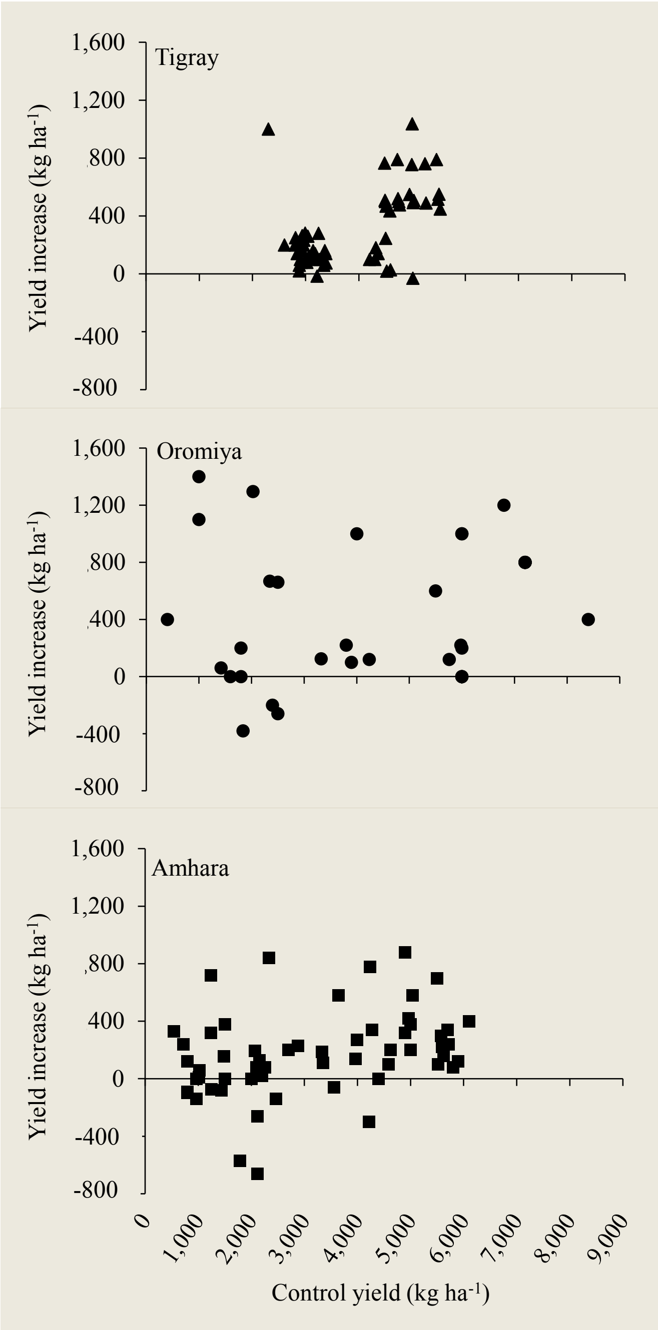


Fig. 4. Wheat absolute yield increase in response to application of 50 kg KCl ha^{-1}, as a function of the control yield in three regions of Ethiopia.

Wheat

Control wheat yields in Tigray were bound to a relatively narrow range, from 2,300 to 5,500 kg ha^{-1} (Fig. 4). Excluding two plots, K application resulted in yield increases ranging from a few to 1,000 kg ha^{-1}, averaging at 307 kg ha^{-1}. In Oromiya, control yields displayed very high variability, ranging from 400 to 8,400 kg ha^{-1}. Also here, with the exception of three plots, the majority of the plots displayed yield increases from a few to 1,400 kg ha^{-1}, with an average of 448 kg ha^{-1}. In Amhara, control wheat yields ranged from 540 to 6,100 kg ha^{-1}. Potassium application brought about the lowest average yield increase, only 170 kg ha^{-1}. However, it included a number of negatively responding plots (17%), while the additional yield among the majority of the plots ranged from a few to 880 kg ha^{-1} (Fig. 4).

The highest relative yield responses to K application seemed to occur where control yields were below 2,000 kg ha^{-1}, as was particularly noticed in Amhara and Oromiya (Fig. 5). The added yield was, in some cases, as high as 100-140% in Oromiya, and about 40-60% in Amhara. Nevertheless, most cases of a negative response also occurred at this range of control yield, making it difficult to illustrate any solid relationships between the control yield and the rate of yield response to K application. Above a control yield of 2,000 kg ha^{-1}, the relative yield increase varied up to a threshold of 20%, which was very seldom crossed.

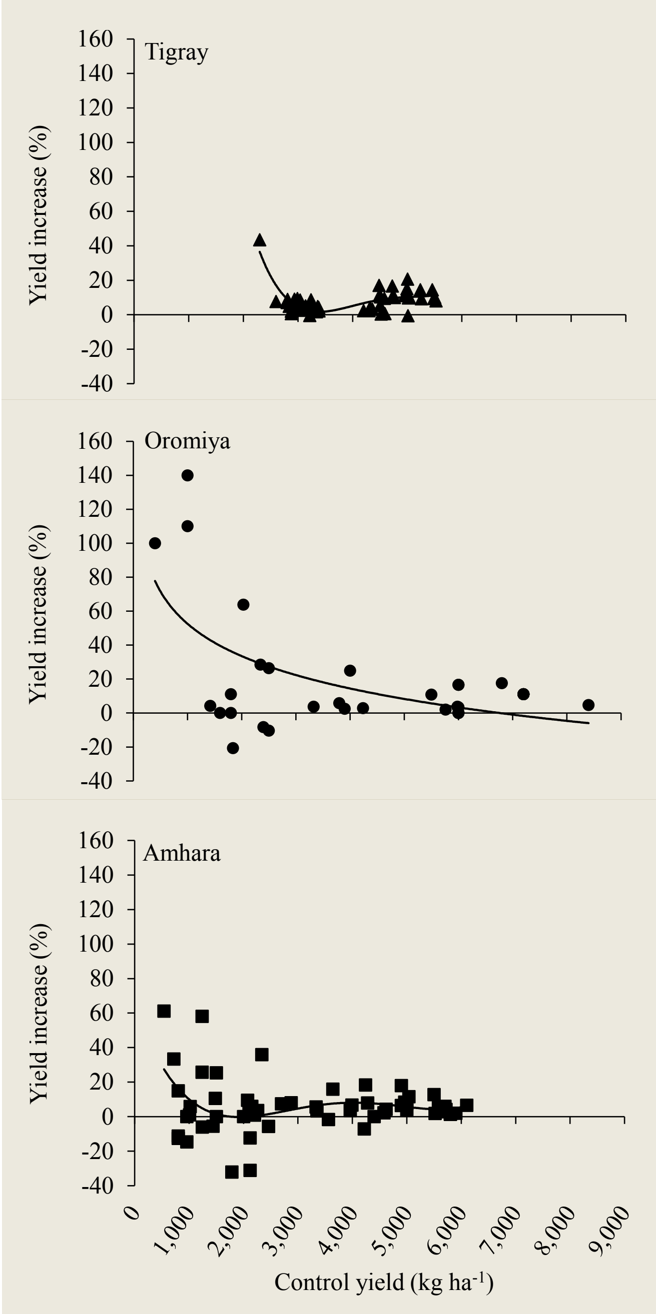


Fig. 5. Wheat relative yield increase in response to application of 50 kg KCl ha^{-1}, as a function of the control yield in three regions of Ethiopia.

Discussion

On average, the supplemented dose of 50 kg KCl ha^{-1} brought about significant increases in both teff and wheat yields in all three Ethiopian regions (Table 2). These preliminary results indicate that, generally, soils in most experimental locations have undergone some nutrient depletion and lack available K. Consequently, the idea to disseminate K fertilization practices seems to have considerable potential to increase cereals productivity in Ethiopia.

Nevertheless, there was an immense diversity in the control yields, where no K fertilizer was added. Teff yields ranged from as low as 300 up to 3,000 kg ha^{-1} in Oromiya, and from 450 to 3,300 kg ha^{-1} in Amhara (Figs. 2 and 3). In a similar way, wheat yields ranged from 400 up to 6,100 or 8,400 kg ha^{-1}, in Oromiya and Amhara, respectively (Figs. 4 and 5). Tigray, on the other hand, displayed narrower yield ranges, from 2,000 to 4,000 kg ha^{-1} for teff, and from 2,300 to 5,500 kg ha^{-1} for wheat. This diversity in yields, within as well as between regions, calls for careful dissection before any recommendations are disseminated.

A major reason for yield variability is the particular topography and climate of the Ethiopian highlands, where the survey took place. The altitude of teff and wheat production areas, which may vary from 1,800 to 2,800 m, plays an important role in the distribution of wheat production through its influence on rainfall, temperature, and disease presence. Since teff and wheat are often grown to meet farmers' basic self-nutritional requirements, with no alternatives, yield levels are seldom considered. This, along with the unpredictable precipitation regime and distribution characterizing many regions in Ethiopia, may provide possible explanations for the unusually wide range of yields within the same region.

Teff is an allotetraploid cereal crop indigenous to Ethiopia (Ingram and Doyle, 2003). It comprises about 25% of the local cereal consumption, and has recently gained significant worldwide attention as a 'super food' (Gebremariam *et al.*, 2014). During centuries of local trade and cultivation, teff has developed significant internal diversity, including several recognized varieties and numerous landraces (Belay *et al.*, 2006). Wheat diversity in Ethiopia is much more complex (Gebre-Mariam *et al.*, 1991). While bread wheat (T. *aestivum*) cultivars were gradually introduced into Ethiopia during recent centuries, durum wheat (T. *durum*) is indigenous to Ethiopia where it has been cultivated since ancient times (Mengistu and Pé, 2015; Mengistu *et al.*, 2016). Tradition, personal experience, soil fertility, and altitude are among the major considerations made by the local smallholder when they choose a variety, a landrace, or often a mixture from the considerable genetic range of wheat available (Dea and Scoons,

Table 2. Mean yield contribution of K application (50 kg KCl ha^{-1}) above control, measured for teff and wheat crops in a countrywide experiment at farmers' fields in Tigray, Oromiya, and Amhara, Ethiopia.

Crop/region	Plots	Mean yield difference	±SE
		---kg ha^{-1}---	
Teff			
Tigray	16	289.4	75.5
Oromiya	18	160.3	32.4
Amhara	49	183.2	52.3
Wheat			
Tigray	58	307.0	34.6
Oromiya	34	448.5	82.8
Amhara	58	170.0	38.9

2003). Besides the great potential of this genetic diversity for the improvement of wheat productivity (Mengistu *et al.*, 2016), tremendous variability is obviously introduced into any broad-scale on-farm experiment. The inordinate genetic variation, in both teff and wheat, offers additional perspectives to the yield diversity presented here.

Yield response to the added K dose, illustrated against the control yield at each location, also displayed significant variation (Figs. 3 and 5). It would be reasonable to expect relatively high response rates to additional K at the lower range of control yields, assuming that K availability was a limiting factor. Indeed, that kind of response was quite often observed. However, in too many cases, the response was weak or even negative (Figs. 3 and 5). A weak response at the lower yield range may be associated with other limiting factors, prior to the assumed K shortage. A transient water scarcity at early developmental stages may disturb tillering and significantly reduce the reproductive potential of cereal crops. Insufficient precipitation over the whole growing season would also result in significant yield reduction. In both situations, K application is expected to have only a minor influence in boosting yields. High crop density has been recently found to limit teff yield. Consequently, it was suggested to reduce crop density to 25 plants m^{-2}, thus providing more space for tillering (Berhe and Gebretsadik, 2010). Lack of micronutrients is another possible constraint reducing crop yields on a local basis; Haileselassie *et al.* (2011) found that zinc application could significantly increase teff yields.

Cases of significant negative response to K application, observed mainly in Amhara but also in Oromiya, are difficult to explain at the physiological level. However, they might indicate substantial local variation in soil features, which may even affect the yields of close neighboring plots in a farm, a situation reported by Dea and Scoons (2003).

Considerable variation in response to K application may arise from interaction between free K^+ and clay crystals, particularly in long term K-depleted Vertisols. A single small K dose applied to such soils might be rapidly fixed into the clay particles, before any uptake by the crop occurs. Significantly larger K quantities would therefore be required before any effect on the crop is observed.

Acid soils, which frequently occur in the tropical areas of south Ethiopia (Paulos, 1996; Abayneh and Birhanu, 2006), including Oromiya and Amhara, may provide an opposite reason for insufficient response to K application. In such soils, the free K^+ ions hardly adhere to the positively charged surface of the clay crystals and are leached from the rhizosphere by the frequent rains, with little chance to be taken up by the crop. Possible solutions for such cases would be liming, in order to increase soil pH, and frequent K applications to widen the opportunity window for root-K^+ interaction.

When K uptake by the crop does occur, its effect on yield largely depends on interactions with other nutrients, such as N, P, and S, as well as micronutrients. Nitrogen deficiency, which might often occur when fertilizer is improperly applied, inhibits plant growth and development and, subsequently, strongly restricts the response to K application.

There is no way to predict crop response to K application at a given location other than by conducting a comprehensive soil test. A relevant approach can then be tailored accordingly and include a whole package of solutions. On the other hand, Haileselassie *et al.* (2005) concluded that closing nutrient balances at field scale to achieve sustainability would be too costly and difficult. Examining three perspectives of the Tigray grain production system, Kraaijvanger and Veldkamp (2015) suggest that gradually strengthening the existing mixed farming system by using fertilizers, organic manure and legume fallows would support crop productivity while maintaining other aspects of sustainability, such as food security and profitability.

Conclusions

After decades of K-free fertilization policy, several recent surveys have indicated a considerable degradation in soil fertility under the current soil uses in the Ethiopian highlands, including severe K depletion (Haileselassie *et al.*, 2005; Duguma *et al.*, 2010). The results of the present broad scale study show that supplementing with an application of 50 kg KCl ha^{-1} brought about, on average, a significant increase in teff and wheat yields in the Tigray, Oromiya, and Amhara regions. However, the immense variation in yields, and furthermore, in the response to K application, indicate that practical prescriptions for elevating cereal productivity in Ethiopia should include a revised attitude to K fertilizers, but would also require careful locally-based analyses and amenable approaches aimed at preserving the sustainability of the Ethiopian agricultural system.

Acknowledgements

This project was jointly conducted by Ministry of Agriculture and Natural Resources (MoANR), regional Bureaus of Agriculture and Natural Resources (BoANR) and ATA. The project received financial support from the International Potash Institute (IPI) with the aim to support one of the MoANR's initiatives to test the effectiveness of different fertilizer sources at different locations and with priority crops so as to increase production and productivity in the GTP periods. Experts at different woreda, zonal and regional levels supported the demonstration activities in one way or another and the Authors are thankful for all. Authors are especially thankful to Gebretsadic Reda, Abiot Belay, and Likisa Kurmana respectively from Tigray, Amhara and Oromia BoANRs and Fanosie Mekonen from MoANR for their overall support and facilitation in undertaking these trials and data collection.

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Regional activities/sub-Saharan Africa/Ethiopia

Research Findings

Research team evaluating the field experiment. Photo by Bao Pham Vu.

Effect of Potassium Fertilizer Types and Rates on Peanut Growth and Productivity on Coastal Sandy Soil in South Central Vietnam

Truong Thi Thuan[(1)], Duong Minh Manh[(1)], Pham Vu Bao[(1)*], Ho Huy Cuong[(1)], Hoang Minh Tam[(1)*], and Tran Quoc Dat[(1)]

Abstract

Two potassium fertilizer types (potassium chloride {KCl} and potassium sulfate {K_2SO_4}), at five distinct doses (0, 30, 60, 90, and 120 kg K_2O ha^{-1}) were applied to determine a suitable potassium (K) fertilization approach for a new peanut cultivar, LDH.09, especially selected for peanut cultivation on the saline coastal sandy soils of Binh Dinh province, Vietnam. While neither fertilizer significantly influenced peanut growth and yield parameters under the majority of doses, the effect of dose on yield was dramatic, particularly at low doses (30 and 60 kg K_2O ha^{-1}), illustrating a saturation curve. The economic optimum was already reached at a dose of 30 kg K_2O ha^{-1}. Excluding a significant rise in soil pH due to liming, soil fertility remained very low at the end of the trial, indicating an unsustainable crop system. These results suggest that most of the applied K was wasted before reaching the plants' roots. Therefore, alternative approaches to fertilization for highly productive and sustainable

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peanut crop systems in Binh Dinh, should be considered. This could include splitting the K dose into many frequent applications, and/or employing fertilizers which exhibit slow-release nutrient properties.

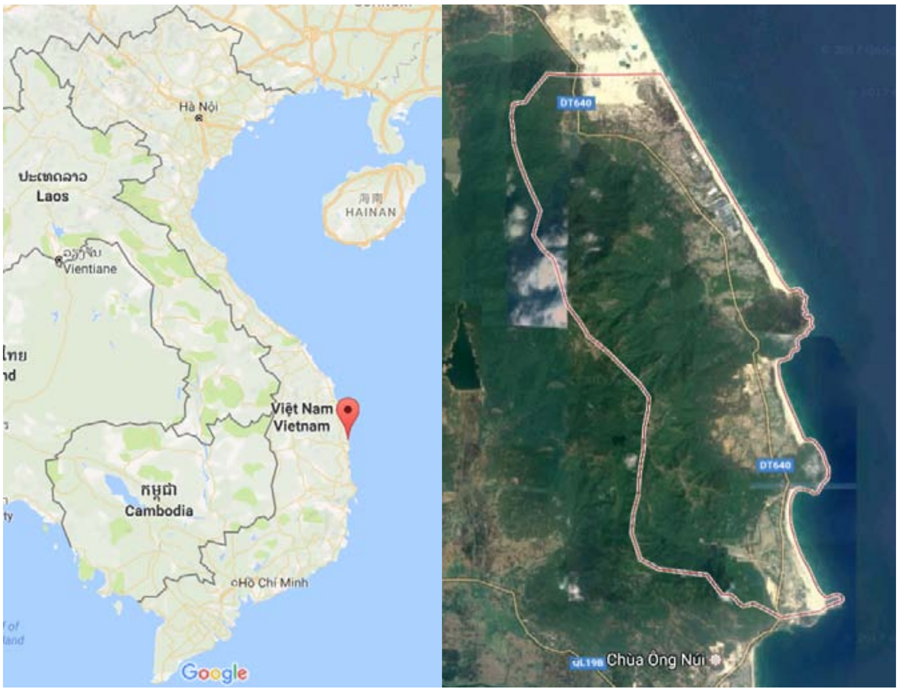
Keywords: Acid soil; *Arachis hypogaea* L.; potassium; saline; sand.

Introduction

Peanut (*Arachis hypogaea* L.) is a short-term industrial oil crop with high nutritional and economic values. In Vietnam, this crop is aimed at replacing less profitable and unsustainable crops and has recently gained priority in many provinces, including Binh Dinh (Map 1). The land area in Binh Dinh used to cultivate peanut has increased from 7,700 ha in 2005 to 10,200 ha in 2013. Peanut is mainly grown on the saline coastal soils of Binh Dinh due to competition from alternative crops on alluvial and poor gray soils. This area of peanut cropping is generally characterized by poor soil fertility, high salinity, frequent droughts and water shortage (Keen *et al.*, 2013). Nevertheless, these challenges have promoted research efforts to define the factors limiting peanut culture in the area; to select suitable cultivars; and to examine innovative farming techniques.

In the frame of these efforts, the Agricultural Science Institute of Southern Central Coastal region of Vietnam has recently selected a new peanut cultivar LDH.09, a H1 hybrid combination of ICG20 x 9205. Under moderate saline conditions, LDH.09 consistently displays 32 and 51% higher productivity than the control L14 and the local Se cultivars, respectively (Cuong *et al.*, unpublished data).

However, the poor soil fertility - particularly the low potassium (K) status - and the most effective approach to supply peanut K requirements under the local conditions, are of great concern. Several studies ended with disparate



Map 1. Cat Hai, Phu Cat district, Binh Dinh Province, Vietnam. *Source:* Google Maps, 2017.

results regarding the most productive and economically efficient K dose that should be applied to peanuts on the saline sandy soils in Binh Dinh. From various studies, the recommended K dose for optimum growth is 60 kg K_2O ha^{-1} (Dan, 1995; Bo *et al.*, 1999; Chinh, 2005). This is supported by Chinh *et al.* (2012) and Hoa *et al.* (2012), who concluded in separate studies that 60 kg K_2O ha^{-1} is the optimum K dose for peanut crops on the sandy soils in Thanh Hoa and Binh Dinh. However, several more recent experiments yielded widely ranging optimum K values from 8 to 76 kg K_2O ha^{-1}. Tam *et al.* (2014, unpublished data), and Minh (2014) found that a higher K dose of 80 kg ha^{-1} was the most productive and economically efficient measure on sandy soil in Quang Binh. Hung (2011) suggested an even higher optimum dose of between 90 and 120 kg K_2O ha^{-1} for the saline sandy soils of Thai Binh and Thanh Hoa.

These contradictory results, and the need to establish solid fertilizer recommendations for the new peanut cultivar LDH.09, have set the objective of the present study - to determine the appropriate K fertilizer type and dose for peanut grown on the saline coastal sandy soils in Binh Dinh.

Materials and methods

The experiment was carried out on the coastal saline soil at the Cat Hai Commune, Phu Cat district, Binh Dinh province. Prior to the trial the soil was acidic (pH_{KCl} 4.85), with low organic material (humus content - 0.56%), poor total nitrogen (N) content (0.09%), high phosphorus (P) (0.05%), low K (0.07%), and moderate to high chlorine (Cl) (0.07%).

Basal fertilizer application comprised of 5 Mg manure, 15 kg N (urea), 90 kg P_2O_5 (superphosphate), and 250 kg powdered limestone, per hectare. The first top dressing took place at the emergence of 2-3 true leaves with an application of 15 kg N (urea), and the second one, carried out at full bloom, consisted of an additional 250 kg ha^{-1} of limestone.

The field was ploughed and 1.2 m wide and 0.15 m high seedbeds were prepared, separated at a distance of 0.3 m. Seeds were sown in four rows per seedbed, at 30 and 10 cm, apart and within a row, respectively (33.3 plants m^{-2}).

Treatments included two types of K fertilizer - potassium chloride (KCl) and potassium sulfate (K_2SO_4), and each was tested at five doses split evenly between two applications: basal, and the first side dressing at the emergence of 2-3 true leaves (Table 1). The experiment was designed in split-plot layout with three replications of 12 m^2 each.

Water was supplied to maintain soil moisture above 65%. Pests and diseases were managed according to their occurrence at threshold levels, implementing common recommendations. Harvest took place when 80-85% of fruit had reached maturity. Fruit were collected separately from each plot and dried to a 10% grain moisture level.

Crop development (plant height, plant survival, time of full bloom) was recorded for each plot from germination to harvest. Evaluations of pests and major diseases were carried out throughout the season. At harvest, 10 plants per plot were sampled to determine fresh and dry plant biomass and yield determinants such as the number of filled pods per plant, the weight of 100 pods, and the weight of 100 dry (10% moisture content) seeds, as well as the total dry grain yield. The economic assessment was founded on the calculation of costs (as influenced by the two fertilizers), revenue (dry grain yield, quality, and price), net profit to the farmer, and the benefit rate (profit and cost ratio). Soil examinations were carried out on each plot before sowing and after harvest to measure pH_{KCl}, and total quantity (%) and availability (mg 100 g^{-1}) of N, P_2O_5 and K_2O.

The experiment was repeated three times: spring to summer 2015, summer to fall 2015, and spring to summer 2016. Data analysis was carried out using Statistix 8.2.

Results

Fertilizer type and dose did not have any significant influence on the LDH.09 peanut cultivar regarding the time required for plant growth, which ranged from 90 to 92 days for all three crops. The levels of leaf spot (*Cercospora personatum* {Berk. & Curt.}), leaf rust (*Puccinia arachidis* Speg.), bacteria wilt (*Ralstonia solanacearum* Smith.), and root rot (*Aspergilus niger*) remained very low to low for all crops and throughout all treatments. No effects were observed either for plant disease resistance, excluding L_1K_0 which occasionally displayed slightly higher susceptibility to the leaf spot and the leaf rust diseases.

Fertilizer types KCl and K_2SO_4 had minor effects on plant height, which was higher under KCl but had no significant influence on other plant development and yield determining parameters. The harvested yield was slightly, but insignificantly higher under KCl treatments (Table 2).

In contrast, K dose had significant effects on most parameters of plant growth, yield, and consequently, grain yield (Fig. 1). No effects were observed regarding the number of plants reaching harvest, branching rate, and the seed to fruit ratio. For all parameters influenced, saturation curves were found to best depict the K dose effect. The lowest K dose of 30 kg K_2O ha^{-1} had the most significant effect, boosting plant height and pod number, whereas the effect of higher K doses were insignificant or relatively minor (Fig. 1AB). A K dose of 60 kg ha^{-1} appears to bring about a consequent rise in pod or seed weight (Fig. 1C), which was possibly projected on the final grain yield (Fig. 1D). However, the higher K doses of 90-120 kg ha^{-1}, did not give rise to any advantage for peanut crop growth in the present study. The interaction between fertilizer type and dose was statistically insignificant for all measured parameters.

Table 1. Description of K fertilization treatments employed in the peanut experiment held at Cat Hai, Binh Dinh Province, Vietnam.

Fertilizer type	Treatment	Basal	At 2-3 true leaves	Total
		K dose (kg K_2O ha^{-1})		
KCl	L_1K_0 (control)	0	0	0
	L_1K_1	15	15	30
	L_1K_2	30	30	60
	L_1K_3	45	45	90
	L_1K_4	60	60	120
K_2SO_4	L_2K_0 (control)	0	0	0
	L_2K_1	15	15	30
	L_2K_2	30	30	60
	L_2K_3	45	45	90
	L_2K_4	60	60	120

Table 2. Effect of K fertilizer type on the growth and yield of peanut (cv. LDH.09) grown on the coastal saline sandy soil in Binh Dinh, Vietnam. Values are means of three cropping seasons in 2015 and 2016. Different letters indicate significant statistical differences at p = 0.05.

Treatment	Harvested plants	Plant height	Number of primary branches	Number of pods	Weight of 100 pods	Seed to fruit ratio	Harvested yield
	Plant m^{-2}	*cm*	*Plant^{-1}*		*g*	*%*	*Mg ha^{-1}*
L_1 (KCl)	28.3	26.1^a	4.9	12.6	166.1	65.3	3.18
L_2 (K_2SO_4)	28.6	23.7^b	4.9	12.8	167.3	65.1	3.08
P type	*0.1266*	*0.0119*	*0.0632*	*0.2784*	*0.0819*	*0.6887*	*0.0586*

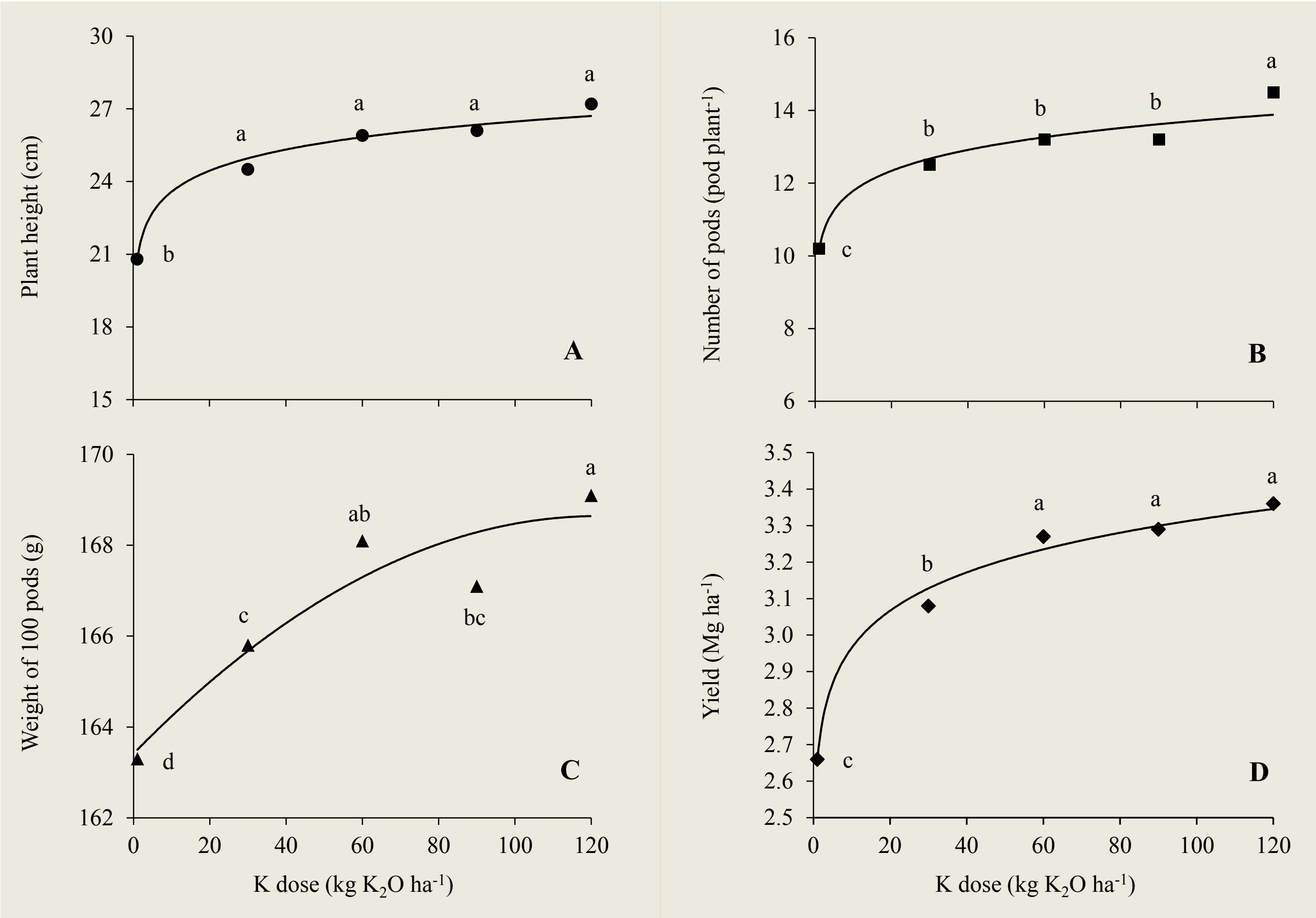


Fig. 1. Effect of K dose on the growth and yield of peanut (cv. LDH.09) grown on coastal saline sandy soil in Binh Dinh, Vietnam. Values are means of three cropping seasons in 2015 and 2016. Different letters indicate a significant statistical difference at $p = 0.05$.

As the K_2SO_4 fertilizer was more expensive than KCl, the cost of peanut production under this treatment linearly increased with K dose, which gradually opened significant gaps in the total cost between crops fertilized with KCl and K_2SO_4 (Fig. 2A). The profit obtained from KCl-applied crops upsurged dramatically in response to the lowest K dose of 30 kg ha^{-1}, but any further increase in profit was insignificant. The increase in net profit was much slower for the K_2SO_4-applied crops, peaking with a dose of 60 kg K_2O ha^{-1} but then declining steeply with increased K doses (Fig. 2B). A similar trend was observed for the profit to cost ratio (Fig. 2C).

The soil analyses results for before and after the trials are shown in Table 3. Interestingly, soil pH_{KCl} increased considerably from an acidic 4.85 before the trails, to a neutral range of 6-7. Total N content, which was low before the trails at 0.09%, significantly declined further under the KCl treatments and fluctuated incosistently under K_2SO_4. Soil available N fluctuated between 2.98 and 4.48 mg 100 g^{-1} with no obvious relation to fertilizer type

Peanut growth performance field experiment. Photo by Bao Pham Vu.

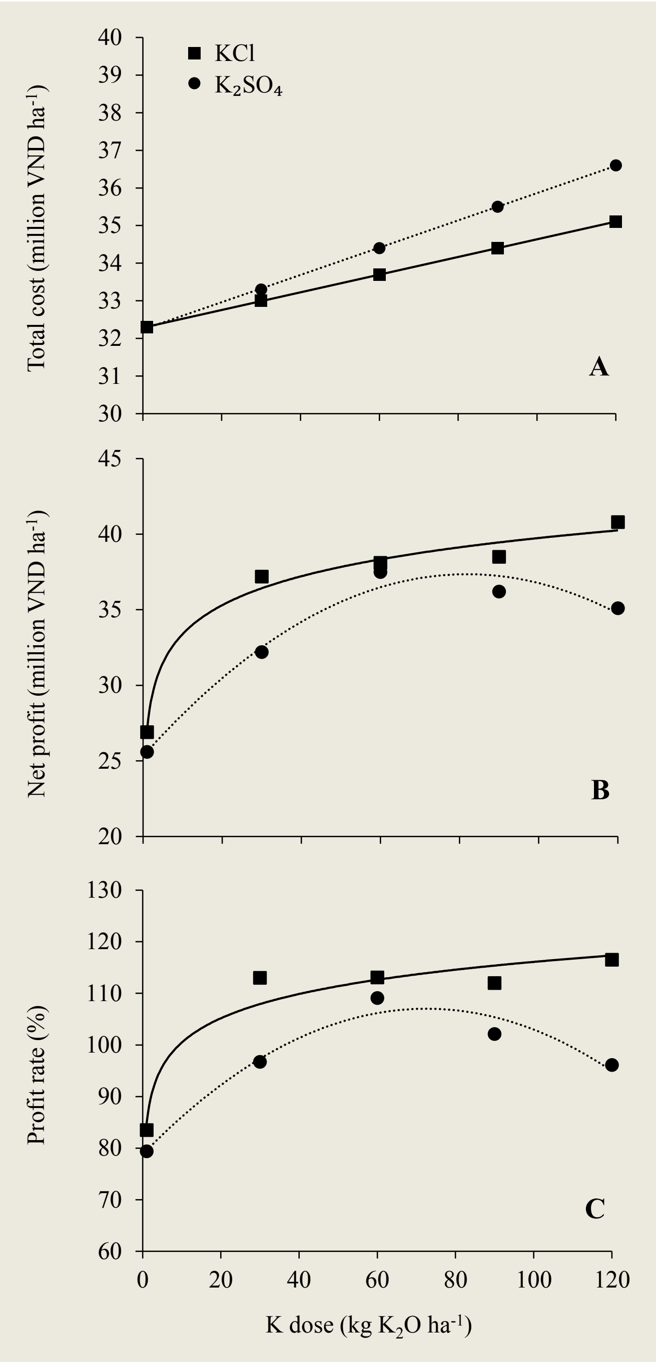


Fig. 2. Effects of K fertilizer type and dose on the total cost (A), net profit (B), and profit to cost ratio (C) for peanut crops grown on saline coastal sandy soil in Binh Dinh, Vietnam.

or dose. Total P levels were high before the trials and increased towards the end of the trials. The levels of available P after trials ranged between medium to very high. Total soil K, which was very poor before the trials (0.07%), slightly increased or remained at the same range. Available K remained at poor to very poor levels, ranging from 2.05 to 5.06 mg 100 g^{-1} irrespective of fertilizer type and dose, and yield levels. The soil salinity level, as indicated by the chloride concentrations, slightly decreased during the trial.

Discussion

A sustainable agricultural system largely depends consistent soil fertility. In cases of poor initial soil fertility, as with saline sandy soils, steps should be taken to steadily improve it. The increase in soil pH observed during trials is a positive sign, although reassessment is required to verify the stability of this trend. For peanut, the recommended pH range is betweem 5.8 and 6.2. If pH is less than 5.8, zinc toxicity problems can occur (Balota, 2014).

Nevertheless, the prevailing poor N status of the soil (Table 3) is a concern as this will restrict any crop, regardless of which and to what extent other fertilizers are supplied. Peanut gets most of its N from nitrogen-fixing bacteria (Bradyrhizobium) colonizing the plant's roots. Poorly inoculated fields will not usually show any yellowing until the beginning of flowering, so checking for nodulation before flowering is important. Failure of natural inoculation can be expected in very humid soils, in such cases, N fertilizer should be applied carefully to reach a sufficient range of 3.5-4.5% in leaves at bloom or early pegging (Balota, 2014). Urea application to acidic soils might further decrease soil pH (Bouman *et al.*, 1995; Tong and Xu, 2012), inhibit soil microflora (Geisseler and Scow, 2014), and weaken N_2-fixation by legume crops (Miller, 2016). Therefore, the replacement of urea with other N-donating fertilizers should be considered.

Evaluations of K supply efficiency to peanut crops provide three important comprehensions: 1) crop and yield responses were largely limited to the lowest K doses applied i.e. 30 and 60 kg ha^{-1}. Under higher dosage, even at 120 kg ha^{-1}, any further yield increase was negligible (Fig. 1); 2) soil K status did not change significantly, remaining very poor at harvest, irrespective of K dose (Table 3); 3) the two K fertilizers, KCl and K_2SO_4, did not differ in their influence on crop growth and soil fertility. This result is not surprising for sandy, acid soils (De Geus, 1973). Soil particles with low specific surface area (sand), combined with high proton concentrations in the liquid soil phase (high acidity), substantially repress soil cation exchange capacity. Thus, the chances for free-K^+ ions - applied through fertilizers - to be transiently adsorbed by the soil particles and establish higher K availability, are extremely low. Instead, the K^+ ions are flushed away by frequent rains before they can be taken up by the crop hence, only a small fraction reaches the plants regardless of fertilizer dose, and the rest is wasted.

There are two approaches to overcome this problem - the first is to split the K dose into many frequent applications, thus increasing the chances for K uptake. Where supplemental irrigation

Table 3. Effect of K fertilizer type and dose on soil chemical properties.

Fertilizer type	Treatments	pH_{KCl}	Total N	Total P_2O_5	Total K_2O	Available N	Available P_2O_5	Available K_2O	Cl^-
	K_2O (kg ha^{-1})		-------------%------------			--------*mg 100 g^{-1}*-------			%
		Before trials							
		4.85	0.09	0.05	0.07	-	-	-	0.07
		After trials							
KCl	0	6.6	0.06	0.08	0.10	4.48	25.07	3.37	0.05
	30	6.3	0.06	0.06	0.09	4.27	12.53	2.41	0.05
	60	6.5	0.06	0.07	0.08	3.40	14.62	2.05	0.04
	90	6.7	0.05	0.05	0.09	3.78	22.34	4.10	0.04
	120	7.1	0.06	0.06	0.09	3.12	25.55	5.06	0.04
K_2SO_4	0	7.0	0.09	0.08	0.06	3.64	20.09	2.41	0.04
	30	6.3	0.05	0.05	0.08	3.68	15.43	2.89	0.05
	60	6.9	0.10	0.13	0.07	3.29	23.46	4.46	0.04
	90	6.8	0.12	0.14	0.06	2.98	18.48	4.46	0.06
	120	7.1	0.09	0.05	0.08	3.92	18.48	4.58	0.04

is employed, K should be applied simultaneously with the water, preferably toward the end of the irrigation event. The second approach is to employ relatively slow-release fertilizers, as suggested by Keen *et al.* (2013). A good example of this approach can be found in a recently published study by Tam *et al.* (2016), where polyhalite was tested against KCl in peanut and significantly increased soil K availability after harvest.

Figure 2 demonstrates the economic benefit of using one fertilizer over another; although in general, no significant differences occurred between the two fertilizers in regards to yield (Fig. 1D), there was a slight, insignificant advantage under the KCl treatment at a dose of 30 kg ha^{-1} (3.19 vs. 2.98 Mg ha^{-1} under KCl and K_2SO_4, respectively). This, together with the higher cost of the K_2SO_4 fertilizer, determined that economically, the most efficient treatment was KCl at a dose of 30 kg ha^{-1} (Fig. 2B). However, the modified fertilization approaches mentioned above might bring about significantly higher yields with higher fertilizer requirements, but under more sustainable conditions. As such, a reassessment of the economic calculations would be required.

Acknowledgements
The authors want to acknowledge the Ministry of Agriculture and Rural Devolopment (MARD), Vietnam for financing this project and the International Potash Institute (IPI), Switzerland, for re-writing this paper.

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Photo by Cuong Ho Huy.


Arachis hypogaea flower. Photo by Cuong Ho Huy.

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The paper "Effect of Potassium Fertilizer Types and Rates on Peanut Growth and Productivity on Coastal Sandy Soil in South Central Vietnam" also appears on the IPI website at:

Regional activities/Southeast Asia

Events

November 2016

Group photo of organizers, sponsors and invited guests with Chief Executive Punjab Agricultural Research Board. Photo by authors.

Significance of Potash Use in Pakistani Agriculture: A Conference Report

Sajid Ali[(1)], and Abdul Wakeel[(2)*]

The International Conference on the Significance of Potash Use in Pakistani Agriculture took place from 24-25 November 2016. The conference was organized by the Institute of Agricultural Sciences (IAGS), University of the Punjab, Lahore in collaboration with the International Potash Institute (IPI), Switzerland under the umbrella of the Office of Research Innovation and Commercialization (ORIC), University of the Punjab. Financial support was provided by the University of the Punjab, IPI, Fatima Fertilizer Company (Private) Ltd., Fauji Fertilizer Company (Pvt.) Ltd., and Agrifert Pakistan. Around 200 national participants attended the conference. One of the international speakers, Dr. Muhammad Arshad Javaid (Universiti Teknologi Malaysia), was able to deliver his lecture in person, whereas Mr. Hillel Magen (IPI, Switzerland) and Prof. Richard Bell (Australia) delivered their lectures through video message.

The Inaugural Session

The inaugural session began with a recital from The Holy Quran. Sent on behalf of Punjab's Agricultural Minister, Dr. Noor-ul-Islam, Chief Executive of the Punjab Agricultural Research Board (PARB), was the chief guest in the inaugural

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session. Other distinguished guests included Prof. Dr. Javed Iqbal Qazi, Dean of the Faculty of Life Sciences, Prof. Dr. Sajid Rasheed Ahmad, Principal of the College of Earth and Environmental Sciences (CEES), and Prof. Dr. Muhammad Saleem Haider, Director of IAGS. Dr. Sajid Ali (Conference Secretary and Assistant Professor at IAGS) briefed conference participants about the objectives of the conference, before Prof. Dr. Haider welcomed the speakers, participants and sponsors. In his welcome address, Prof. Dr. Haider highlighted the importance of crop nutrition, and especially potash, in agricultural production in Pakistan. He also described the importance of holding conferences for sharing and discussing research being carried out in different parts of the country and abroad, and disseminating the research to farming communities. He thanked the participants for attending the event, sponsors for their financial support, and the organizers and volunteers for arranging the conference.

Key Note Address

Significance and Status of Potash use in Pakistani Agriculture

Dr. Muhammad Rashid, General Manager Technical (Ret.), National Fertilizer Marketing (Pvt.) Ltd.

Dr. Rashid outlined the contribution of the agriculture sector to the national economy stating that it contributes 21.4% to GDP, employs 45% of the country's labor, and provides raw materials to agro-based industries. He said that from 1990 to 2010, the average annual agricultural growth rate was about 4%, with a lower rate of 3% from 2011 to 2016. Dr. Rashid emphasized the importance of balanced use of nitrogenous, phosphatic and potassic fertilizers for meeting the maximum yield potential. In addition to outlining the forms of K in the soil and its role in increasing the productivity of different crops, Dr. Rashid also presented the K uptake of different crops in Pakistan, compared the per hectare yield of these crops with advanced countries, and detailed average retail fertilizer prices, fertilizer use status for the year 2014-15, the main factors contributing to low productivity in Pakistan, and concluded with recommendations regarding the use of potash for increasing agricultural production in Pakistan:

- Supply potash to farmers at subsidized rates. Restart effective agricultural advisory services, particularly training and visiting programs for agricultural extension staff.
- Make effective use of print and electronic media for agricultural advisory programs.
- Enhance soil and plant analysis services provided by agricultural departments.
- Publish results of analysis, particularly regarding potassium (K) in soil and plants, for farmers, agricultural extension staff and research workers.
- Carry out research and development (R&D) work on the response of K fertilizers in Pakistani soils.
- Establish a potash research institute in Punjab to conduct R&D work on various crops and fruits, similar to the Potash Research Institute of India. In this regard, the assistance of IPI and Canada's Potash & Phosphate Institute should be sought.

IPI, its Mission, Activities and Objectives in Pakistan

Hillel Magen, Director, IPI, Switzerland

Mr. Hillel Magen explained that IPI, which was founded in 1952 by German and French potash producers, aims to develop and promote balanced fertilization of crops to produce higher yields and more nutritious food, together with ensuring sustainability of production through the conservation of soil fertility for future generations. Mr. Magen said that IPI is promoting scientific evaluation and demonstration of potash use in Pakistani agriculture. He explained that Pakistan is using huge quantities of nitrogen (N) and phosphorus (P) and alarmingly low quantities of potash. He summarized experiment and research results from different parts of the world under different agro climatic zones which have demonstrated the important role potash plays in plant nutrition:

- Potash increases Nitrogen Use Efficiency (NUE) by about 20%.
- Potash improves the quality of harvested crops, and to get better quality produce we have to go beyond the K levels required for getting high yield.
- Resistance against pests and disease. He elaborated with the example of late blight in potato, which in several experiments was reduced by the application of potash.
- Preservation of soil fertility for agricultural sustainability.

Mr. Magen added that the role of IPI is to sharpen the above-mentioned points in Pakistan to improve the income of farmers and preserve the environment. At the end he thanked the organizers of the conference, particularly Patron in Chief, Prof. Dr. Mujahid Kamran, Prof. Haider and Dr. Abdul Wakeel, IPI coordinator in Pakistan, for organizing such an informative event.

Technical Presentations

Nutrient Use Efficiency in Plants with Special Reference to Potassium

Dr. Muhammad Arshad Javed, Faculty of Biosciences and Medical Engineering (FBME), Universiti Teknologi Malaysia (UTM), Johor Bahru, Malaysia

Dr. Javed began by outlining the factors affecting sustainable agriculture and agricultural productivity. He then talked about soil and plant based nutrient management and the role of potash in agricultural productivity. Dr. Javed briefed the participants about how the genetic improvement of crops could improve potash use efficiency (KUE) by:

- Optimizing the root architecture (primary root; lateral root; root hair).
- Enhancing K uptake and translocation abilities.
- Coordinating K absorption and translocation with other nutrients like N.
- Exploring the natural variation of KUE in crops.

The speaker concluded by suggesting that the development of new cultivars with higher NUE, coupled with best management practices, will contribute to sustainable agricultural systems that protect and promote soil, water and air quality. Dr. Javed also pointed out that natural variation exists for tolerance to K deficiency, thus improvement of this important trait in field crops is possible.

Foliar Application of KNO_3 in Combination with Basal Dose Boost Seed Cotton Yield and Potassium Uptake

Dr. Dilbaugh Muhammad, Retired Principal Scientific Officer, Head Agronomy Section, Central Cotton Research Institute (CCRI), Multan

Dr. Dilbaugh presented one of his many experiments where he worked with potash in cotton. He shared that boll number, weight and seed cotton yield varied significantly with K-application rate and foliar spray. The seed cotton yield and its components were improved with soil applied K, whereas foliar spray further enhanced the efficiency of soil applied K. He concluded his presentation by saying that K application, either through foliar or soil application, is necessary to harvest maximum seed cotton yield. Foliar application alone is not a wise approach to fulfill the K requirement for maximum fruit setting and seed cotton yield. However, K deficiency can be prevented with external K supply supplemented with four foliar sprays of 2% KNO_3 to boost the yield response.

Perspectives of Potassium Solubilizing Microorganisms in Crop Production

Dr. Muhammad Naveed, Assistant Professor, Institute of Soil & Environmental Sciences, University of Agriculture, Faisalabad

Dr. Naveed stated that food shortages are becoming a great danger due to the ever-increasing global population. At the same time, crop yields in many parts of the world are stagnant. Strategies to increase yields must include the introduction of high yielding cultivars, but this leads to nutrient depletion especially K. Then Dr. Naveed threw light on the importance of potash in crop production. He added that the presence of huge reserves of K in the soils developed from Mica minerals may mean that chemical fertilizers do not need to be used, as long as K levels can be managed by adopting efficient strategies.

One strategy, among many, that is adopted to dissolve K minerals, is Efficient Rhizospheric Microbes (ERM) which are effective and economical. Dr. Naveed described the functioning of these microbes for K-dissolution: organic acid production, lowering of soil pH, chelation, acidolysis, exchange reactions, hydrolysis, biofilm formation, exo-polysacrides production, tunnels formation by fungi, and complexation. Additionally, Potassium Solubilizing Microorganisms (KSM) adopt a number of other mechanisms which could enhance plant growth, production of growth hormones, N-fixation, P dissolution, siderphore production, Indole Acetic Acid (IAA) production, ACC-deaminase production, enlargement of root systems and antibiotic production. Dr. Naveed stated that the biggest problem in this respect is the commercial propagation of KSMs because the presence of indigenous soil microbes is not high enough to fulfill plant K requirements, so there is need for an inoculum or fertilizer for sustainable development. He concluded that integrated use of biofertilizers could be a better strategy to improve crop production, can be used to reduce the increasing demand of synthetic fertilizers, and can support environment friendly agriculture.

Potassium Management to Decrease Crop Stress Induced by Drought and Frost

Dr. Richard Bell, Professor, Department of Food and Agriculture, University of Western Australia, Australia

Prof. Bell started by stating how K nutrition can be managed to alleviate crop stress by illustrating the forms and physiology of K in soils, its response to crop stress, crops responses, critical K levels, its status in sub-soil, its distribution in soil profiles etc. He then described the physiological roles of K, stating that K is a dominant cation in the cytoplasm consisting of 1-5% plant dry matter (DM) (~200 mM in cytoplasm). Prof. Bell then presented few of the roles ascribed to K in alleviating the stress including:

- Increased rate of photosynthesis.
- Improved translocation of photosynthyates.
- Detoxification of reactive oxygen species.
- Osmotic adjustment under low water supply.
- Protection of plant tissues against dehydration/freezing.
- Optimized stomatal control for better water use efficiency.
- Deeper water acquisition and increased soil water storage.

Prof. Bell presented the hypothesis of the study: “Stress in crops due to chilling/frost/drought can be alleviated by higher internal nutrient concentrations than required in non-stressed plants. Higher external (soil test) nutrient levels are required to alleviate crop stress due to chilling/frost/drought”. He then described the reasons for selecting K for this particular study, followed by the value of subsoil K and explained it in the light of the Agricultural Production Systems sIMulator (APSIM) model. Prof. Bell then presented some of the published results highlighting the role of K and leaf water potential to photosynthesis, the response of K to crop stress, and the effect of K stress in wheat. He supported his results by comparing photographs of the K stressed and normal seedlings. Prof. Bell showed the results of frost damage in potato foliage and then described the methodology and treatments used during the study for the years 2015-16. He reported that K reduced frost-induced sterility in both varieties used during the study and concluded that:

- K in soils is commonly low and it can be detected by soil/plant analysis.
- Subsoil K levels down to 50 cm may be important for crop nutrition.
- K improves crop tolerance to drought stress.
- K increases tolerance to frost-induced sterility in wheat.

Role of Potassium in Cotton Production in Pakistan

Dr. Niaz Ahmed, Associate Professor, Department of Soil & Environmental Sciences, Bahahuddin Zakariya University, Multan

Dr. Ahmed described cotton as the economic engine of Pakistan, highlighting its contribution to GDP, foreign exchange earnings, and value addition in agriculture. He outlined the pattern of cotton production for the last six decades in Pakistan and then detailed nutrient use in cotton. Dr. Ahmed stated that the N:K ratio in Pakistan is vestigial (108:1) in comparison with the N:P ratio (3.4:1). He detailed the functions of K and facts about its use in cotton and highlighted the importance of foliar application of K in cotton:

- Mid to late season foliar application of K on cotton can increase yield.
- Foliar K response increased where:
  - soil K is low (low soil test level or fixation);
  - root uptake is compromised;
  - petiole analysis indicates a pending shortage.
- Foliar K begins to enter plant within six hours.
- Maximum uptake occurs between 24 and 48 hours after application (60 to 65% of K).
- Once absorbed, K is translocated to bolls with little delay.

Dr. Ahmad finished his presentation with the following conclusions:

- About two-thirds of soils used to cultivate cotton are deficient in K.
- Soils that have exchangeable-K of less than 80 mg kg^{-1} soil should be fertilized with 100 kg K_2O ha^{-1}.
- Three foliar application of 4.1 kg ha^{-1} of KNO_3 and balanced use of fertilization for optimum cotton production is beneficial.

Potassium Improves Boll Setting in Early and Mid-Maturing Cotton Cultivars by Primarily Influencing Vegetative Growth Under Both Control and Water-Deficit

Dr. Ahmad Naeem Shahzad, Assistant Professor, Department of Agronomy, Bahahuddin Zakariya University, Multan

Dr. Shahzad stated that cotton is an exhaustive crop and requires NPK in large amounts. Despite high K requirements, K use in cotton production in Pakistan is very limited, probably due to the fact that soils used to be sufficient in this precious resource. He then described the methodology of the presented experiments and said that K application significantly increased plant height in early and late-maturing cultivars, under both control and drought stress conditions. In drought treatment, both 100 and 200 kg K ha^{-1} significantly improved the bolls per plant at 135 day after sowing in early and late-maturing cultivars. However, K treatments had no significant effect on boll number in drought-stressed late cultivars.

Effect of NPK Fertilizers and Biofertilizers on Growth and Yield of Mungbean Under Field Conditions

Dr. Arshad Javaid, Associate Professor, Institute of Agricultural Sciences, University of the Punjab, Lahore

Dr. Javaid presented research work carried out on mungbean. He described the methodology of the experiment and shared some of the findings. Dr. Javaid concluded by saying that to boost grain yield of mungbean under field condition, *B. japonicum* TAL-102 should be inoculated in combination with *Glomus mosseae* and the recommended dose of NPK fertilizer should be applied.

Nutrient Regime for Management of Groundnut Root Rot in Punjab, Pakistan

Fareeha Jabeen, PhD Research Scholar, Department of Botany, University of the Punjab, Lahore

Jabeen, a PhD student, shared the results of an experiment on the management of root rot in groundnut by means of nutrient regime management. She began by introducing groundnut, the dangers of root rot and the importance of nutrient management to cope with the disease. Jabeen outlined the methodology and shared some of the results. She concluded that an understanding of disease interactions with each specific nutrient, and the effects on the plant, pathogen and the environment, can be used to enhance disease control, and improve yield competency and crop quality. The effect of mineral nutrient on disease depends on the host plant, the pathogen and other factors. Appropriate modes of fertilizer application, rates and time improve crop productivity and reduce disease incidence.

Importance of Potash and FFC Role in its Promotion

Muhammad Zahid Aziz, Senior Executive Marketing, Fauji Fertilizer Company (Pvt.) Ltd., Lahore

Aziz started by detailing the nutrition sources for crop plants and described the process of translocation of plant food and the deficiency symptoms that appear on the plants due to shortages of these nutrients, in particular K. He then outlined the fertility status of soils and the usage of NPK, and their ratios, in Pakistan. Aziz presented the potash status of Pakistani soils along with the proportion of NPK presently used in Pakistan and stated that these should normally be used at a ratio of 1:0.5:0.25. He concluded with an overview of the facilities provided by Fauji Fertilizer Company (FFC) to the farming community, including farm advisory centers, models for fertilizer analysis/application and economic models (FFC vs farmer fields).

Farmers' Session

The International Conference on the Significance of Potash Use in Pakistani Agriculture also brought academia, research and farmers together. Constructive scientific discussions occurred on the first day and the second day was reserved for progressive farmers from different parts of Punjab. During the farmers' session, Dr. Abdul Wakeel, IPI representative in Pakistan, presented the importance of K for balanced fertilizer use in Pakistani agriculture. Afterwards Mr. Naseer Ullah Khan from Fatima Fertilizer Company and Mr. Muhammad Tahir Naeem from FFC presented. As the session was focused on farmers, most of the presentations and discussions were in Urdu.

Balancing Fertilizers Use with Potassium in Pakistani Agriculture

Dr. Abdul Wakeel, IPI Consultant, Pakistan

Dr. Wakeel commenced his presentation with the requirements of plants to live and survive followed by the important roles of K in plants. He then gave a tabulated view of the uptake of nutrients (highlighting K uptake) by different major and important crops of Pakistan. Dr. Wakeel presented a chronological status of K in Punjab soils, showing that more than 40% of Pakistani soils are K deficient. He illustrated graphically the yield trends of wheat, rice and maize for the last three decades, followed by use of fertilizers for five major crops (wheat, rice, maize, cotton, sugarcane) in Pakistan. After providing a chronological overview of the fertilizers offtake in Pakistan for the last 50 years, Dr. Wakeel summed up his presentation by showing the difference between produce grown with and without the application of K. He also threw some light on the importance of K in agricultural production and human health, and its balanced use with N and P to get maximum benefits from applied fertilizer.

Improving Crop Productivity by Realizing Untapped Crop Potential in Pakistan Through Balanced Use of Fertilizers – Challenges, Prospects and Opportunities

Mr. Naseer Ullah Khan, Senior Executive Marketing, Fatima Fertilizer Company (Pvt.) Ltd., Lahore

Mr. Khan stated that with an increasing population rate, land available for food production per person is reducing day by day. He said that in 1960 there was one acre available per person but by 2020 there will only be one acre per 2.7 people. He outlined the production of major crops and fertilizer demand in Pakistan over the next 5-10 years and said that increased production and fertilizer demand is forecasted. Mr. Khan also explained that the contribution of balanced use of fertilizers towards increased yield varies between 30 and 50% in different crop production regions in Pakistan. After presenting the status of plant nutrient and use efficiencies, he reported major crop yields gap analysis and percentage usage in different crops, fertilizers offtake and nutrient wise consumption (kg ha^{-1}), and the consumption of fertilizers for arable land. He compared the fertilizer consumption of Brazil, China, Egypt, India and Pakistan. Mr. Khan revealed that increasing prices of agricultural commodities are contributing towards decreasing input costs. He concluded that untapped potential of crops remains at 57% because the following factors:

- Degradation of soils.
- Nutrient mining.
- Imbalanced use of fertilizers.
- Inefficient use and management of fertilizers and irrigation water.

Photo by authors.

Photo by authors.

- Primitive nature of farming (low mechanization).
- Negligible availability of quality seeds.
- High post-harvest losses - especially in fruits and vegetables.
- Poor supply chain system for agricultural commodities.

Importance of Potassic Fertilizers

Muhammad Tahir Naeem, Senior Executive Marketing, Fauji Fertilizer Company (Pvt.) Ltd., Lahore

Naeem began by describing nutrition sources for crop plants, the process of translocation of plant food, and the deficiency symptoms that appear on plants due to shortage of these nutrients. He briefed the participants about the fertility status of Pakistani soils, the usage of NPK and the ratios being used, the role of macro nutrients i.e. NPK, and provided a brief overview of potash deficiency symptoms in plants and different ways to overcome the nutrient deficiency. Naeem revealed the potash status of Pakistani soils along with the proportion of NPK used, and concluded with an overview of the facilities provided by FFC to farming communities, including farm advisory centers, and soil/plant analysis.

Poster Session

Posters from different participants were displayed during the evening of 24.11.2016. Three judges from different institutions (University of the Punjab, Lahore, University of Agriculture, Faisalabad and Bahauddin Zakariya University, Mutlan) judged the posters on prescribed proforma and the top three posters were awarded with cash prizes and shields.

1st Poster Prize (PKR 10,000 and Shield)

Role of Potassium Nutrition in Alleviating the Adverse Effects of Saline Sodic Condition in Rice (*Oryza Sativa* L.) at Different EC_w:SAR_w Ratios

Presenters: Alia Munir, Muhammad Moeen-ud-Din, Ghulam Murtaza, Umair Riaz, Humaira Aziz.

2nd Poster Prize (PKR 8,000 and Shield)

Relationship Between Soil NPK and Soil-Borne Mycoflora in Wheat-Rice Cropping System of Punjab

Presenters: Ammara Kanwal, Arshad Javaid, Rashid Mahmood and Naureen Akhtar.

3rd Poster Prize (PKR 6,000 and Shield)

Effect of Elevated K-Fertilization on Wheat Growth on Saline-Sodic Soil

Presenters: Mehreen Gul, Zafar-ul-Hay and Abdul Wakeel.

Concluding Session

The concluding session was started with a recital from The Holy Quran by Dr. Hafiz Azhar Ali Khan, Assistant Professor of IAGS followed by Nasheed for Prophet by Noor-e-Sahar, an IAGS student. Afterwards, the conference secretary, Dr. Sajid Ali, wrapped up the two-day conference and thanked the participants and sponsors. Ch. Afzal Gill, Chairman of the Standing Committee on Agriculture, Government of the Punjab, and Dr. Muhammad Anjum Ali, Director General of Agriculture Extension and Adaptive Research were the guests of honor. Certificates for participants, organizers and sponsors were distributed before Prof. Dr. Muhammad Saleem Haider thanked, the guests, participants, and sponsors, particularly IPI, Fatima Fertilizer Company and FFC for extending their cooperation for the conference. He expressed his hope that these organizations would continue to work for welfare of the farming community and that cooperation among researcher, academia and industry will flourish. He also thanked the organizers for successfully organizing the event.

Final Recommendations

- Recent reports on soil analysis confirm that ~40% Pakistani soils are deficient and need potassic fertilizers for better crop production.
- As K is being removed from fields due to the introduction of high yielding crops and intensive agriculture, potassic fertilizers are required for agricultural sustainability.
- To improve the quality of agricultural produce, especially for high value export crops, there is a need to apply extra K fertilization.
- For pest and insect resistance, crops, especially cotton, should be fertilized with K.
- Regarding climate change, K fertilizer should be applied to combat abiotic stresses.
- Agricultural commodity prices are very uncertain in Pakistan; therefore, the government should provide subsidies on agricultural inputs, including potassic fertilizers.
- There is a great need to train extension workers and farmers for balanced use of fertilizers.
- A potash research institute, initially in Punjab, should be established to conduct R&D work on various crops and fruits, similar to the Potash Research Institute of India.

This report also appears on the IPI website at:

Regional activities/WANA

Events cont.

International Symposia and Conferences

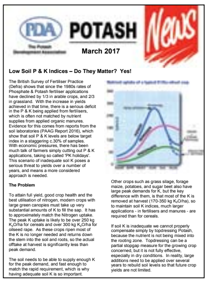
August 2017

18th International Plant Nutrition Colloquium, 21-24 August 2017, Copenhagen, Denmark.

The venue will be the Tivoli Hotel and Congress Center, situated right in the middle of Copenhagen. The main theme of the 18th International Plant Nutrition Colloquium is: "Plant Nutrition for Global Green Growth". For more information go to the IPNC 2017 website.

Publications

Publications by the PDA


PDA POTASH News
March 2017
Low Soil P & K Indices – Do They Matter? Yes!

Low Soil P & K Indices – Do They Matter? Yes!

POTASH News, March 2017.

The British Survey of Fertiliser Practice (Defra) shows that since the 1980s rates of Phosphate & Potash fertiliser applications have declined by 1/3 in arable crops, and 2/3 in grassland. With the increase in yields achieved in that time, there is a serious deficit in the P & K being applied from fertilisers, which is often not matched by nutrient supplies from applied organic manures. Evidence for this comes from reports from the soil laboratories (PAAG Report 2016), which show that soil P & K levels are below target index in a staggering c.30% of samples.

Potash Development Association (PDA) is an independent organisation formed in 1984 to provide technical information and advice in the UK on soil fertility, plant nutrition and fertilizer use with particular emphasis on potash. See also www.pda.org.uk.

Scientific Abstracts

K in the Literature

Follow us on Twitter on: https://twitter.com/IPI_potash

Follow our Facebook on: https://www.facebook.com/IPIpotash?sk=wall

Quantitative Limitations to Photosynthesis in K Deficient Sunflower and their Implications on Water-Use Efficiency

Jákli, B., E. Tavakol, M. Tränkner, M. Senbayram, and K. Dittert. 2017. J. Plant Physiol. 209:20-30. DOI: http://dx.doi.org/10.1016/j.jplph.2016.11.010.

Abstract: Potassium (K) is crucial for crop growth and is strongly related to stress tolerance and water-use efficiency (WUE). A major physiological effect of K deficiency is the inhibition of net CO_2 assimilation (A_N) during photosynthesis. Whether this reduction originates from limitations either to photochemical energy conversion or biochemical CO_2 fixation or from a limitation to CO_2 diffusion through stomata and the leaf mesophyll is debated. In this study, limitations to photosynthetic carbon gain of sunflower (*Helianthus annuus* L.) under K deficiency and PEG- induced water deficit were quantified and their implications on plant- and leaf-scale WUE (WUE_P, WUE_L) were evaluated. Results show that neither maximum quantum use efficiency (F_v/F_m) nor in-vivo RubisCo activity were directly affected by K deficiency and that the observed impairment of A_N was primarily due to decreased CO_2 mesophyll conductance (g_m). K deficiency additionally impaired leaf area development which, together with reduced A_N, resulted in inhibition of plant growth and a reduction of WUE_P. Contrastingly, WUE_L was not affected by K supply which indicated no inhibition of stomatal control. PEG-stress further impeded A_N by stomatal closure and resulted in enhanced WUE_L and high oxidative stress. It can be concluded from this study that reduction of g_m is a major response of leaves to K deficiency, possibly due to changes in leaf anatomy, which negatively affects A_N and contributes to the typical symptoms like oxidative stress, growth inhibition and reduced WUE_P.

Potassium Placement Effect on Dynamics of Barley (*Hordeum vulgare* L.) Nutrition

Pavlov, K., and L. Voronina. 2016. Soil Sci. Plant Nutr. 62(5-6):500-503. DOI: http://dx.doi.org/10.1080/00380768.2016.1247384.

Abstract: The effects of local placement of potassium (K) on mineral nutrition dynamics of barley (*Hordeum vulgare* L.) in fertile Chernozem were studied. A pot experiment with local K-placement at 4-5 cm soil depth was carried out and the dynamics

of nitrogen, phosphorus, potassium (NPK) concentrations in tillers, organs and parts of spring barley was measured. K-placement increased the productivity index from 0.49 to 0.54, despite optimal and slightly varying NPK concentrations during the second half of the vegetation period (60-100 d). This occurs due to partitioning of assimilates, N, K, and especially P in generative organs of primary and secondary tillers forming quality grains. Nutrient concentrations in certain primary tiller parts of a 60-d plant (senescing leaves and the main spike axis) proved to be more sensitive indicators of the K-placement effect than average whole-plant characteristics. While being beneficial, K-placement had little impact on the overall NPK removal in barley, which shows a significant role of factors related to K uptake kinetics. Thus, the chosen parameters in the soil–plant system (the high content of available K in Chernozem, in the second part of the vegetation period) have for the first time allowed the evaluation of the impact of local K-placement on mineral nutrition dynamics in barley.

Cloning and Functional Characterization of *HKT1* and *AKT1* Genes of *Fragaria* spp. - Relationship to Plant Response to Salt Stress

Garriga, M., N. Raddatz, A.A. Véry, H. Sentenac, M.E. Rubio-Meléndez, W. González, and I. Dreyer. 2017. J. Plant Physiol. 210:9-17. DOI: http://dx.doi.org/10.1016/j.jplph.2016.12.007.

Abstract: Commercial strawberry, *Fragaria* x *ananassa* Duch., is a species sensitive to salinity. Under saline conditions, Na^+ uptake by the plant is increased, while K^+ uptake is significantly reduced. Maintaining an adequate K^+/Na^+ cytosolic ratio determines the ability of the plant to survive in saline environments. The goal of the present work was to clone and functionally characterize the genes *AKT1* and *HKT1* involved in K^+ and Na^+ transport in strawberry and to determine the relationship of these genes with the responses of three *Fragaria* spp. genotypes having different ecological adaptations to salt stress. FaHKT1 and FcHKT1 proteins from *F.* x *ananassa* and *F. chiloensis* have 98.1% of identity, while FaAKT1 and FcAKT1 identity is 99.7%. FaHKT1 and FaAKT1 from *F.* x *ananassa*, were functionally characterized in *Xenopus* oocytes. FaHKT1, belongs to the group I of HKT transporters and is selective for Na^+. Expression of FaAKT1 in oocytes showed that the protein is a typical inward-rectifying and highly K^+-selective channel. The relative expression of *Fragaria HKT1* and *AKT1* genes was studied in roots of *F.* x *ananassa* cv. Camarosa and of *F. chiloensis* (accessions Bau and Cucao) grown under salt stress. The expression of *AKT1* was transiently increased in 'Camarosa', decreased in 'Cucao' and was not affected in 'Bau' upon salt stress. *HKT1* expression was significantly increased in roots of 'Cucao' and was not affected in the other two genotypes. The increased relative expression of *HKT1* and decreased expression of *AKT1* in 'Cucao' roots correlates with the higher tolerance to salinity of this genotype in comparison with 'Camarosa' and 'Bau'.

Optimal Fertilization for High Yield and Good Quality of Waxy Sorghum (*Sorghum bicolor* L. Moench)

Wang, C., L. Zhou, G. Zhang, Y. Xu, L. Zhang, X. Gao, J. Gao, N. Jiang, and M. Shao. 2017. Field Crops Research 203:1-7. DOI: http://dx.doi.org/10.1016/j.fcr.2016.12.009.

Abstract: Nitrogen (N), phosphorus (P), and potassium (K) are three crucial factors that affect the yield and quality of waxy sorghum (*Sorghum bicolor* L. Moench), which is used in liquor production. To optimize the fertilization measures for high yield and high amylopectin/total starch ratio in the Hongliangfeng 1 waxy sorghum cultivar, 23 treatments with five levels of three variables (N, P, and K fertilizers) were arranged in a quadratic orthogonal rotation combination design. Results showed that N fertilizer had significant effects on both the yield and amylopectin/total starch ratio, whereas P fertilizer significantly affected only the yield. K fertilizer and the interactions of the three studied factors showed no significant effects on the yield or amylopectin/total starch ratio. The effects of the three studied factors on yield and the amylopectin/total starch ratio were ranked as N fertilizer > P fertilizer > K fertilizer and N fertilizer > K fertilizer > P fertilizer, respectively. Both yield and amylopectin/total starch ratio increased and then decreased with increasing application of N, P, and K fertilizer. The optimal fertilization combination for a yield greater than 5,800 kg ha^{-1} and an amylopectin/total starch ratio greater than 91% was 262.29–324.30 kg ha^{-1} N, 114.07–139.26 kg ha^{-1} P_2O_5, and 230.22–369.28 kg ha^{-1} K_2O.

Potassium-Induced Freezing Tolerance is Associated with Endogenous Abscisic Acid, Polyamines and Soluble Sugars Changes in Grapevine

Karimi, R. 2017. Scientia Horticulturae 215:184-194. DOI: http://dx.doi.org/10.1016/j.scienta.2016.12.018.

Abstract: Crop nutrition is a practical method against freezing injury which may improves grapevine freezing tolerance (FT) potential by increasing bud nitrogenous and carbohydrates storages. In this study the effect of foliar application of potassium sulfate (PS; K_2SO_4; 0, 1, 2 and 3%) on some physico-chemical properties of fruit and leaf mineral contents of 'Sultana' grapevine (*Vitis vinifera* L.) were studied. Moreover, to further elucidate the efficiency of foliar PS on FT and some relevant morpho-physiological changes were evaluated at four sampling dates: Nov., Jan., Mar., and Apr. following exposure to artificial freezing using electrolyte leakage and bud browning bioassay. In summer 2013 and 2014, PS was sprayed at fruit set, pea-sized berry, verison and maturity on 16 years old grapevines located in Malayer Grape Research Station (Iran) under a randomized complete block design. Based on results, foliar PS significantly affected yield, cluster weights, and berry weight and some fruit quality indices including soluble solids, titratable acidity, pH and

phenolic compounds. Foliar PS significantly changed the leaf N, K, P, Mg, Zn and Fe concentrations. The effect of nutrition treatments was also significant on FT of grapevines at four sampling stages. In Jan., the highest FT (LT_{50} = −25.97 °C) and the lowest FT (LT_{50} = −20.16 °C) was found in 3% PS- treated and control untreated vines, in respectively. Moreover, PS especially at 3% resulted in higher increments in abscisic acid, total phenol, soluble sugars, and polyamines concentrations. Potassium spray increased membrane stability and decreased electrolyte leakage. The ability of Potassium in FT improvement (lower electrolyte leakage) was found to be related to change in endogenous abscisic acid concentration as a stress hormone in preliminary and subsequent changes in other metabolites such as accumulation of soluble sugars, polyamines, and phenolic acids.

Potassium needs more Attention in Crop Nutrition

Hopkins, M. 6 January 2017. Crop Life.

It's well understood that plants require the right combination of the 14 essential mineral nutrients to sustain their growth, writes Rob Mikkelsen, Director, North American Program, International Plant Nutrition Institute. However, it frequently seems like just a few of the nutrients get most of the attention due to their cost or their environmental impacts. Potassium (K) is too often overlooked as a key component in every successful farming operation. The 'Frontiers of Potassium Science' conference looks at all aspects of K behavior in soils and plants, and how to improve potash fertilizer management.

Chapter Three - Bio-Intervention of Naturally Occurring Silicate Minerals for Alternative Source of Potassium: Challenges and Opportunities

Basak, B.B., B. Sarkar, D.R. Biswas, S. Sarkar, P. Sanderson, and R. Naidu. 2017. Advances in Agronomy 141:115-145. DOI: http://dx.doi.org/10.1016/bs.agron.2016.10.016.

Abstract: Soil needs simultaneous replenishment of various nutrients to maintain its inherent fertility status under extensive cropping systems. Replenishing soil nutrients with commercial fertilizer is costly. Among various fertilizers, deposits of potassium (K) ore suitable for the production of commercial K fertilizer (KCl) are distributed in few northern hemisphere countries (Canada, Russia, Belarus, and Germany) which control more than 70% of the world's potash market. Naturally occurring minerals, particularly silicate minerals, could be used as a source of K, but not as satisfactorily as commercial K fertilizers. In this context, bio-intervention (in combination with microorganisms and/or composting) of silicate minerals has been found quite promising to improve plant K availability and assimilation. This is an energy efficient and environmentally friendly approach. Here we present a critical review of existing literature on direct application of silicate minerals as a source of K for plant nutrition as well as soil fertility enhancement by underpinning the bio-intervention strategies and related K solubilization mechanisms. An advancement of knowledge in this field will not only contribute to a better understanding of the complex natural processes of soil K fertility, but also help to develop a new approach to utilize natural mineral resources for sustainable and environmental friendly agricultural practices.

Spatial Variability of Potassium in Agricultural Soils of the Canton of Fribourg, Switzerland

Blanchet, G., Z. Libohova, S. Joost, N. Rossier, A. Schneider, B. Jeangros, and S. Sinaj. 2017. Geoderma 290:107-121. DOI: http://dx.doi.org/10.1016/j.geoderma.2016.12.002.

Abstract: Potassium (K) is a crucial element for plant nutrition and its availability and spatial distribution in agricultural soils is influenced by many agro-environmental factors. In Switzerland, a soil monitoring network (FRIBO) was established in 1987 with 250 sites distributed over the whole of the canton of Fribourg (representing 4% of the surface area of Switzerland), whose territory is shared between the Swiss Midlands and the Western Alp foothills. In this study area, diverse geological deposits (sandstone, marlstone, silts and calcareous rocks), soil types (Cambisols, Gleysols, Rendzinas, Luvisols and Fluvisols) and land uses (cropland, permanent grassland and mountain pasture) are present, making the network interesting for assessing the relative contribution of environmental variables and land use management on soil properties. The aims of the present study were to (i) characterize the soil K status in the Fribourg canton according to four different extraction methods; (ii) analyse the spatial variability of soil K in relation to land use, soil type, soil parent material and topography; (iii) evaluate the spatial predictability of K at the canton level; and (iv) analyse the implications for K fertilization management. The overall amount of soil total K averaged 13.6 g kg^{-1} with significant variations across the sites (5.1-22.1 g kg^{-1}). The spatial distribution of total K content was influenced by relatively extended soil forming processes, as suggested by (i) a significant global spatial autocorrelation measure at the 10 km scale (Moran's I = 0.43); (ii) significant differences observed among soil types and soil parent materials and (iii) significant correlations with land attributes such as elevation (r = − 0.51). On the other hand, available mean K forms were significantly different among land uses, with the highest mean values of available K encountered in permanent grasslands, from 46.3 mg kg^{-1} (water extraction) to 198 mg kg^{-1} (acetate ammonium + EDTA extraction). All K forms (total and available) showed similar spatial regional patterns for all spatial interpolation methods, with areas dominated by permanent grassland and crops presenting higher values. However, these

trends were less pronounced for the available K forms due to the prevalence of on-farm management practices for these K forms (e.g. fertilization), likely inducing high spatial and temporal variability. This hypothesis was supported by spatial clustering of low and/or high K fertility status that could be related to local particular farming practices. Grasslands require particular attention with regard to overall high K fertility status.

Molecular Cloning and Functional Analysis of a Na^+-Insensitive K^+ Transporter of *Capsicum chinense* Jacq

Ruiz-Lau, N., E. Bojórquez-Quintal, B. Benito, I. Echevarría-Machado, L.A. Sánchez-Cach, M. de Fátima Medina-Lara, and M. Martínez-Estévez. 2016. Front. Plant Sci. DOI https://doi.org/10.3389/fpls.2016.01980.

Abstract: High-affinity K^+ (HAK) transporters are encoded by a large family of genes and are ubiquitous in the plant kingdom. These HAK-type transporters participate in low- and high-affinity potassium (K^+) uptake and are crucial for the maintenance of K^+ homeostasis under hostile conditions. In this study, the full-length cDNA of *CcHAK1* gene was isolated from roots of the habanero pepper (*Capsicum chinense*). *CcHAK1* expression was positively regulated by K^+ starvation in roots and was not inhibited in the presence of NaCl. Phylogenetic analysis placed the CcHAK1 transporter in group I of the HAK K^+ transporters, showing that it is closely related to *Capsicum annuum* CaHAK1 and *Solanum lycopersicum* LeHAK5. Characterization of the protein in a yeast mutant deficient in high-affinity K^+ uptake (WΔ3) suggested that CcHAK1 function is associated with high-affinity K^+ uptake, with K_m and V_{max} for Rb of 50 µM and 0.52 nmol mg^{-1} min^{-1}, respectively. K^+ uptake in yeast expressing the CcHAK1 transporter was inhibited by millimolar concentrations of the cations ammonium (NH_4^+) and cesium (Cs^+) but not by sodium (Na^+). The results presented in this study suggest that the CcHAK1 transporter may contribute to the maintenance of K^+ homeostasis in root cells in *C. chinense* plants undergoing K^+-deficiency and salt stress.

Root-to-Shoot Hormonal Communication in Contrasting Rootstocks Suggests an Important Role for the Ethylene Precursor Aminocyclopropane-1-carboxylic Acid in Mediating Plant Growth under Low-Potassium Nutrition in Tomato

Martínez-Andújar, C., A. Albacete, A. Martínez-Pérez, J.M. Pérez-Pérez, M.J. Asins, and F. Pérez-Alfocea. 2016. Front. Plant Sci. DOI: https://doi.org/10.3389/fpls.2016.01782.

Abstract: Selection and breeding of rootstocks that can tolerate low K supply may increase crop productivity in low fertility soils and reduce fertilizer application. However, the underlying physiological traits are still largely unknown. In this study, 16 contrasting recombinant inbred lines (RILs) derived from a cross between domestic and wild tomato species (*Solanum lycopersicum* × *Solanum pimpinellifolium*) have been used to analyse traits related to the rootstock-mediated induction of low (*L, low shoot fresh weight*) or high (*H, high shoot fresh weight*) vigor to a commercial F1 hybrid grown under control (6 mM, *c*) and low-K (1 mM, *k*). Based on hormonal and ionomic composition in the root xylem sap and the leaf nutritional status after long-term (7 weeks) exposure low-K supply, a model can be proposed to explain the rootstocks effects on shoot performance with the ethylene precursor aminocyclopropane-1-carboxylic acid (ACC) playing a pivotal negative role. The concentration of this hormone was higher in the low-vigor *Lc* and *Lk* rootstocks under both conditions, increased in the sensitive *HcLk* plants under low-K while it was reduced in the high-vigor *Hk* ones. Low ACC levels would promote the transport of K *vs.* Na in the vigorous *Hk* grafted plants. Along with K, Ca, and S, micronutrient uptake and transport were also activated in the tolerant *Hk* combinations under low-K. Additionally, an interconversion of *trans*-zeatin into *trans*-zeatin riboside would contribute to decrease ACC in the tolerant *LcHk* plants. The high vigor induced by the *Hk* plants can also be explained by an interaction of ACC with other hormones (cytokinins and salicylic, abscisic and jasmonic acids). Therefore, *Hk* rootstocks convert an elite tomato F1 cultivar into a (micro) nutrient-efficient phenotype, improving growth under reduced K fertilization.

Comparisons of Grain Yield and Nutrient Accumulation and Translocation in High-Yielding Japonica/Indica Hybrids, Indica Hybrids, and Japonica Conventional Varieties

Wei, H., T. Meng, C. Li, K. Xu, Z. Huo, H. Wei, B. Guo, H. Zhang, and Q. Dai. 2017. Field Crops Research 204:101-109. DOI: http://dx.doi.org/10.1016/j.fcr.2017.01.001.

Abstract: In China, high-yielding rice varieties called "super rice" have been developed among indica hybrid (IHS), japonica conventional (JCS), and japonica/indica hybrid (JIHS), but yield differences among these three rice groups have not been documented. In this study, four IHS varieties, four JCS varieties, and four JIHS varieties were compared for their yield formation including utilization of nitrogen (N), phosphorus (P), and potassium (K), in field experiments in 2013 and 2014 at Ningbo, Zhejiang, China. The average grain yield of JIHS across varieties and years was 12.4 t ha^{-1}, 11.3% and 15.3% higher than that of JCS and IHS, respectively. JIHS showed more spikelets per panicle and longer total growth duration compared with JCS and IHS. Compared with JCS and IHS, JIHS showed higher dry matter accumulation after stem elongation and higher leaf area index at heading and maturity stages. The higher grain yield produced by JIHS was accompanied by a higher total N, P, and K accumulation compared with JCS and IHS. Compared with JCS and IHS,

JIHS showed higher N translocation from the stem and lower P translocation from the leaf during the period from heading to maturity.

Genetic Engineering of the Biosynthesis of Glycinebetaine Leads to Alleviate Salt-Induced Potassium Efflux and Enhances Salt Tolerance in Tomato Plants

Wei, D., W. Zhang, C. Wang, Q. Meng, G. Li, T.H.H. Chen, and X. Yang. 2017. Plant Sci. 257:74-83. DOI: http://dx.doi.org/10.1016/j.plantsci.2017.01.012.

Abstract: Tomato (*Solanum lycopersicum* cv. 'Moneymaker') was transformed with the choline oxidase gene *codA* from *Arthrobacter globiformis*, which was modified to allow for targeting to both chloroplasts and the cytosol. Glycine betaine (GB) was accumulated in transformed plants, while no detectable GB was found in wild-type (WT) plants. Compared to WT plants, transgenic lines showed significantly higher photosynthetic rates (Pn) and antioxidant enzyme activities and lower reactive oxygen species (ROS) accumulation in the leaves when exposed to salt stress. Furthermore, compared with WT plants, K^+ efflux decreased and Na^+ efflux increased in roots of transgenic plants under salt stress; resulted in lower Na^+/K^+ ratios in transgenic lines. The exogenous application of GB also significantly reduced NaCl-induced K^+ efflux and increased Na^+ efflux in WT plants. A qRT-PCR assay indicated that GB enhanced NaCl-induced expression of genes encoding the K^+ transporter, Na^+/H^+ antiporter, and H^+-ATPase. These results suggest that the enhanced salt tolerance conferred by *codA* in transgenic tomato plants might be due to the regulation of ion channel and transporters by GB, which would allow high potassium levels and low sodium levels to be maintained in transgenic plants under salt stress condition.

Challenging the Potassium Deficiency Hypothesis for Induction of the Ripening Disorder Berry Shrivel in Grapevine

Griesser, M., S. Crespo Martinez, M.L. Weidinger, W. Kandler, and A. Forneck. 2017. Scientia Horticulturae 216:141-147. DOI: http://dx.doi.org/10.1016/j.scienta.2016.12.030.

Abstract: Berry shrivel (BS) is a ripening dysfunction resulting in grapes with low sugar content, high acidity, reduced anthocyanins and flaccid berries. In this study we challenge the K^+-deficiency hypothesis as underlying cause for BS in grapevine. The hypothesis is based on empirical vineyard studies and proposes that K^+-deficiency or a disbalance of K^+/Mg^{2+} in plant content cause of BS. Recent studies on more grapevine varieties and further geographical locations lack supporting evidence for the K^+ hypothesis. Here we review existing evidence from the field and apply physiological analyses to study processes involved in K^+ and nutrients transport in BS and non-symptomatic clusters. For the first time the molecular background of K^+ transportation is being studied over the course of BS disorder.
Our objectives were (1) to determine the distribution of nutrients in BS vines and clusters and (2) to evaluate the role of selected potassium transport proteins and channels during grape berry development and BS induction in pedicels and berries. Our results with ICP-MS show a strong and significant reduction of K^+ concentration in rachis and pedicels of BS grapes, whereas boron, zinc, copper and aluminum were increased. Concentration of nutrients in BS berries were either not changed or increased compared to non-symptomatic clusters. Expression analyses with qPCR in pedicels revealed no pre-symptomatic differences of genes involved in potassium transport (VviKUP1, VviKUP2 and VviK1.2), but later during ripening reduced expression was observed. In BS berries the expression of VviK1.2 was reduced before veraison. We show significant K^+ deficiency in BS rachis and pedicels along with partial reduced expression of K^+ transporter genes. Consequently K^+ phloem transport is involved in BS induction, however our study did not provide conclusive evidence to support the K^+ deficiency hypothesis as a single factor for BS induction. Instead the idea that a combination of further stress factors influences K^+ and assimilates translocation towards sink organs before veraison is proposed.

Effects of Low Sink Demand on Leaf Photosynthesis under Potassium Deficiency

Pan, Y., Z.Lu, J. Lu, X. Li, R. Cong, and T. Ren. 2017. Plant Physiology and Biochemistry 113:110-121. DOI: http://dx.doi.org/10.1016/j.plaphy.2017.01.027.

Abstract: The interaction between low sink demand and potassium (K) deficiency in leaf photosynthesis was not intensively investigated, therefore this interaction was investigated in winter oilseed rape (*Brassica napus* L.). Plants subjected to sufficient (+K) or insufficient (−K) K supply treatments were maintained or removed their flowers and pods; these conditions were defined as high sink demand (HS) or low sink demand (LS), respectively. The low sink demand induced a lower photosynthetic rate (P_n), especially in the −K treatment during the first week. A negative relationship between P_n and carbohydrate concentration was observed in the −K treatment but not in the +K treatment, suggesting that the decrease in P_n in the −K treatment was the result of sink feedback regulation under low sink demand. Longer sink removal duration increased carbohydrate concentration, but the enhanced assimilate did not influence P_n. On the contrary, low sink demand resulted in a high K concentration, slower chloroplast degradation rate and better PSII activity, inducing a higher P_n compared with HS. Consequently, low sink demand decreased leaf photosynthesis over the short term due to sink feedback regulation, and potassium deficiency enhanced the photosynthetic decrease through carbohydrate accumulation

and a lower carbohydrate concentration threshold for initiating photosynthesis depression. A longer duration of limited sink demand and sufficient potassium supply resulted in a higher photosynthesis rate because of delayed chloroplast degradation. This finding indicates that the nutritional status plays a role in leaf photosynthesis variations due to sink-source manipulation.

Long-Term P and K Fertilisation Strategies and Balances Affect Soil Availability Indices, Crop Yield Depression Risk and N Use

van der Bom, F., J. Magid, and L. Stoumann Jensen. 2017. Europ. J. Agron. 86:12-23. DOI: http://dx.doi.org/10.1016/j.eja.2017.02.006.

Abstract: The last century has seen a large increase of fertiliser use, along with a subsequent rise of crop productivity. However, in many places its intensive use has become a burden to the environment, and legislation has been introduced to restrict nutrient applications. In combination with changing production scenarios as a result of climate change, this means an improved understanding is needed of how low nutrient availability and climatic stress factors affect yields and yield stability.

We examined the long-term effects mineral and organic fertilisation on a nutrient-depleted field, and observed large annual variations: depending on the year, average spring barley yields under unfertilised management (U) were between 17-75% lower than the reference $N_{½}P_{½}K_{½}$ (60-10-60 kg ha^{-1}). Yields increased up to 174% under $N_1P_1K_1$ (120-20-120 kg ha^{-1}), while animal manure applications at an N availability level corresponding to N_1 were between 79 and 137%. No temporal yield trends could be observed, but long-term changes of Olsen-P and exchangeable K were related to the nutrient balances (inputs-offtake) (r^2 = 0.60 and 0.59, respectively, $P < 0.001$).

Multiple linear regression analysis was used to examine the effects of the treatments in combination with annual weather variations. The results could be split into two outcomes, 1) a general relation between yields and temperatures for the periods of early spring ($P < 0.01$, multiple $R^2 = 0.31$) and summer ($P < 0.001$, multiple $R^2 = 0.45$), and 2) an interaction between temperature and nutrient applications during crop establishment, leading to a diverse response of relative yields ($P < 0.001$, multiple $R^2 = 0.64$), i.e. relative yield losses under the unfertilised treatment (U) were greater in years with lower spring temperatures, and, conversely, the increased nutrient availability in the fully mineral and organically fertilised treatments could partially alleviate the negative effects.

After 13 years of repeated fertilisation, inputs were suspended for a single year and only N was applied to evaluate the residual effects. Yields were significantly affected by the different fertilisation histories ($P < 0.001$). Likewise, apparent nitrogen recovery tended to improve with previous inputs, but the observations were highly variable.

Overall, the analyses agree with the notion that brief periods of stress at a critical stage may significantly affect yields, and confirmed that management of sufficient nutrient availability is critical for maintaining high and stable yields.

Growth Performance and Antioxidative Response in Bread and Durum Wheat Plants Grown with Varied Potassium Treatments under Ambient and Elevated Carbon Dioxide

Yilmaz, O., K. Kahraman, R. Ozgur, B. Uzilday, I. Turkan, and L. Ozturk. 2017. Environmental and Experimental Botany 137:26-35. DOI: http://dx.doi.org/10.1016/j.envexpbot.2017.01.012.

Abstract: It is predicted that atmospheric carbon dioxide (CO_2) level will double by the end of the current century. Although the fertilization effect of CO_2 on plant growth is well documented, studies that investigate plant nutritional requirements under elevated CO_2 are scarce. Potassium (K) is an essential plant nutrient with prominent roles in key physiological processes. Aim of this work, was to determine the effects of K deficiency on plant growth as affected by elevated CO_2 and how antioxidant defense systems (activities of SOD, CAT, POX, APX, GR, MDHAR, DHAR, lipid peroxidation and total antioxidant activity) respond to K deficiency under ambient (a-CO_2: 400 ppm) or elevated (e-CO_2: 900 ppm) atmospheric CO_2 conditions in durum (*Triticum durum* cv. Sarıçanak-98) and bread wheat (*Triticum aestivum* cv. Adana-99). Plants were grown in hydroponics with sufficient (1850 µM), low (60 µM) or deficient (20 µM) K and under a-CO_2 or e-CO_2. As expected, e-CO_2 promoted biomass production with adequate K supply, however in low and deficient K plants biomass was either not affected or even decreased by e-CO_2. It was observed that low or deficient supply of K induced oxidative stress, but e-CO_2 had no significant impact on antioxidative response of plants and thus could not alleviate detrimental effects of K deficiency. Under K deficiency, CAT activity decreased in both species but this decrease was accompanied with increases in POX and APX which may be for adapting to the changing environment. In general, responses in antioxidant defense enzymes were linked to K nutritional status of plants rather than e-CO_2 conditions.

Potassium Fertilizer Improves Drought Stress Alleviation Potential in Cotton by Enhancing Photosynthesis and Carbohydrate Metabolism

Zahoor, R., H. Dong, M. Abid, W. Zhao, Y. Wang, and Z. Zhou. 2017. Environmental and Experimental Botany 137:73-83. DOI: http://dx.doi.org/10.1016/j.envexpbot.2017.02.002.

Abstract: Under drought, limited photo-assimilates synthesis and their poor partitioning is a main constraint to final yield production in cotton (*Gossypium hirsutum* L.). To study the potassium (K) role in photo-assimilation and carbohydrate metabolism in cotton under soil drought stress during flowering and boll formation stage, a two-year pot experiment was conducted in 2015 and 2016. Two cotton cultivars namely Simian 3 (low-K tolerant) and Siza 3 (low-K sensitive) were grown under three K rates (0, 150 and 300 kg K_2O ha^{-1}). Plants were exposed to well-watered [(75 ± 5%) soil relative water content (SRWC)] and water stress (35-40% SRWC) for 7 days followed by re-watering to SRWC (75 ± 5%). The results showed that water-stressed plants under K0 application exhibited significant decline in net photosynthesis, stomatal conductance, intercellular CO_2 concentration and ribulose-1,5-bisphosphate carboxylase (Rubisco) activity and resulting in reduced photo-assimilates synthesis and partitioning towards reproductive organs in both cultivars. Conversely, K application decreased the decline in photosynthesis, Rubisco activity and biomass accumulation and partitioning. The positive effects of K application increased as increasing K rates, and that was more pronounced in Siza 3 than Simian 3. Drought stress decreased starch content but increased sucrose content; whereas, K application maintained higher concentration of sucrose in leaves of water-stressed plants through the regulation of higher sucrose phosphate synthase (SPS), sucrose synthase (SuSy) and lower soluble acid invertase (SAI) activities. The results of the study concluded that K application regulated the photo-assimilation and translocation process along with the related enzymes activities in cotton. The study suggests that K nutrient management strategy has the potential to minimize the impacts of drought stress in cotton.

Chloride Fertilizers Increase Spring Wheat Yields in the Northern Great Plains

Graham, C., H. Woodard, A. Bly, P. Fixen, and R. Gelderman. 2017. Agron. J. 109(1):327-334. DOI: 10.2134/agronj2016.04.0205.

Abstract: Chloride (Cl^-) plays an important role in osmoregulatory functions within the plant and aids in disease suppression. Previous research established a soil sufficiency level and fertilizer Cl^- recommendations based on a 0- to 60-cm soil depth sample. This work found spring wheat (*Triticum aestivum* L.) yield was responsive to Cl^- fertilizers on soils with low Cl^- soil tests. However, the response was often variable and cultivar specific, which suggested that further refinements to the Cl^- fertilizer recommendations were necessary. In this research, the impact of Cl^- fertilizer on yield, test weight, and protein of three spring wheat cultivars (Forge, Marshall, and Oxen) was tested in a randomized complete block experiment in 1997, 1998, 1999, 2000, and 2002 in Aurora, SD. Across all years and cultivars, results showed a statistically significant grain yield increase of 0.17 t ha^{-1} with Cl^- addition. Similarly, Cl^- increased test weight by 0.98 kg hL^{-1}. Protein, on the other hand, showed a cultivar by Cl^- response with Cl^- increasing protein by 2.28 g protein kg^{-1} in Oxen and decreasing protein 2.52 g protein kg^{-1} in Forge. Where pre-plant-soil test Cl^- levels were lower than 1.87 mg kg^{-1}, fertilizer Cl^- applications increased grain yield by 0.26 t ha^{-1} with an average return of $18.42 ha^{-1}. However the potential profitability of Cl^- fertilizer application is highly dependent on the choice of cultivar. Further research is necessary to assess if increasing spring rainfall in the region will increase Cl^- yield responses.

Eight-Year Long Potassium Fertilization Effects on Quantity/Intensity Relationship of Soil Potassium under Double Rice Cropping

Islam, A., A.J.M. Sirajul Karim, A.R.M. Solaiman, Md. Shafiqul Islam, and Md. Abu Saleque. 2017. Soil and Tillage Research 169:99-117. DOI: http://dx.doi.org/10.1016/j.still.2017.02.002.

Abstract: Present research was undertaken to understand the effect of long-term potassium (K) fertilization @ 0 kg (K_0) and 80 kg (K_{80}) K ha^{-1} on the quantity/intensity (Q/I) parameters for K in soil and characterize the Aeric Haplaquept soil for K supplying capacity under long-term continuous rice cropping. The study involved laboratory experiments on Q/I parameters of the soils in different depths (0-75 cm depth) from long-term K management experimental field. The Q/I parameters showed a linear relationship for both K omission and K fertilized soils at different depths. Omission of K decreased the equilibrium K concentration ratio (CR_0^K) compared to K applied to the soil and slightly decreased the labile K (K_L) and non-specifically available K (-ΔK_0) but had no effect on specifically available K (K_X). The K omission increased the potential buffering capacity (PBC^K) compared to K fertilized soil. Potassium management had little effect on equilibrium exchangeable K (EK_0), magnitude of the conversion of added K to exchangeable pool (α) and non-exchangeable pool (β). However, equilibrium solution K (CK_0) in K omission soil was lower than K applied soil. β was higher than α in both the K management conditions. The PBC^K for non-exchangeable pool was also higher than exchangeable pool both in K omission and K fertilized soils. Potassium management influenced critical solution K (CKr) and critical exchangeable K (EKr) but had no effect on minimum exchangeable K (Emin). Since the exchangeable K (EK), EKr and EK_0 is very close to Emin it is concluded that EKr and Emin should be consider in interpreting the K fertility specially the EK of soil under long-term wetland double rice cultivation.

Chemistry and Transport of Potassium during the Non-Steady State of Syenite Leaching

Kejing Li, K., and C.A. Dawydiak. 2017. Soil Sci. Soc. Amer. J. 81(1):29-40. DOI: 10.2136/sssaj2016.09.0300.

Abstract: Syenite is mainly composed of potassium feldspar (Kfs), which is a structural K-bearing mineral in soil, typically

considered as an insoluble K resource. In contrast to the slow dissolution process, the initial non-steady state stage usually gives a fast K^+ release rate and quickly decreasing, which is closely related with surface reactions. This process in a flow reactor has not been fully understood with a kinetic model. Earlier research about albite found that ion exchange and surface cation desorption occur rapidly, which leads to experimental efforts of this work. The 140-mesh (105-µm) and 325-mesh (44-µm) syenite leaching tests were performed under room temperature and pressure, using pH 1 and 3 diluted nitric acids, and flow rates from 0.01 to 1 mL min^{-1} in a packed-bed flow reactor. Inductively coupled plasma mass spectrometry was used to measure the ions' (K^+, Na^+, Al^{3+}, Si^{4+}, Ca^{2+}, Fe^{3+}, Ba^{2+}) time-dependent concentrations simultaneously. The pH measurement was added to monitor the consumption of reactant H^+, providing reactant information crucial for understanding the surface reactions. The two fast surface reactions previously observed with albite were also observed with Kfs during the non-steady state. The initial K^+ release kinetics were different from H^+ adsorption and other surface atoms detachment. The slow dissolution reaction and the influence of transport factors were also evaluated. A model has been built with two parts that include the fast reactions and the transport-dissolution terms, conforming to the first-order equation with a leachant pH correction factor and a parabolic diffusion equation.

Documentation of Five Potassium- and Phosphorus-Solubilizing Bacteria for their K and P-Solubilization Ability from Various Minerals

Debabrata Nath, B. Ram Maurya, and V. Singh Meena. 2017. Biocatalysis and Agricultural Biotechnology 10:174-181. DOI: http://dx.doi.org/10.1016/j.bcab.2017.03.007.

Abstract: The ability of a few soil bacteria to transform unavailable forms of phosphorus (P) and potassium (K) to an available form is an important feature in plant growth-promoting bacteria for increasing crop yields of high- P and K-demand crops. In this research, screening and characterization of thirty-five K-solubilizing bacterial (KSB) and P-solubilizing bacteria (PSB) isolate which were evaluated for their ability to solubilize K and P from the waste muscovite (WM), waste biotite (WB), tri-calcium phosphate (TCP) and rock phosphate (RP) by analyzing the soluble P and K content after 7, 14, 21 days after incubation (DAI) at 28±2 °C on MABs (Modified Aleksandrov Broths) and Pikovskaya's medium. The soluble P and K contents in all isolates were significantly ($p < 0.01$) higher than the contents in nonbacteria treatment. K-release from WB varied significantly from 3.5 to 5.0 µg mL^{-1}, 4.4-6.3 µg mL^{-1} and 5.3-7.2 µg mL^{-1} at 7, 14 and 21 DAI, respectively. Herein, isolate KSB-105 had caused significantly higher K-release as compared to rest of isolates. Overall K-release from WB was highest by PSB-56 with 7.2 µg mL^{-1}. While, significant higher amount of P-release was observed at 21 DAI (13.7 µg mL^{-1}) followed by at 14 DAI (12 µg mL^{-1}) and lowest was recorded at 7 DAI (5.1 µg mL^{-1}). PSB-56 showed it's significantly superiority in P-release from TCP at 21 DAI (13.7 µg mL^{-1}) as compared rest of isolates. Overall, it can be concluded that the diversity of KSB and PSB as bioinoculants to release K and P provides a win-win situation under in vitro condition. Therefore, it is crucial to adopt efficient KSB and PSB isolates in interventions for the judicious use of chemical and biological resources for maximizing food production while reducing pollution and rejuvenating degraded land for sustainable agriculture.

Effect of Potassium Foliage Application Post-Anthesis on Grain Filling of Wheat under Drought Stress

Lv, X., T. Li, X. Wen, Y. Liao, and Y. Liu. 2017. Field Crops Research 206:95-105. DOI: http://dx.doi.org/10.1016/j.fcr.2017.02.015

Abstract: Potassium foliage application of (KFA) is widely used for wheat production in China. The objective of this study was to investigate the effect of KFA on grain filling of wheat under different soil moisture conditions and the underlying mechanisms. The results indicate that KFA increased the zeatin (Z), Z riboside (ZR), and abscisic acid (ABA) contents and the ethylene (ETH) evolution rate in inferior grains during the early and middle grain filling stages, which promoted sink strength. However, KFA decreased the activities of superoxide dismutase (SOD), peroxidase (POD), and catalase (CAT), as well as the soil-plant analyses development (SPDA) value and increased the malondialdehyde (MDA) content in the flag leaves. The effect of KFA on grain filling also exhibited a notable genotypic difference. In the heavy-panicle cultivar, KFA had no significant effect on grain filling under the well-watered (WW) treatment, but it decreased the rate and active period of the grain filling of inferior grains and significantly decreased the grain weight following soil-dried (SD) treatment. In the light-panicle cultivar, KFA significantly promoted the grain filling rates of inferior grains and increased the grain weight under the WW treatment. However, KFA significantly decreased the active grain filling period but increased the grain filling rate and, therefore, had no significant effect on the grain weight under the SD treatment.

Read On

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Impressum *e-ifc*
ISSN 1662-2499 (Online); ISSN 1662-6656 (Print)

Publisher: International Potash Institute (IPI)
Editors: Amnon Bustan, Israel; Susanna Thorp, WRENmedia, UK; Patrick Harvey, Green-Shoots, UK; Hillel Magen, IPI
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