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# Editorial



Dear readers,

2019 is the 150th anniversary of the periodic table of chemical elements. To mark this anniversary the United Nations General Assembly and UNESCO proclaimed this year as the International Year of the Periodic Table of Chemical Elements (IYPT 2019).

The first periodic table was published by Russian chemist Dmitri Mendeleev in 1869. The Periodic Table of Chemical Elements is one of the most significant achievements in science, capturing the essence not only of chemistry, but also of physics and biology.

Out of the 118 confirmed elements in the table, there a few that are of particular importance for agriculture. Using the periodic table, biologists have been able to pinpoint 17 elements that are essential to plants for nutrition. To thrive, every plant needs these 17 essential nutrients, including nitrogen (N), phosphorus (P), potassium (K), sulfur (S), calcium (Ca), magnesium (Mg), boron (B), chlorine (Cl), copper (Cu), iron (Fe), manganese (Mn), molybdenum (Mo), nickel (Ni), and zinc (Zn). Three non-fertilizer elements, carbon (C), hydrogen (H), and oxygen (O) complete the list.

These nutrients are the building blocks of plant life and without them, farmland would be barren. Farmers must therefore ensure their crops have access to the nutrients they need. The application of fertilizers and organic manures to supplement what is already in the soil is at the heart of agriculture. And we can say with absolute certainty that Dmitri Mendeleev made a great contribution to the development of modern farming and fertilizers.

In this *e-ifc* edition, we present results on how the proper use of these nutrients can increase crop yield and quality. First of all, potassium, in two important crops: maize in Kenya and rice in India. Three additional nutrients, sulfur, calcium and magnesium, were also tested along with potassium for soybean production in Argentina and Paraguay.

This last paper was written by Dr. Ricardo Melgar from Argentina, who conducted the soybean project. Sadly, Ricardo passed away shortly after finishing this paper. Ricardo was a great friend of IPI and worked with us for more than 20 years as a consultant and in setting up numerous field experiments, as well as participating in our international symposia. We have lost a valued friend and an authority for soil science and agronomy. We will miss him greatly and will always cherish his great contribution to science and to our institute.

I wish you an enjoyable read.

**Dr. Patricia Imas**
**IPI Scientific and Communications Coordinator**

**Photo cover page:** Potash deficiency in soybean in an experiment at Alvorada farm, Luis Eduardo Magalhaes, Bahia state, Brazil. Photo by I. Döwich.

# Research Findings

Wheat response to polyhalite application, most likely due to sulfur contribution. Photo by R. Melgar.

## Polyhalite for Grain in Soybean-Based Production Systems in Argentina and Paraguay

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### Abstract

South American countries are huge grain producers, primarily cultivating soybean (*Glycine max*), wheat (*Triticum aestivum*), and maize (*Zea mays*). The long-term maintenance of prolific grain production systems largely depends on soil fertility. Beyond liming, which is a necessary common practice due to the low soil acidity prevailing in most of the arable lands, preserving adequate soil availability of the macronutrients nitrogen (N), phosphorus (P), potassium (K), and sulfur (S), throughout a single or successive cropping cycles, has become a considerable challenge. Starter fertilizer blends frequently fail to support the anticipated crop yield and grain quality. Polyhalite is a natural marine sediment, which consists of 14% potassium oxide ($K_2O$), 48% sulfur trioxide ($SO_3$), 6% magnesium oxide (MgO) and 17% calcium oxide (CaO). As a fertilizer, polyhalite releases nutrients

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*Note: Fabio Vale has taken on the role of corresponding author as, sadly, Ricardo Melgar passed away before publication of this paper.*

considerably slower than other K-containing fertilizers, thus suggesting additional means to improve soil K availability. The main objective of the trials set in Argentina and Paraguay was to compare, under field conditions, the agronomic efficiency of bulk fertilizer blends that include polyhalite with other formulations currently in use.

Three field trials were conducted in Argentina - one experiment at Nueve de Julio with wheat and two at Mercedes with soybean and maize - and were designed to evaluate the direct effects on a single crop. The treatments included mono-ammonium phosphate (MAP) alone (control), single super phosphate (SSP), MAP + gypsum (34/66%), and MAP + polyhalite at three different ratios 37/63%, 22/78%, and 16/84% that provided increasing levels of K, magnesium (Mg), and S. The crop responses to S were obvious at all growth stages and the average yield increases were 1,371, 1,303 and 754 kg $ha^{-1}$, (29%, 24% and 39%) for wheat, maize and soybean, respectively. Among the three crops, only soybean yield increased significantly in response to elevated polyhalite rates.

In Paraguay, a single trial was carried out at Itapúa with soybean as the initial crop grown using the starter fertilizer blend, and maize as the succeeding crop testing the residual soil effects. Treatments included MAP (control), compared with two common fertilizer blends which differed in their phosphorus pentoxide and potassium oxide ratio ($P_2O_5$:$K_2O$) - 3:1 vs. 2:1 - comprising MAP, SSP, and a K donor (KCl or polyhalite). Both crops demonstrated significant yield increases in response to the higher K dose applied with the 2:1 P:K ratio. The use of polyhalite also gave rise to a slight but significant soybean yield increase at the 3:1 P:K ratio.

In conclusion, polyhalite is an effective S source on S-deficient soils. In addition, it can successfully replace KCl fertilizers on K-deficient soils. However, the long-term impact of polyhalite is quite limited and cannot be accounted for under successive cropping cycles. Moreover, the advantages of supplemented S, K, or MgO are observable only where the requirements of other essential macronutrients, such as N and P, are adequately met. Otherwise, polyhalite or other corresponding nutrient donors are prone to fail in supporting grain production systems in South America.

*Keywords: Glycine max*; potassium; starter fertilizers; sulfur; *Triticum aestivum; Zea mays.*

## Introduction

Soybean is the most important crop in large grain production systems of southern South America. In this region, fertilization practices differ significantly in quantity, source, methodology and timing, mainly due to considerable ecological divergence arising from different climates and soils. While phosphorus (P) and sulfur (S) are usually applied in all regions, other nutrients are applied less consistently; for instance, potassium (K) is commonly used in Brazil and Paraguay, but is applied to a lesser extent in Uruguay, and almost not at all in Argentina. Magnesium (Mg) is also included in some fertilizing formulas, but only in Brazil and Paraguay.

Current fertilization practices in Argentina only just supply sufficient P and S for the grain crops commonly grown on typical Pampean soils, which usually contain enough K and Mg to avoid supplementation (Garcia and González-Sanjuan, 2013; Grasso and González-Sanjuan, 2018). Nevertheless, recent surveys have revealed the occurrence of K and Mg depletion symptoms in many areas (Sainz Rozas *et al.*, 2013; Herrrera and Rotondaro, 2017). This is particularly evident where soil texture is more sandy than loamy, indicating that K reserves might be low. Crops grown in regions known as ‘sandy pampas’ and in the Eastern provinces of Corrientes and Entre Rios are expected to respond to K and Mg application, especially under conditions of heavy yields.

Typically, soybean is the most important crop, functioning as the base of a crop rotation system, complemented with wheat and maize. Often, when wheat precedes soybean, only the former receives fertilization. Depending on the region, median fertilization for soybean in Argentina usually includes 40 kg phosphorus pentoxide ($P_2O_5$) $ha^{-1}$ and 10 kg S $ha^{-1}$ of varying sources, with no potassium oxide ($K_2O$) or magnesium oxide (MgO). The nutrients are all applied at sowing and within the seed line. Maize usually receives a higher volume of inputs, i.e., about 60 kg $P_2O_5$ and 20 kg S $ha^{-1}$, plus variable amounts of nitrogen (N), ranging from 90 to 120 kg $ha^{-1}$ under different application modes (Grasso and González-Sanjuan, 2018; Fertilizar AC, 2018).

In contrast, fertilization practices for soybean cultivation in Paraguay, along with the neighboring states of Parana and Santa Catarina in Brazil, originated from the traditional approach of extensive and generous P and K application. Median soybean fertilization in Paraguay includes 200 kg $ha^{-1}$ of 4-30-10-4 N-P-K-S, (comprising of 60, 20, and 8 kg $ha^{-1}$ of $P_2O_5$, $K_2O$, and S, respectively), and formulation of 5-30-10 N-P-K. A typical rotation is soybean followed by maize as the second crop (Cubilla, 2005; Wendling, 2005).

While P tends to accumulate in most of the local soils, K is frequently depleted. This phenomenon may be explained by the nature of the soils, which are highly weathered with poor cation exchange capacity, deep, and well drained. Potassium is usually applied at sowing through soluble NPK formulations, resulting in an extremely high K concentration at germination, followed by a rapid exhaustion of this soluble nutrient, as it is leached away from the rhizosphere during the rainy season.

In both countries, soil K status has become a critical crop nutrition challenge. In sandy as well as highly weathered soils, the development and maintenance of sufficient K availability throughout the crop cycle requires a stable source of the nutrient. Frequent fertilizer applications are impractical or too expensive in large grain production systems. So far, there have been no perceptible alternatives to the pre-plant fertilizer application. However, at least in the case of K, the fertilizer should be much less soluble than in the currently used complex formulations.

In addition to the problem of insufficient K throughout the crop cycle, there are several other crop nutrition aspects requiring better solutions. High soil acidity endangers many arable lands in South America, a problem encountered by extensive calcium (Ca) application through liming (Caires *et al.*, 2015; dos Santos *et al.*, 2018). Crops also require more S fertilizer since the recent significant reductions in the world's atmospheric S pollutants (Haneklaus *et al.*, 2016). While S is recognized as the fifth most important plant macronutrient, responsible for protein metabolism and many other vital processes in the plant biology (Hawkesford, 2000), the decreasing availability of this nutrient in most arable soils necessitates more active fertilization approaches. Gypsum ($CaSO_4$) application is quite common, contributing both S and Ca, however, it lacks K and Mg. Other S fertilizers are combined with N – a nutrient for which crop requirements are easily met using affordable fertilizers.

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

Given the differences in fertilization practices between the two countries, the main common objective of the trials was to compare, under field conditions, the agronomic efficiency of bulk fertilizer blends that include polyhalite with other current formulations applied to soybean. A more specific objective in Argentina was to determine crops' responses to K and Mg on areas with coarse-textured soils. In Paraguay, crop responses to Mg, and the residual effects of fertilizer application to soybean on the succeeding maize crop, were also studied.

## Materials and methods

In Argentina, two locations were chosen on mollisols soils, one in the center (Nueve de Julio) and the other in the northern (Mercedes) Pampean region (Fig. 1). One field experiment with wheat was set in Nueve de Julio, and two trials with maize and soybean in neighboring plots in Mercedes. The three trials were carried out during the 2016-2017 season.

In Paraguay, the field experiment was carried out with soybean followed by maize in two consecutive seasons (2017-2018) on ultisol of Itapúa Dept. (Fig. 1). The soil at each location was sampled before sowing and characterized (Table 1).

Due to significant differences in the common fertilization practices employed in each country, the treatments varied between the two countries. In Argentina, all treatments were based on different sources of S that were applied at sowing and with a single rate of P (30 kg $P_2O_5$ $ha^{-1}$), in addition to other fertilizer combinations, including a control with no sulfur. Gypsum and single super phosphate (SSP) treatments were included, since they were the

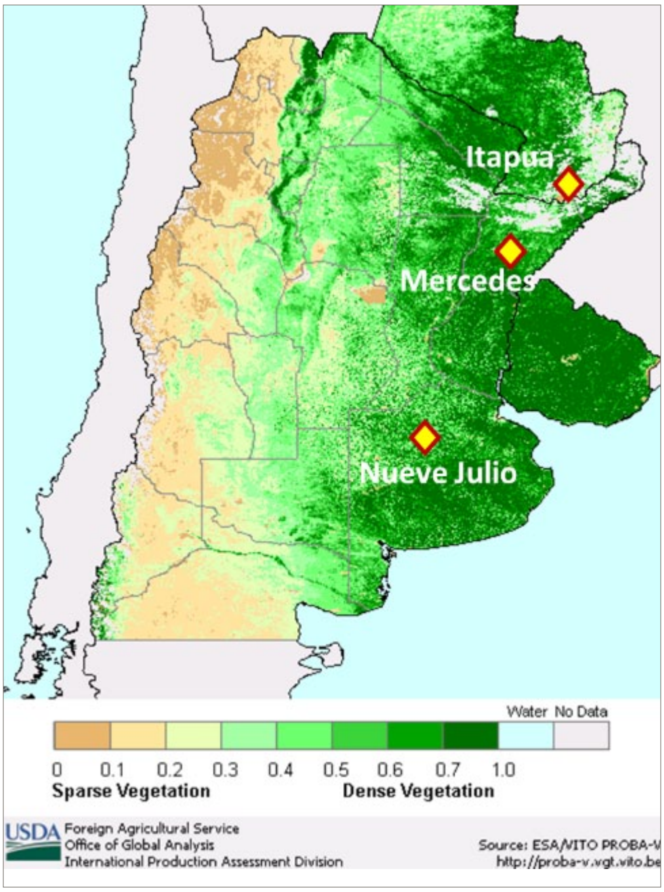


**Fig. 1.** Map of the study area with locations of field trials.

**Table 1.** Soil chemical and textural attributes of the top layer (0.0-0.2 m).

| Site/crop | Soil taxonomy | Texture class | pH | Ca | Mg | K | S | P | O.M. |
|---|---|---|---|---|---|---|---|---|---|
| | | | *Water 1:2.5* | ---------------*cmol$_c$ kg$^{-1}$* | --------------- | | ---------*mg kg$^{-1}$* | --------- | *g kg$^{-1}$* |
| Nueve de Julio/wheat | Entic Hapludoll | Loamy sand | 5.9 | 6.5 | 1.36 | 1.23 | 7.1 | 9.8 | 29 |
| Mercedes/maize | Typic Argiudoll | Sandy loam | 5.4 | 7.4 | 2.10 | 0.50 | 3.1 | 5.8 | 32 |
| Mercedes/soybean | | | 5.2 | 7.8 | 2.20 | 0.20 | 3.1 | 4.7 | 28 |
| Itapúa/soybean | Typic Rhodudult | Clayey | 5.9 | 8.0 | 0.83 | 0.60 | 5.4 | 2.1 | 32 |
| Itapúa/maize | | | 5.9 | 8.0 | 0.81 | 0.61 | 4.8 | 2.3 | 31 |

*Note:* O.M. = 1.72 * Organic carbon ($K_2Cr_2O_7$); Ca, Mg and K (NH4 Ac 1 mol L$^{-1}$); P (Bray 1); S ($Ca_2PO_4$ 1M extraction).

common sources of S with comparable rates of S to polyhalite (Table 2A).

In Paraguay, where bulk blends of NPK with potassium chloride (KCl) are commonly used but S supply is still ignored, two formulations at different grades were evaluated - each with a partial replacement of K from KCl with polyhalite (Table 2B). The five treatments consisted of two grades (5-20-10 and 5-30-15) having different proportions of $P_2O_5$ to $K_2O$ (2:1 and 3:1). These two formulations, typically used within the region's soybean production, were in turn, prepared with different proportions of $K_2O$ originating from KCl and polyhalite. This resulted in the development of formulations with and without MgO. The four grades were compared with mono-ammonium-phosphate (MAP) as a control lacking S, K and Mg. All five treatments received the same rate of 70 kg $P_2O_5$ ha$^{-1}$. The treatments described, including the amount of nutrients applied and the proportion of the compounds are shown in Table 2B.

The treatments for both countries were allocated in a randomized complete block design with four replications. Fertilizers were applied at sowing of the soybean and maize in Argentina, and only to the soybean in Paraguay. The wheat crop in Nueve de Julio received 75 kg N ha$^{-1}$, applied prior to crop emergence in the form of urea. The maize crops at both sites received a broadcast fertilization with N as urea at V4-V6 stage in addition to the N applied through the MAP starter, thus providing 100 and 45 kg N ha$^{-1}$ in Argentina and Paraguay, respectively.

At Nueve de Julio, Argentina, the wheat variety Klein was sown at a density of 278 seeds m$^{-2}$ under no-till, on 16 June 2016. At Mercedes, Argentina, soybean variety DM 8277 I pro was sown on 1 December 2016, at a density of 45 seeds m$^{-2}$ and with a distance of 0.35 m between rows. At an adjacent plot at Mercedes, a maize hybrid (Syngenta 126 VT 3pro) was sown on 5 January 2017, at a density of 5 plants m$^{-2}$ and with 0.52 m spacing between rows.

**Table 2**. Bulk fertilizer starter treatments used within the experiments in Argentina (A) and Paraguay (B), listing the nutrient source, ratios and quantities. Supplement N fertilizer was evenly applied through urea, as detailed in the text.

**A) Argentina**

| Treatment - blends (w/w) | Fertilizer rate | N | $P_2O_5$ | $K_2O$ | MgO | S |
|---|---|---|---|---|---|---|
| | ---------- | ---------- | ---------- | *kg ha$^{-1}$* | ---------- | ---------- |
| Control - MAP | 58 | 6 | 30 | - | - | - |
| SSP | 158 | 0 | 30 | - | - | 19 |
| MAP + gypsum (34%/66%) | 167 | 6 | 30 | - | - | 19 |
| MAP + polyhalite (37%/63%) | 158 | 6 | 30 | 14 | 6 | 19 |
| MAP + polyhalite (22%/78%) | 258 | 6 | 30 | 28 | 12 | 38 |
| MAP + polyhalite (16%/84%) | 358 | 6 | 30 | 42 | 18 | 57 |

*Note:* MAP: 11-52-0-0S; SSP: 0-19-0-12S. Treatments 3-5 are bulk blends of MAP, granular gypsum (0-0-0-17S) and polyhalite (0-0-14-19S-3.6 Mg).

**B) Paraguay**

| Treatment (fertilizer blend) | $P_2O_5$:$K_2O$ | Grade NPKS | Fertilizer rate | N | $P_2O_5$ | $K_2O$ | MgO | S |
|---|---|---|---|---|---|---|---|---|
| | | | ---------- | ---------- | ---------- | *kg ha$^{-1}$* | ---------- | ---------- |
| Control - MAP | - | 10-52-0-0 S | 135 | 15 | 70 | - | - | - |
| MAP, SSP, KCl | 3:1 | 5-30-10-5 S | 233 | 11 | 70 | 23 | - | 11 |
| MAP, SSP, polyhalite | 3:1 | 6-30-10-6 S | 233 | 15 | 70 | 23 | 5 | 15 |
| MAP, SSP, KCl | 2:1 | 5-30-15-3 S | 233 | 12 | 70 | 35 | - | 8 |
| MAP, SSP, polyhalite | 2:1 | 6-30-15-4 S | 233 | 15 | 70 | 35 | 3 | 10 |

*Note:* Treatments 2-5 are bulk blends of MAP (11-52-0-0S), SSP (0-19-0-12S), KCl (0-0-60) and polyhalite (0-0-14-19S-3.6 Mg).

In Paraguay, 45 kg seeds ha$^{-1}$ of the soybean variety Nidera 5959 was sown using farmers' machinery on 18 October 2017, with 0.45 m spaced rows under no tillage. After harvesting the soybean, a maize hybrid (Pioneer 4285 YHR) was sown on 9 March 2018 under no-till, at a density of 6.1 plants m$^{-2}$, and with row spacing of 0.45 m. The maize crop was applied with 115 kg NPK fertilizer ha$^{-1}$ (11-15-15), adding 14 kg $K_2O$ ha$^{-1}$ to all treatments.

Weed, pest, and disease control were performed with the best information available at each site using farmer's machinery and practices. When the crops reached physiological maturity, a selected central zone of each plot at every site was harvested with an experiment-scale combine. Grains were weighted and sampled for their humidity content. Wheat samples were also analyzed for quality parameters, such as protein and gluten contents and grain size (test weight). Grain yields were adjusted to the commercial humidity standard of 13.5% and expressed as Mg ha$^{-1}$ (ton ha$^{-1}$). Results were analyzed statistically using the SAS package and general linear model procedure.

## Results and discussion

### Argentina

#### *Wheat (Nueve de Julio, Argentina)*

The experiment was conducted in a field typical of the region, presenting very low soil nutritional values (Table 1). Soil S was particularly low and close to being deficient. Since all treatments were applied with similar doses of N and P, the differences in results could be attributed to the levels of S, K or Mg (Table 2A).

Yield response to S application was significant, unequivocal (Table 3), and even visible in the field (Fig. 2). The S-applied wheat obtained on average 1,371 kg grain ha$^{-1}$ more than the control, which is a 29% increase. These results support previous studies that demonstrated wheat S requirements (Shah *et al.*, 2018; Yu


**Fig. 2.** A wheat field in Nueve de Julio, Argentina with the control treatment (without S) left vs. the highest S-applied treatment (57 kg S ha$^{-1}$, 84% polyhalite), at the vegetative stage (above) and near harvest (below). Photos by R. Melgar.

*et al.*, 2018). Among the polyhalite-applied treatments, yield tended to increase with the higher polyhalite rate in the fertilizer blend; however, these differences were not statistically significant.

Grain protein levels ranged from 9-11%, which is below the minimum industry standards of 11% (Delwiche and Miskelly, 2017). The highest wheat protein content, 11%, was obtained by the control, which also had the lowest grain yield, while the protein content of wheat applied with S was quite stable at 9.1-9.3% (Table 3). Consequently, the calculated protein yield ranged from 520-581 kg ha$^{-1}$ with no significant differences between treatments. Thus, in contrast to the significant relative increase in the grain yield in response to S application, the corresponding protein yield increment was small and similar to the control (Fig. 3 and Table 3). Interestingly, grain test weights were much greater than the commercial set for the best grade (above 79). However, any significant differences found among treatments could not be ascribed to any specific nutrient rate (Table 3). Gluten contents corresponded with the protein pattern.

**Table 3.** Mean grain yield and quality parameters of wheat as affected by different fertilizer treatments at Nueve de Julio experiment.

| Treatment | Grain yield | Protein | | Test weight | Gluten |
|---|---|---|---|---|---|
| | *Mg ha$^{-1}$* | ----%---- | ---*kg ha$^{-1}$*--- | *g 1,000$^{-1}$ seeds* | *% of protein* |
| Control - no S | 4.719b | 11.0a | 520 | 84.5ab | 26.7a |
| SSP | 5.934a | 9.1c | 537 | 82.4b | 22.0c |
| MAP + gypsum | 6.165a | 9.3b | 572 | 86.6a | 22.9b |
| MAP + polyhalite 37/63 | 5.919a | 9.3b | 549 | 86.4a | 22.9b |
| MAP + polyhalite 22/78 | 6.089a | 9.2b | 562 | 85.8ab | 22.5bc |
| MAP + polyhalite 16/84 | 6.345a | 9.2bc | 581 | 87.6ab | 22.1c |
| $P_{Treatment}$ | <0.001 | <0.001 | | 0.08 | <0.001 |
| $LSD_{5\%}$ | 474 | 0.15 | | 3.58 | 0.73 |
| CV % | 5.4 | 1.1 | | 2.8 | 2.1 |

*Note:* Data followed by equal letters are not statistically different within a column.

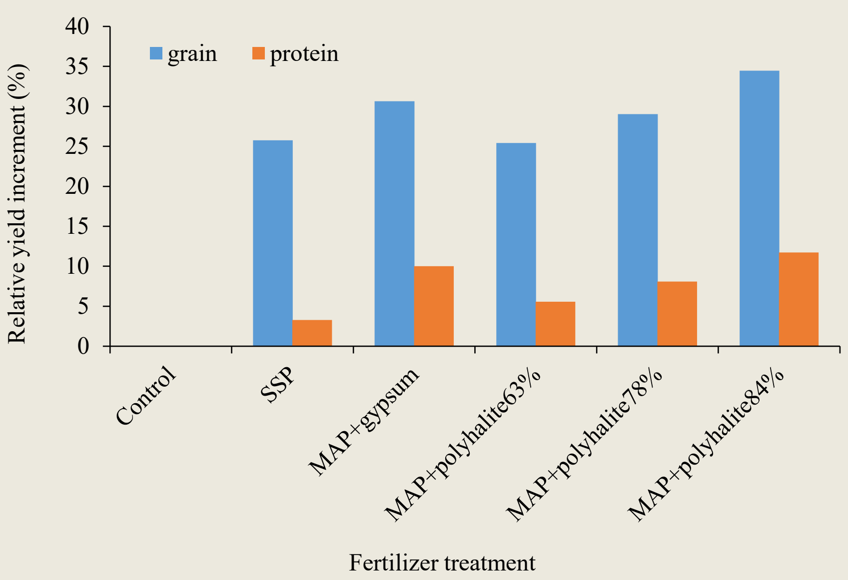


**Fig. 3.** Effects of fertilizer treatments on the relative increment in wheat grain and protein yields. For a detailed description of fertilizer treatments refer to Table 2.

While the improved S, K, and Mg availability in some of the treatments gave rise to a much higher grain yield, it may be speculated that the soil status of another macronutrient, probably N, was too poor during the wheat-cropping season to support higher grain protein contents. Nitrogen, although generously applied through urea prior to wheat emergence, is essential to protein metabolism (Hawkesford, 2014). However, urea is a temporal N source, as it rapidly breaks down and disappears from the rhizosphere. Therefore, a single urea application at sowing, or even additional but sporadic broadcasts of an N fertilizer during the season, might support plant growth and even normal grain development, but would fail to provide the high protein content expected (Geng *et al.*, 2016; Thierry and Larby, 2018).

### *Maize (Mercedes, Argentina)*

Under a similar fertilization program at Mercedes, Argentina, the maize response was a bit different. SSP fertilizer, contributing 19 kg S ha$^{-1}$ but no K, Ca, and Mg, brought about a slight grain yield increase, about 10% above control, which was insignificant statistically (Fig. 4). MAP + gypsum, which added S and Ca, gave rise to a much more significant yield increase of 1.7 Mg ha$^{-1}$, 32% above control. The three MAP + polyhalite blends also obtained high yields, however, these did not differ from that of MAP + gypsum (Fig. 4).

These results demonstrate the importance of meeting Ca and S requirements for improved crop yield (Sirikare *et al.*, 2015; Ahmad *et al.*, 2016). On the other hand, in this maize experiment, the higher doses of K, Mg and S provided by the polyhalite did not have any significant effects on crop development or yield. It should also be said that maize potential yields in this region normally reach 10 Mg ha$^{-1}$, much higher than the level obtained in the present study. These facts may indicate other yield limiting factors, such as insufficient N (Zheng *et al.*, 2016) and/or

P, and drought or extreme weather events having some significant negative impact on the maize crop performance.

### *Soybean (Mercedes, Argentina)*

On the same site, the soybean crop performed much better than the maize, and the yield achieved was closer to the expected potential of the area. Crop response to the different fertilizer treatments were observable on-field at the early reproductive stage, as well as at harvest (Figs. 5A, 5B). Soybean grain yield demonstrated a measurable increase, about 10% above the control, in response to additional S through SSP (Fig. 6). A similar S dose, combined with Ca through gypsum application, obtained a significant yield increase of about 0.5 Mg ha$^{-1}$, 26% above the control. Replacing the gypsum with polyhalite gave rise to a further significant yield increase, adding 303 kg grain ha$^{-1}$. This yield increase is attributed to the additional $K_2O$ and MgO amounts - 14 and 6 kg ha$^{-1}$, respectively, supplied through the polyhalite, and under a similar S input of 19 kg ha$^{-1}$. Enriching the fertilizer blend with polyhalite at the partial expense of MAP (Table 2) brought about further yield increases of up to 3.089 Mg grains ha$^{-1}$. This is a 61% increase when compared to the control treatment, and 28% above the yield of the conservative treatment of MAP + gypsum (Fig. 6).

As a legume species, soybean plants can utilize atmospheric N and hence, their reliance on N fertilizer is significantly small, compared to cereal crops (Collino *et al.*, 2015; Ciampitti and Salvagiotti, 2018; Santachiara *et al.*, 2018; Tamagno *et al.*, 2018). Assuming that N limitation did not occur throughout the experiment, soybean crop requirements of other macronutrients could be met and studied. In the absence of Ca, a pivotal soil ameliorator in many regions of South America (Caires *et al.*, 2015; dos Santos *et al.*, 2018), crop response to S alone was very poor, though positive. The application of gypsum established a significantly higher yield level, demonstrating the importance of the two nutrients (Ca and S). However, polyhalite, providing both $K_2O$ and MgO, in addition to Ca and S, supported higher yields still. Moreover, this study shows that soybean crops do require these nutrients, and maybe at even higher doses.

### Paraguay

The experiments in Paraguay aimed to test the effects of the ratio between P and K in the fertilizer blend, applied at sowing, on the grain yields of two successive crops - soybean (I), and maize (II). Potassium was applied using KCl or through

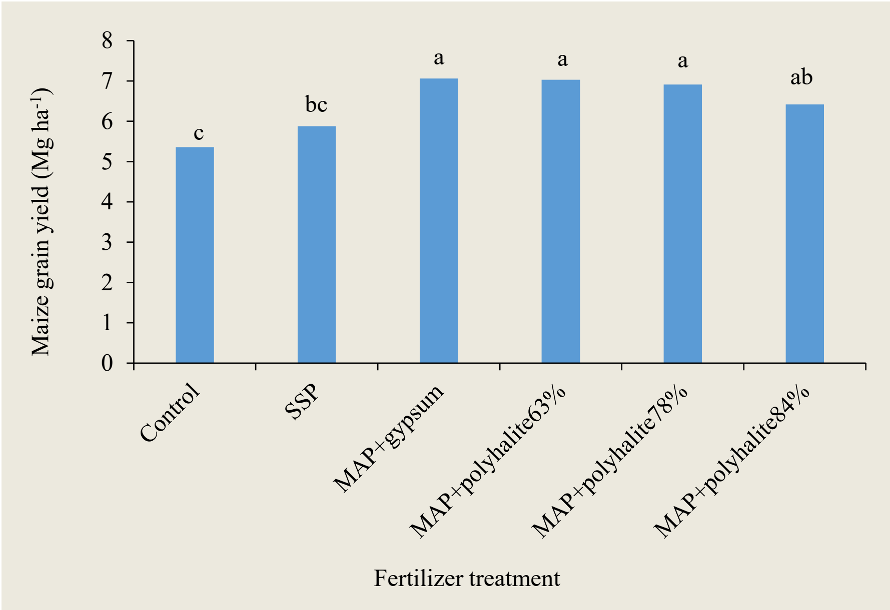


**Fig. 4.** Maize yield response to the fertilizer treatments at Mercedes, Argentina. For detailed treatment description, see Table 2. Similar letters indicate non-significant statistical differences between treatments at P=0.05.

**Fig. 5A.** Soybean plant samples from the Mercedes, Argentina study at an early reproductive stage. For detailed treatment description, see Table 2. Photo by R. Melgar.


**Fig. 5B.** Soybean plant samples from the Mercedes, Argentina study after harvest. For detailed treatment description, see Table 2. Photos by R. Melgar.

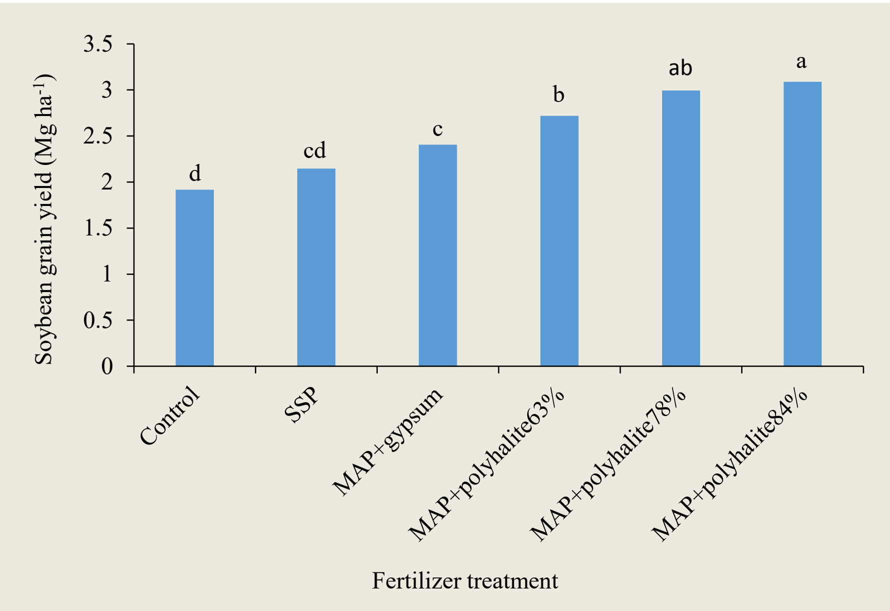


**Fig. 6.** Soybean yield response to the fertilizer treatments at Mercedes, Argentina. For detailed treatment description, see Table 2. Similar letters indicate non-significant statistical differences between treatments at P=0.05.

polyhalite, which also contributed Ca and MgO. Sulfur was applied through SSP or polyhalite. Generally, soybean and maize yields were within the range common for the region and in line with the weather conditions that prevailed during the cycle.

No significant yield increase was observed for the soybean crop following S and K application through SSP and KCl, respectively, at a P:K ratio of 3:1 (Table 4). However, similar doses of these two nutrients applied through polyhalite resulted in significant increases in grain size and yield. When the P:K ratio decreased to 2:1 by increasing the $K_2O$ rate from 23 to 35 kg ha$^{-1}$, soybean grain size and yields increased further to about 166 g 1,000$^{-1}$ seeds and 4.3 Mg ha$^{-1}$, which was roughly 11% more than the control treatment. At this paired treatments, there was no advantage to either KCl nor to polyhalite (Table 4).

Yields of the successive maize crop did not respond to the lower K rates of the initial fertilizer blends, compared to the control (Table 4). This may be due to the additional 14 kg $K_2O$ ha$^{-1}$ applied to all treatments at maize sowing. However, the fertilizer blend with the higher K rate did have a significant effect on the maize yield, with only a slight increase of about 300 kg grains ha$^{-1}$ (Table 4). At the study in Paraguay, polyhalite did not have any significant effect on the maize yield. It is questionable whether the maize crop required the additional Ca and MgO provided through polyhalite. Alternatively, the postulated long-term impact of polyhalite might be over-estimated in the case of successive crops.

## Conclusive remarks

Polyhalite can be very effective as part of fertilizer blends applied at the pre-plant stage. On S-deficient soils, polyhalite is a suitable source of this nutrient and has the same positive effect as other fertilizers currently used to support grain production in South America. In addition to S, polyhalite provides other essential nutrients - K, Ca, and MgO. Thus, polyhalite can successfully replace KCl fertilizers on K-deficient soils. Furthermore, the slower rate of K release from polyhalite expands the duration of K supply during the crop cycle, which is a considerable advantage over soluble-K fertilizers. However, the long-term impact of polyhalite in soils is quite limited and cannot be relied upon during successive cropping cycles. Moreover, the advantages of supplemented S, K, or MgO can be manifested only where the requirements of other essential macronutrients, such as N and P, are adequately met. Otherwise, polyhalite or other corresponding nutrient donors, are prone to fail in supporting grain production systems.

**Table 4**. Effects of pre-plant fertilizer treatments on the yield and seed weight of successive soybean and maize crops in Itapúa, Paraguay. For detailed description of treatments, see Table 2.

| Treatment | $P_2O_5$:$K_2O$ | Rate | $K_2O$ | MgO | Yield (Mg $ha^{-1}$) | | Seed weight (g $1,000^{-1}$) | |
|---|---|---|---|---|---|---|---|---|
| | | | | | soybean | maize | soybean | maize |
| | | ---------------------*kg* $ha^{-1}$ | ------------------ | | | | | |
| Control - MAP | - | 135 | 0 | 0 | 3.898c | 3.621b | 159bc | 269ab |
| MAP, SSP, KCl | 3:1 | 233 | 23 | 0 | 3.952c | 3.687b | 159c | 276a |
| MAP, SSP, polyhalite | 3:1 | 233 | 23 | 2 | 4.163b | 3.642b | 164ab | 263b |
| MAP, SSP, KCl | 2:1 | 233 | 35 | 0 | 4.298a | 3.945a | 166a | 276a |
| MAP, SSP, polyhalite | 2:1 | 233 | 35 | 3 | 4.318a | 3.953a | 166a | 278a |
| CV % | | | | | 2.7 | 6.0 | 3.1 | 3.4 |
| Pr > F | | | | | <0.001 | 0.007 | 0.005 | 0.02 |
| LSD 5% | | | | | 115 | 229 | 5 | 3.3 |

*Note:* Data followed by equal letters are not statistically different within a column.

The soybean experiment in Itapúa Dpt., Southern Paraguay, at vegetative stage and during harvest. Photos by R. Melgar.

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**The paper "Polyhalite for Grain in Soybean-Based Production Systems in Argentina and Paraguay" also appears on the IPI website.**

**Dr. Ricardo Melgar**

It is with deep sorrow we learned that Dr. Ricardo Melgar has left us. Dr. Melgar was a leading researcher at INTA (National Agricultural Research Institute) in Argentina. He dedicated his career to soils, crops fertilization and plant nutrition. We have lost a valued friend and an authority for soil science and agronomy. We will miss him greatly and will always cherish his great contribution to science and to our institute.

# Research Findings

**Photo 1.** Maize fields at Bungoma County, Kenya. Photo by S. Kimani.

## Potassium Application Enhances Maize Productivity in Kenya

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### Abstract

Many soils in western Kenya are acidic and potassium (K) deficient. Subsequently, maize (*Zea mays*) productivity is far below crop potential for the region. While the use of nitrogen (N) and phosphorus (P) fertilizers has been widely accepted among local farmers, K application is still ignored.

The present study aims to sustainably increase maize yields through the application of K under balanced fertilization. The specific objectives were to study maize response to K application rate, with and without lime; to test possible benefits of applying slow-release N fertilizer compared with top-dressed N; and to evaluate the effects of three types of K fertilizers on maize yield. Experiments took place in 2018 in five locations: Ndengelwa and Mabanga (Bungoma County), and Kamidi, Wepukhulu and Githanga (Trans Nzoia County). Two experiments were conducted at each location. The first experiment evaluated eight fertilizer treatments, with lime (2 Mg ha$^{-1}$) and without lime. The treatments included six pre-planting K rates of 0, 40, 80, 120, 160,

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and 200 kg $K_2O$ ha$^{-1}$, slow-release N applied with 80 kg $K_2O$ ha$^{-1}$, and an unfertilized control (UFC).

All treatments except UFC received pre-planting N and P through the application of di-ammonium phosphate and side dressing with urea to bring the levels up to 150 kg N and 100 kg $P_2O_5$ per ha. In the second experiment, three types of K fertilizer - muriate of potash (MOP), sulphate of potash (SOP), and NPK-17-17-17 (SSS) were compared at 80 kg $K_2O$ ha$^{-1}$, with and without liming.

Application of N and P at different K levels increased maize yields from 2 and 3 Mg ha$^{-1}$ under UFC, to 6 and 12 Mg ha$^{-1}$, in Bungoma and Trans Nzoia County, respectively.

Water availability significantly restricted the duration of the cropping season and, consequently, reduced yields. Beyond this obstacle, liming displayed insignificant and inconsistent impacts on maize yields. K application displayed a significant potential to increase yields, although adverse effects were evident at rates higher than 40 kg $K_2O$ ha$^{-1}$. In conclusion, K application should be divided into separate doses and delivered throughout the season or through slow-release fertilizers. Moreover, the amount and type of K fertilizer, as well as liming requirements, should be evaluated in each location according to the local soil properties and in consideration of the economic benefits.

*Keywords:* Liming; relative yield; slow release; soil acidity; *Zea mays*.

### Introduction

Maize (*Zea mays*) is the most important staple crop in Kenya, and is grown across a wide range of agro-ecological zones, accounting for about 40% of daily calories (Kibaara, 2005). Approximately 3.5 million small-scale farmers are involved in maize production in Kenya, constituting 75% of the total maize crop, while about 1,000 large-scale farmers produce the remaining 25%. Annual *per capita* maize consumption in Kenya is estimated at 98 kg. Over the years, production has fallen behind the national demand for maize, and the deficits have had to be met through import. In 2017, for example, the shortage of maize led to an increase in maize flour prices - from 55 to 75 KES kg$^{-1}$, forcing the government to subsidize maize flour prices through imports of 100,000 Mg (ton), thus lowering prices to 45 KES kg$^{-1}$ (KIPPRA, 2017).

The national average maize yields are estimated at 1.8 Mg ha$^{-1}$. These yields are about one fifth of those attained among world-leading maize producing countries, such as Argentina. In the early 1980s, maize yields began to increase following adoption of hybrid maize varieties and accompanying high fertilizer use to the extent that by 1986, the average national yields were over 2 Mg ha$^{-1}$ (Nyoro, 2002). However, this growth has not been sustained, due to various biophysical and socio-economic factors, including declining soil fertility, high input costs, lack of suitable seeds, pest and diseases, lack of access to credit, inadequate extension services, and unfavorable markets (Republic of Kenya, 1997; 2004; 2010). Poor weather has also affected the output of maize in some years.

As mentioned above, a major constraint of maize production in Kenya is low and declining soil fertility. Nutrient input and output studies on farmlands across Kenya and sub-Saharan Africa (SSA) show an alarming negative balance leading to widespread land degradation. Soil nitrogen (N), phosphorus (P), and potassium (K) balances, established for 13 countries in SSA, show consistent negative trends (Smalling *et al.*, 1993). About 200 million ha of cropland lost 660 kg N ha$^{-1}$, 75 kg P ha$^{-1}$ and 450 kg K ha$^{-1}$ during the 30 years between 1960 and 1990, with particularly high to very high depletion rates in East and Central Africa. As a result, the originally fertile lands that had yielded 2-4 Mg ha$^{-1}$ of cereal grains in the past became infertile, obtaining very poor cereal crop yields (below 1 Mg ha$^{-1}$) during 1990-2000 (Sanchez *et al.*, 2002). Furthermore, the practice of intensive continuous cropping, with limited or imbalanced fertilizer management, or no nutrient replenishment at all, has resulted in further nutrient depletions.

The cost of production has increased tremendously over the last decade, as prices of farm inputs have correspondingly escalated (KIPPRA-MoA Report, 2007). Consequently, food insecurity is rampant in the region, with up to 90% of households having to buy food to supplement their harvest. The problem of declining soil fertility is exacerbated in recent years by climate change, manifested by growing weather variability, increasingly shorter cropping seasons, and droughts.

Most soil fertility efforts have focused on N and P application, two of the most limiting nutrients in crop production in Kenya (Okalebo *et al.*, 1997). In maize production, N and P are usually applied in compound forms, mainly as di-ammonium phosphate, or through other combinations. The nutrients are applied at planting in the compound form, and N is further supplemented with top-dressing during the early vegetative growth stage of the crop. Considering the heavy rainstorms in most seasons, this practice opens up opportunities for N losses through leaching. Applying slow-release N fertilizers - such as coated N formulas - at planting, might reduce N leaching and ensure a better synchronization of N release with crop requirements.

While efforts have been made to fertilize soils with N and P, there has been very limited focus on K fertilization. In the 1970s and 1980s, it was generally assumed that K was not important for Kenyan soils, and there were no specific recommendations for K application. Studies by Mangale (1995) did not show clear responses to K, however, Kanyanjua *et al.* (2006) recommended application of 25 kg potassium oxide ($K_2O$) $ha^{-1}$. In recent years, Kenyanya *et al.* (2013) found that in western Kenya, maize crop development and yield parameters (plant height, stem thickness, ear dimensions, and grain yield) rose steadily with increasing K doses. Optimum output, with grain yields of 3.3 Mg $ha^{-1}$, were reached at K rates of 150 kg $K_2O$ $ha^{-1}$, nevertheless, the content of other macronutrients diverged out of their optimum ranges (Kenyanya, 2015). These studies indicate that further research is essential to determine accurate K application recommendations.

The decline of soil fertility is largely associated with another confounding limitation to maize productivity in Kenya - soil acidity. In Kenya, acid soils occupy 13% of the total land area, and the acidity is mainly a result of parent materials of acid origin, leaching of base cations and use of acid forming fertilizers, such as di-ammonium phosphate and calcium ammonium nitrate. These soils have high aluminum (Al) levels (above 2 cmol Al $kg^{-1}$ soil, and above 20% Al saturation), and are low in soil available P (less than 5 mg potassium oxide ($P_2O_5$) $kg^{-1}$ soil) due to moderate-high P sorption (107-402 mg P $kg^{-1}$ soil). Therefore, the recovery of P fertilizers in these soils is quite limited. Application of lime, P fertilizer and organic manure increases soil pH and available P, and reduces Al toxicity on Kenyan acid soils. The application of lime, P fertilizer and organic manure has been found to increase maize grain yield by 5-75, 18-93 and 70-100%, respectively, on Kenyan acid soils.

Nevertheless, soil acidity also largely affects soil K status and K availability. High soil acidity means high proton ($H^+$) concentration in the soil solution. With their higher electrical affinity to the negative charge of the soil particle surface, the protons displace other positively charged ions, such as $K^+$. Thus, K ions that cannot adhere to the soil particles remain in the soil solution. Under rainy conditions, these ions can be leached away with the water or down below the rhizosphere. This very short and transient availability might be the fate of any soluble K fertilizer, unless soil acidity is reduced. The process of liming can decrease soil acidity by enriching the soil with hydroxide ions ($OH^-$). In addition, the considerable supply of calcium ions ($Ca^{2+}$) through liming improves the balance between positively and negatively charged nutrients, altogether providing better access of $K^+$ to the solid soil phase.

The present study aims to sustainably increase maize yields through K application under balanced fertilization for enhanced food security in western Kenya. The specific objectives were to study maize response to K application rate, with and without lime; to test the possible benefits of applying coated N fertilizer compared with top-dressed N; and to evaluate the effects of three types of K fertilizers on maize yield.

## Materials and methods

Field experiments were conducted at Bungoma and Trans Nzoia Counties (Fig. 1) in western Kenya, which is considered the breadbasket region for the country. Bungoma and Trans Nzoia Counties cover about 3,032 and 2,496 $km^2$, respectively. In both locations, the mean annual temperature is 18.9°C. March is the warmest month, with an average temperature of 20°C, and July is the coldest month, with an average temperature of 17.9°C. Precipitation averages at 1,262 mm $year^{-1}$. The lowest monthly precipitation is 25 mm (January), and the highest is 175 mm (May). Soils are clay loams, with high acidity.

In Trans Nzoia County, experiments took place at three farm sites: Githanga, Kamidi, and Wepukhulu. In Bungoma County, experiments were carried out at Mabanga Agricultural Training Centre (ATC) and at Ndengelwa.

Two different experiments were conducted. Experiment 1 was set up to evaluate maize response to different rates of potash fertilizer (0-200 kg $K_2O$ $ha^{-1}$) in order to establish the optimum K requirement for maximum crop yield. Generally, soils in the maize-growing areas are acidic, and hence liming is a common practice. To evaluate the advantage of using lime, the experiment included liming as a second primary factor (no lime vs. lime). The lime was applied to the designated plots at 2,000 kg $ha^{-1}$. All treatments except the unfertilized control (UFC) received pre-planting N and P through the application of di-ammonium phosphate and side dressing with urea to bring the levels up to 150 kg N and 100 kg $P_2O_5$ per ha. Potassium was applied pre-planting at 0, 40, 80, 120, 160 and 200 kg $K_2O$ $ha^{-1}$, giving rise to treatments $K_0$, $K_{40}$, $K_{80}$, $K_{120}$, $K_{160}$, and $K_{200}$, respectively. One additional treatment, a slow-release N fertilizer (Agromaster®

**Photo 2.** Protus Makokha (left), Crops Officer at Mabanga ATC, instructs students and a farm worker about plot layout and the importance of liming. Photo by S. Kimani.

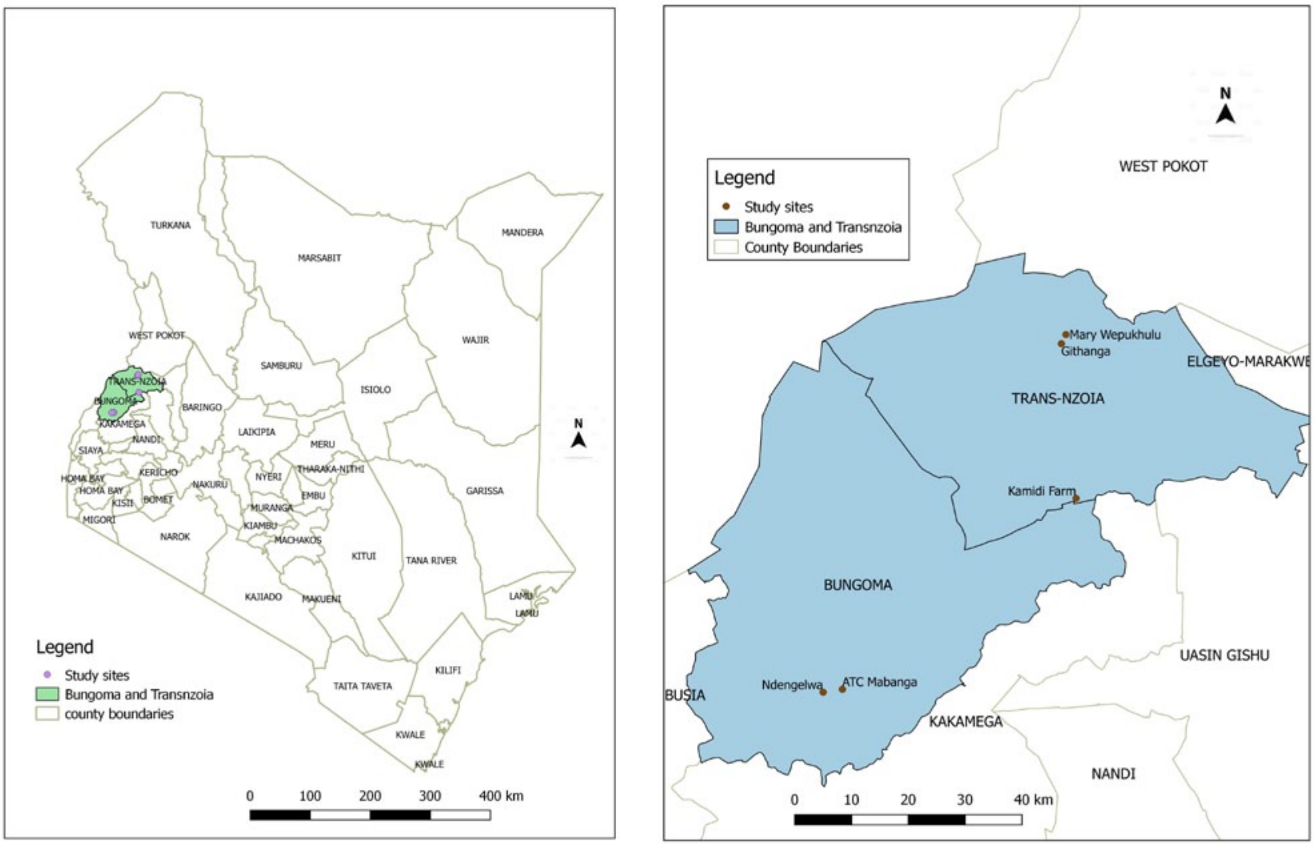


**Fig. 1.** Maps of the experiment locations; Bungoma and Trans Nzoia Counties in Kenya (left), and the specific sites in each county (right).

NP, ICL Specialty Fertilizers) combined with $K_{80}$ (SRN $K_{80}$), was applied at planting. This replaced the standard N and P application, and was designed to evaluate the contribution of slow-release N to crop performance. The SRN $K_{80}$ treatment was compared with the $K_{80}$ treatment alone. The plan for experiment 1 is summarized in detail in Table 1.

Experiment 2 aimed to evaluate maize response to different potash fertilizers. The three fertilizers tested were sulphate of potash (SOP), muriate of potash (MOP), and NPK-17-17-17 (SSS). MOP is the most common potash fertilizer, while SSS is a common compound fertilizer. Potassium was applied at 80 kg $K_2O$ ha$^{-1}$, while N and $P_2O_5$ were applied at 150 and 100 kg ha$^{-1}$ at planting, respectively. The treatments were applied with and without liming at pre-planting.

**Table 1.** A detailed description of experiment 1. Nitrogen and P were applied through di-ammonium phosphate (DAP) at planting, with two additional side dressings of urea, to complete doses of 150 kg N ha$^{-1}$ and 100 kg $P_2O_5$ ha$^{-1}$. In treatment SRN $K_{80}$, this practice was replaced with a pre-plant application of Agromaster® NP. UFC - unfertilized control.

| K rate | No lime | | Lime | |
|---|---|---|---|---|
| | Treatment code | Fertilizers | Treatment code | Fertilizers |
| *kg $K_2O$ ha$^{-1}$* | | | ---------------2,000 *kg ha$^{-1}$*--------------- | |
| 0 | $K_0$ | DAP+urea | $K_0$ | DAP+urea |
| 40 | $K_{40}$ | DAP+MOP+urea | $K_{40}$ | DAP+MOP+urea |
| 80 | $K_{80}$ | DAP+MOP+urea | $K_{80}$ | DAP+MOP+urea |
| 120 | $K_{120}$ | DAP+MOP+urea | $K_{120}$ | DAP+MOP+urea |
| 160 | $K_{160}$ | DAP+MOP+urea | $K_{160}$ | DAP+MOP+urea |
| 200 | $K_{200}$ | DAP+MOP+urea | $K_{200}$ | DAP+MOP+urea |
| 0 | UFC | - | UFC | - |
| 80 | SRN $K_{80}$ | Agromaster NP | SRN $K_{80}$ | Agromaster NPK |

Both experiments were designed in split plots using four randomized complete blocks (RCBD). Liming and no liming were assigned the main plots, while K rates (Exp. 1) and K fertilizer type (Exp. 2) were assigned the sub-plots. Sub-plots were 6 x 4 m in size with 0.5 m paths between each and 1 m paths between blocks. At all sites, the land was prepared using a hand hoe and furrows were made. Seeds cultivars 'H520' and 'H6213' were sown on 23 March 2018 at Bungoma and Trans Nzoia Counties, respectively. The seeds were positioned at a 5 cm depth within the soil and at a density of 44,444 plants ha$^{-1}$. Precipitation rates during crop development were much higher at Trans Nzoia than at Bungoma County - 637 and 381 mm, respectively (Fig. 2). Consequently, crop development at Trans Nzoia continued until late September, whereas it ceased as early as July at Bungoma. As a result, harvests took place on 3 August and on 5 October 2018, 133 and 190 days after sowing, at Bungoma and Trans Nzoia Counties, respectively. At harvest, grain and stover yields were determined and the harvest index was calculated.

## Results

Absolute grain and stover yields varied considerably among locations. In Bungoma County, grain yields were much higher at Ndengelwa, ranging from 4-7 Mg ha$^{-1}$ with considerable variability, compared to Mabanga where grain yields ranged from 2.5-4.5 Mg ha$^{-1}$. The differences between the two neighboring locations were even greater in regard to the stover yields that ranged from 5-7 and 2-5.5 Mg ha$^{-1}$ at Ndengelwa and Mabanga, respectively. At both locations, harvest indices varied widely from 0.40 to 0.55, with slightly higher values at Mabanga (Fig. 3). Although some significant differences occurred sporadically, liming effects were inconsistent at both locations.

Significant differences in crop performance also occurred between the experiment sites in Trans Nzoia County (Fig. 4). Grain yields were much higher at Wepukhulu, ranging from 5.5-11, compared to 4.5-8 Mg ha$^{-1}$ at Kamidi and Githanga. Stover yields were lower at Kamidi, ranging from 6-10, compared to 8-14 Mg ha$^{-1}$ at Wepukhulu and Githanga. Harvest indices ranged from 0.39-0.51 at Kamidi and Wepukhulu, but tended to be lower at Githanga (0.30-0.44). Liming tended to increase grain yields in most cases, and a similar effect was observed for stover at Kamidi and Wepukhulu but not at Githanga. The impact of liming on harvest index fluctuated inconsistently (Fig. 4).

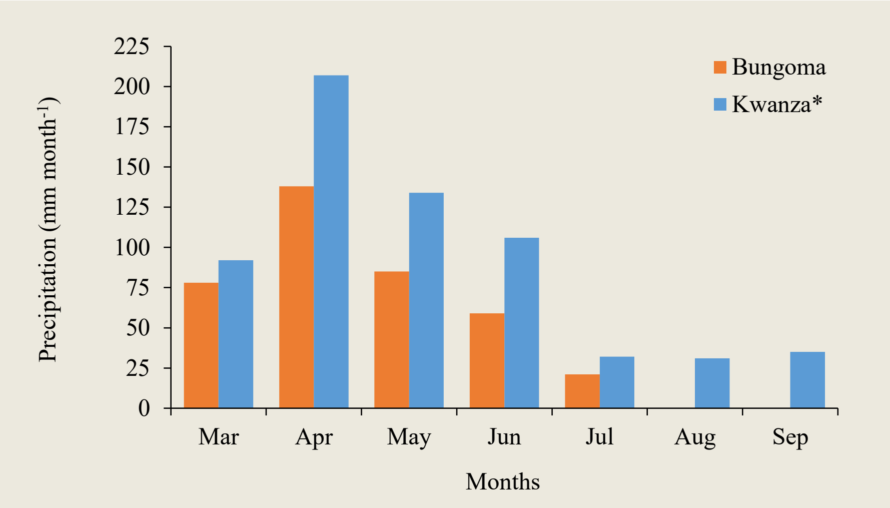


**Fig. 2.** Monthly precipitation rates at Bungoma and Kwanza (Trans Nzoia, near Wepukhulu and Githanga), Kenya, during the 2018 maize cropping season. *Source:* https://www.meteoblue.com/en/weather/forecast/archive/.

**Table 2.** General effect of K application rate on maize grain yields at five experiment sites in Kenya. At each site and K rate, liming sub-treatments were pooled together. Where the same letter appears next to the values, this indicates no significant differences ($p<0.05$) between K rates within each site.

| K rate | Ndengelwa | Mabanga | Kamidi | Wepukhulu | Githanga |
|---|---|---|---|---|---|
| *kg $K_2O$ ha$^{-1}$* | | | *Mg ha$^{-1}$* | | |
| 0 | 4.909 bcd | 2.739 d | 5.497 d | 9.874 a | 6.609 b |
| 40 | 5.998 a | 4.234 a | 7.251 a | 10.071 a | 7.222 a |
| 80 | 4.583 cd | 3.334 bc | 6.643 ab | 8.417 b | 5.125 c |
| 120 | 4.459 cd | 3.472 b | 6.255 bc | 7.316 bc | 5.317 c |
| 160 | 5.180 abc | 2.961 cd | 5.799 cd | 8.076 b | 5.219 c |
| 200 | 5.151 ab | 3.204 bc | 5.435 d | 6.125 c | 4.897 c |

Since liming had inconsistent and non-significant influences on crop performance in most cases, the major variable, namely K application rate, was analyzed at each site, pooling together the lime and no lime sub-treatments (Table 2). The highest grain yields were obtained under the lower K rate of 40 kg $K_2O$ ha$^{-1}$ at all sites. Yields obtained under this treatment were significantly higher than for the $K_0$ treatment, excluding at Wepukhulu. Under K rates higher than 40 kg $K_2O$ ha$^{-1}$, grain yields tended to decline significantly; however, the pattern of that decline was not similar among sites (Table 2).

Pooling together the general effects of K application rates at all sites confirmed the significant increase in grain yields in response to the lower rate of 40 kg $K_2O$ ha$^{-1}$ - about a 25% increase on average - as well as the decline in grain yield levels in response to further rising K rates (Fig. 5A). Interestingly, harvest indices climbed from about 0.40 under $K_0$ to 0.48 under $K_{40}$, but slightly decreased under further rising K rates, remaining at the intermediate range of 0.40-0.44 (Fig. 5B).

The experiments at each site included two additional treatments - UFC and SRN $K_{80}$. In Fig. 5, these two treatments are compared with their corresponding $K_0$ and $K_{80}$ treatments, and with and without liming, to analyze their effects on grain yield. At Ndengelwa, grain yield significantly increased under the $K_0$ treatment as compared to the UFC

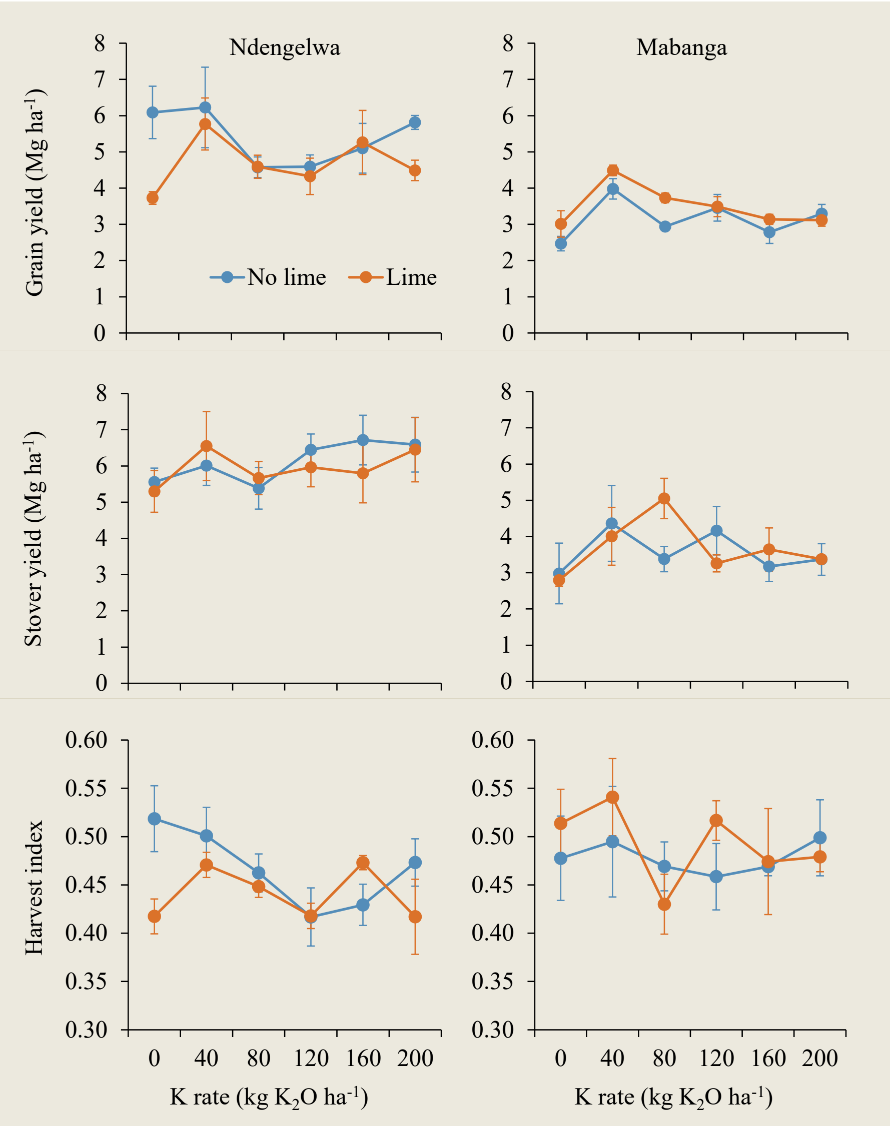


**Fig. 3.** Effects of K application rate on grain and stover yields and on the harvest index of maize at Ndengelwa and Mabanga in Bungoma County, Kenya. Bars indicate SE.

**Photo 3.** Maize top-dressing at Mary Wepukhulu farm, Kwanza, Trans Nzoia. Photo by S. Kimani.

**Photo 4.** Liming the plots. Photo by S. Kimani.

treatment, but liming had a considerable adverse effect on yield. At Mabanga, yields were significantly lower and their response to the elementary N and P fertilizer applied under $K_0$ was very poor, with liming providing only a slight advantage to the treatment. At the Trans Nzoia County sites, grain yields upsurged significantly under $K_0$ as compared to the UFC treatment. Liming also showed positive impacts on yields at Kamidi and Githanga. The most significant response to $K_0$ was observed at Wepukhulu, where grain yield rose from 3.5 under UFC to 10 Mg ha$^{-1}$ under $K_0$, but there was no obvious effect of liming on yield (Fig. 6).

Potassium applied at 80 kg $K_2O$ ha$^{-1}$ ($K_{80}$) did not give rise to overall significant changes in grain yields. Grain yields remained at the levels achieved under the UFC treatment at Ndengelwa, slightly increased at Mabanga and Kamidi, and declined significantly at Wepukhulu and Githanga, compared to the corresponding yields of $K_0$ (Fig. 6). On the other hand, the combination of $K_{80}$ with SRN brought about significant yield increases in most cases (Fig. 6). The general pattern of grain yield responses to these different fertilizer combinations is demonstrated by the relative yield parameter in Fig. 7, where data from all experiment sites were normalized to the UFC grain yield. It is clearly shown, that liming does not have any significant contribution to maize yield; under the terms of the present study, it even had a slight but consistent tendency to reduce yields. On the contrary, the various fertilizer practices did have significant effects on yield, with increases against UFC yields of 81, 76, and 130% gained by treatments $K_0$, $K_{80}$ and SRN $K_{80}$, respectively (Fig. 7).

In Experiment 2, the differences in absolute grain yields between sites remained stable, keeping the order of Wepukhulu > Kamidi ≥ Ndengelwa ≥ Githanga > Mabanga. The effect of different K fertilizer types was sporadic or site-specific, with hardly or no significant differences (Fig. 8). Liming

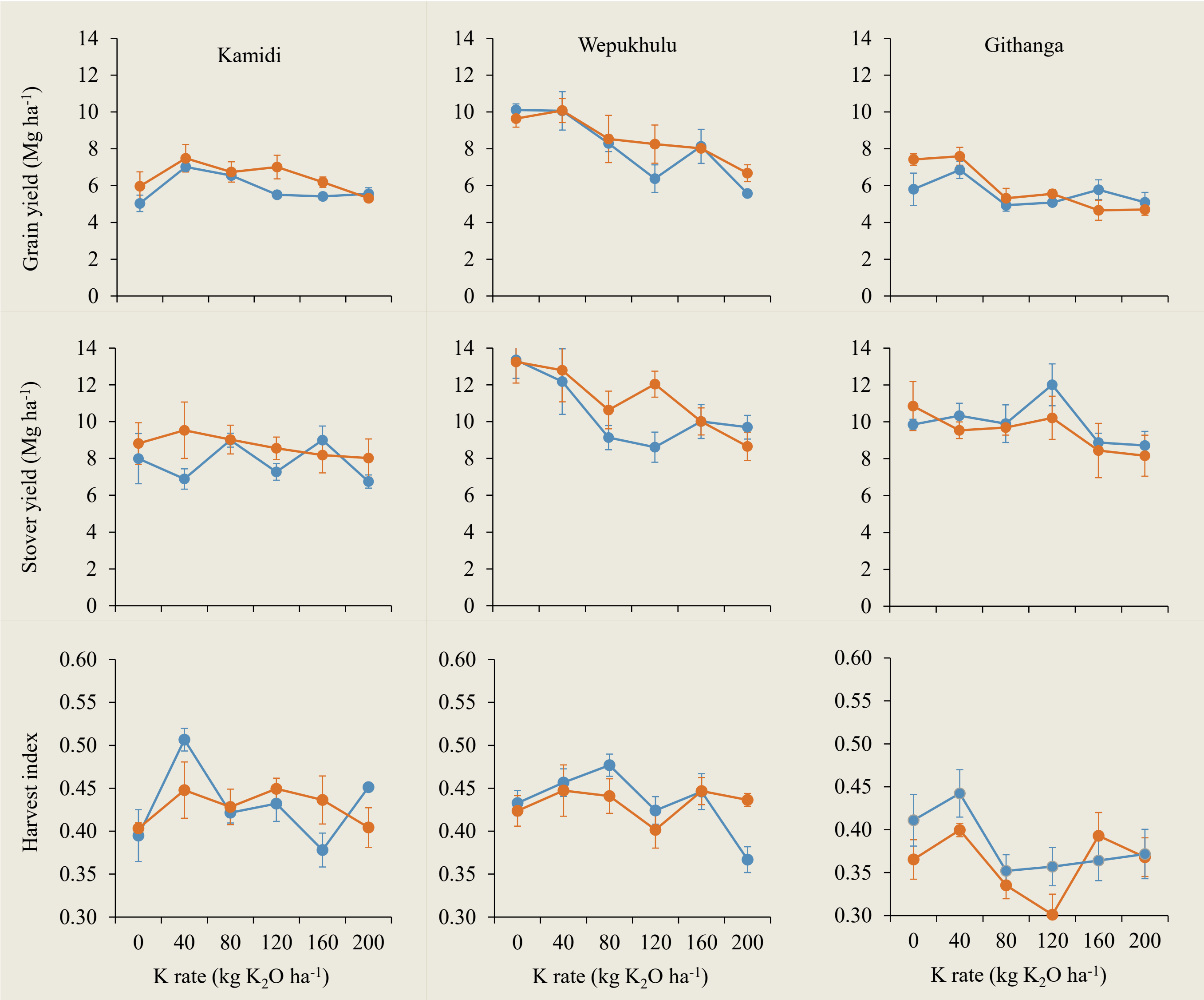


**Fig. 4.** Effects of K application rate on stover and grain yields and on the harvest indices of maize crop at Kamidi, Wepukhulu, and Githanga in Trans Nzoia County, Kenya. Bars indicate SE.

tended to slightly reduce yields, where SOP or SSS were applied, compared to MOP, which increased yields under lime application.

## Discussion

Although the major staple food crop in Kenya, local maize yields are regularly much lower than that of world-leading maize producing countries. This chronic problem can be attributed to many factors, among which, high soil acidity, poor soil fertility and unreliable water availability are dominant and interchangeable.

**Photos 5.** Weighing and sorting cobs and stover samples at Mabanga ATC. Photo by S. Kimani.

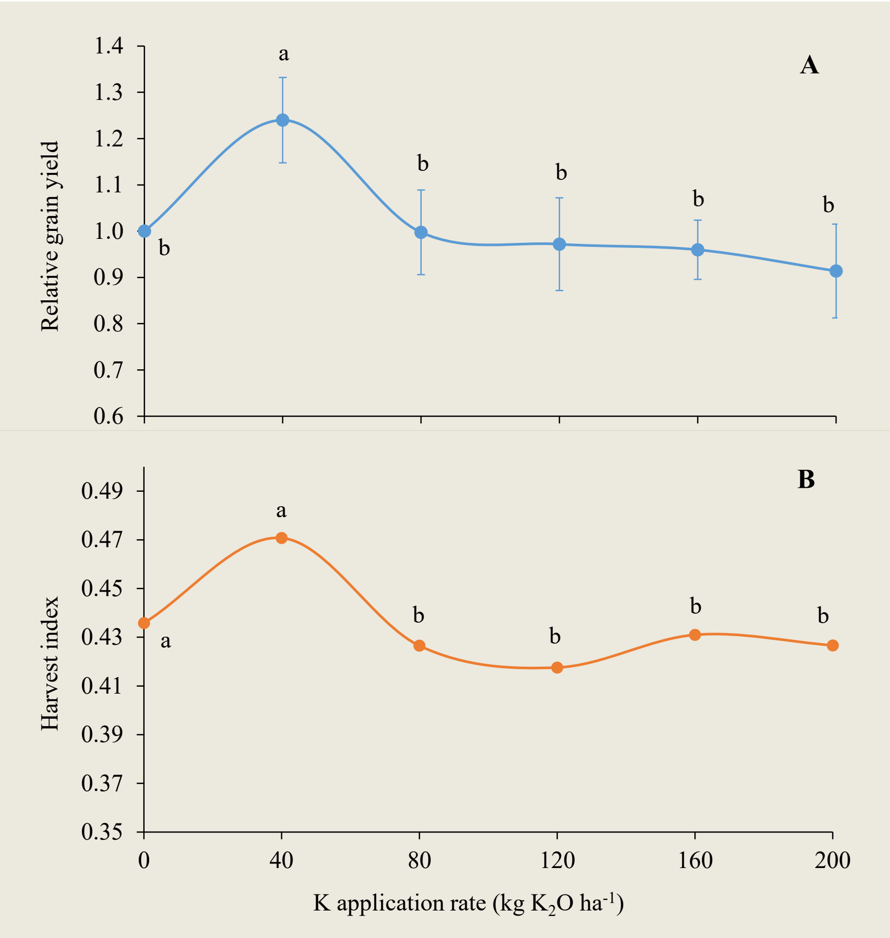


**Fig. 5.** Patterns of the relative grain yield (A) and harvest index (B) responses to K application rate at five maize experiment sites in Kenya (pooled data). Relative yields: yields of the different treatments were normalized to that of $K_0$ at each location. Similar letters indicate no significant differences ($p<0.05$).

Many studies have been carried out to address the problem of soil acidity in Kenya (Kanyanjua *et al.*, 2002; Kanyanjua *et al.*, 2006; Okalebo *et al.*, 1997; Kisinyo *et al.*, 2013), which can be partially reduced and overcome through liming (Oates, 2008). On one hand, a lack of knowledge on the importance of lime, as well as its limited availability in many agro-dealer outlets, significantly restricts and slows the dissemination of this solution in Kenya. On the other hand, liming should not be considered as a miracle cure. As recently suggested by Opala *et al.* (2018) and confirmed in the present study, the effects of liming are site-dependent and largely influenced by agricultural input factors such as fertilizer type and rate. In general, the liming effect on grain and stover yields was insignificant and inconsistent throughout the study, and in some cases, even interfered with the effects of the second major factor - K application rates.

A considerable step towards enhanced maize yields is the application of N and P fertilizers, the contribution of which was clearly demonstrated in most experiments in this study when compared to the rates achieved under the UFC (Figs. 6 and 7). Another important step is the splitting of the N dose into several applications during the cropping season. Alternatively, and even better, is the use of a slow-release N fertilizer, which gave rise to higher yields when compared to splitting of the N dose (Figs. 6 and 7). However, this result might vary under different environmental or practical conditions and, therefore, would require further research.

Considering the serious degradation in soil fertility, particularly in soil K status and availability (Smalling *et al.*, 1993; Sanchez *et al.*, 2002; Kenyana *et al.*, 2013), the effect of K application on maize yields in Kenya is currently presumed to be highly significant and, furthermore, rate dependent. These assumptions have been partially met in the present study. While significant yield increases occurred at all experiment sites, this effect was limited to the lowest K application rate (40 kg $K_2O$ $ha^{-1}$) in most of the cases (Figs. 3-5; Table 2). Moreover, higher K application rates even reduced grain yields, as clearly shown at Mabanga, Kamidi, Wepukhulu, and Githanga, and partially at Ndengelwa (Table 2). The latter phenomenon may indicate a wrong methodology of K application, especially under the Kenyan conditions. When a high K dose is delivered as a single application, concentrated in the vicinity of the germinating seed, a strong adverse effect of salinity might occur, diminishing the nutritional effect, which might significantly restrict crop growth and development. In addition, during the early stages of crop development and under heavy precipitation rates (as often is the case in western Kenya, Fig. 2), the highly soluble K fertilizer might be leached rapidly away from a poorly developed root system. During the rest of the season, the crop would then develop under K deficient conditions. This scenario, which can explain the reduction in crop performance under the higher K application rates, can be easily avoided. As already practiced with N, splitting the seasonal K dose into several applications during crop development may result in a completely different range of yield responses to K application rate. Alternatively, supplying slow-release K fertilizers may appear very useful in stabilizing soil K availability, as demonstrated for N. A combination of the

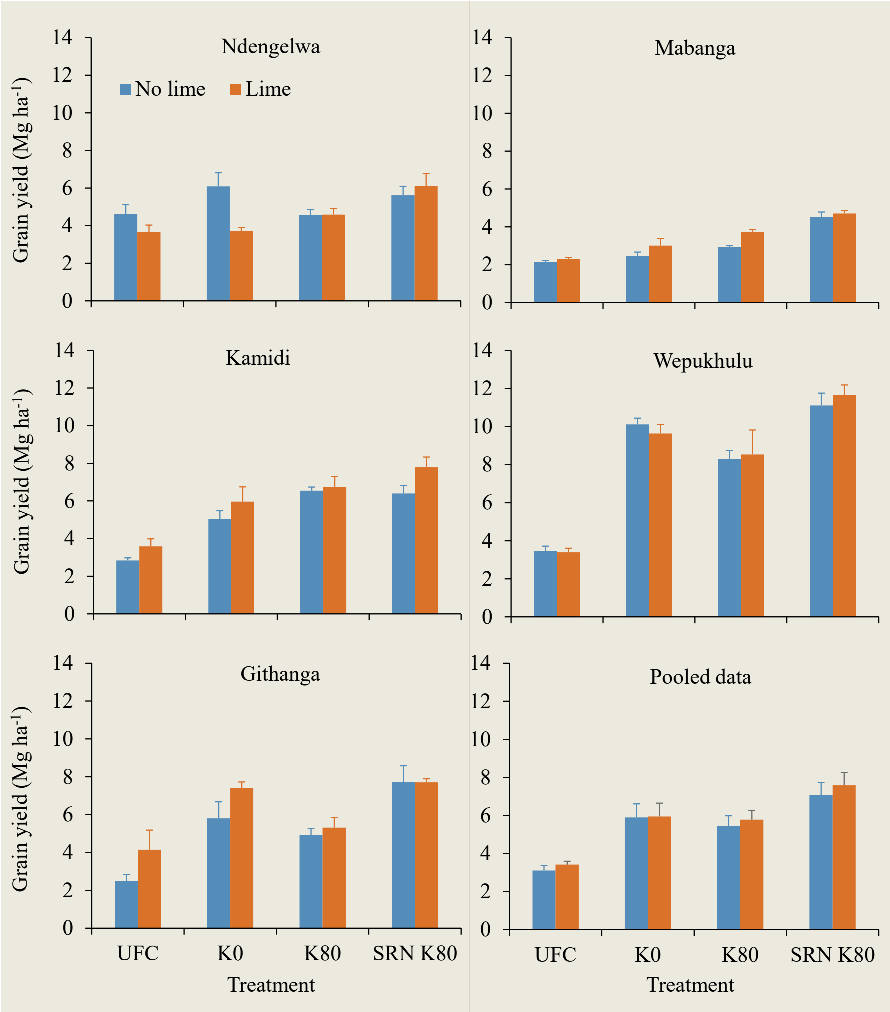


**Fig. 6.** Local as well as general (pooled) effects of UFC, $K_0$, $K_{80}$ and SNR $K_{80}$ fertilizer treatments, and liming/no liming, on maize grain yield at the five experiment sites in Kenya.

two approaches might lead to enhanced precision when supplying K according to crop requirements at each developmental stage (Leigh and Wyn-Jones, 1984; Setiyono *et al*., 2010).

The impact of K fertilizer type on maize performance remains unclear. The limited conditions under which this question has been studied in the present research means that no substantial conclusions can be made. Nevertheless, the significant site-specific responses achieved from this study (Fig. 8) indicate that further attention is required when considering the nature of the local soil and environment, the timing of K fertilizer application, and the crop requirements at a given stage of development.

Large variation occurred in crop performance, including time of harvest and grain and stover yields, between the experiment sites. Naturally, such differences may emerge from local soil properties, practices, and cultivars. Further, the different precipitation patterns seemed also to have a significant role, dictating the duration of the season, and consequently, the yield properties. In 2018, Bungoma County experienced much lower rainfall compared to Trans Nzoia (Fig. 2). Critically low precipitation rates in July - which were significantly less than

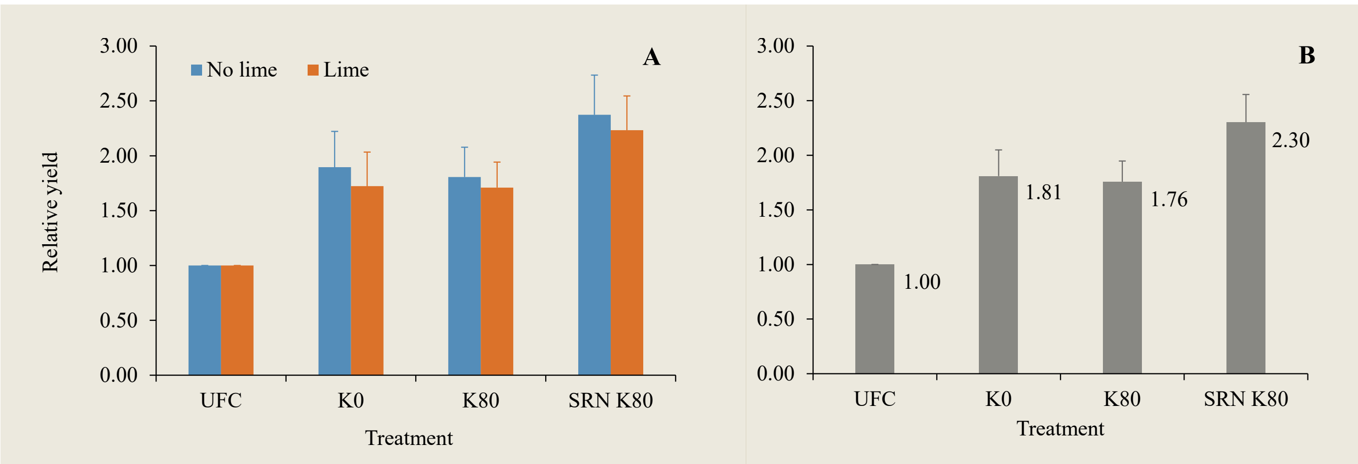


**Fig. 7.** The general impact of UFC, $K_0$, $K_{80}$ and SNR $K_{80}$ fertilizer treatments, and liming/no liming, on the relative maize grain yields at the five experiment sites in Kenya. The treatments: with and without liming (A), and pooled together (B). Relative yields: yields of the different treatments were normalized to that of UFC at each location. Bars indicate SE.

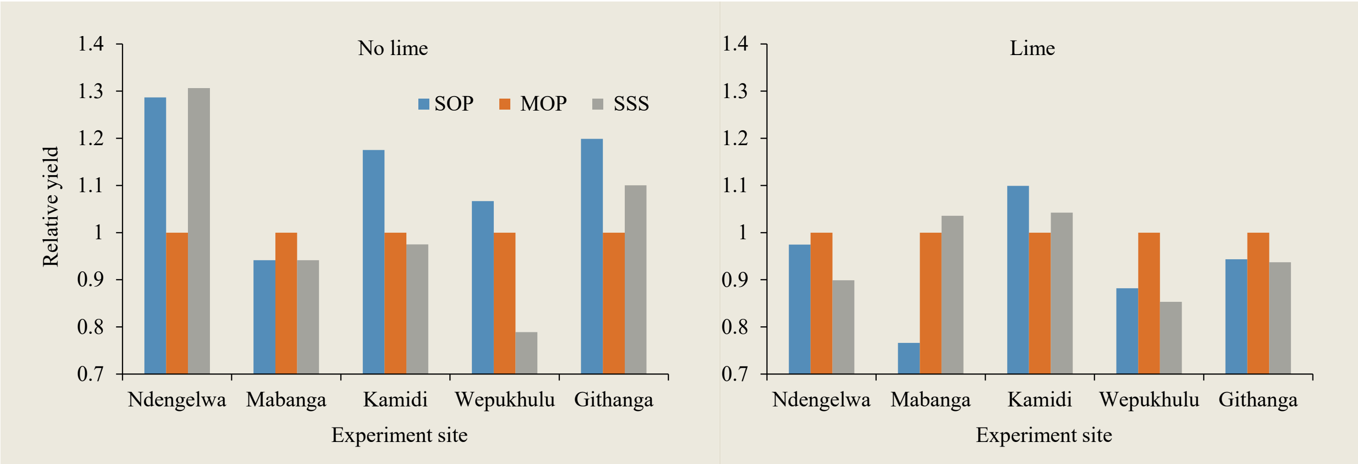


**Fig. 8.** Effects of different K fertilizer types, and liming/no liming, on the relative yield of maize grown at the five experiment sites in Kenya. Grain yields under SOP and SSS were normalized to the corresponding yields under MOP application.

the normal crop water requirements during the grain filling stage (Akinmutimi, 2015) - probably shortened the growing season by as much as 60 days in Bungoma compared to Trans Nzoia, leading to much lower yields (at least at Mabanga).

Matching water availability to crop requirement is a major challenge (Mwesigwa *et al.*, 2017), sometimes greater than providing the required mineral nutrition. Freedom from a dependency on precipitation can be obtained via various irrigation technologies and can substantially enhance maize as well as other crop production. Furthermore, it will materialize the synergy of fertigation.

## Conclusions

The potential of maize production in Kenya, which the present study only partly reveals, is much greater than the currently achieved yield levels (Kabaara and Kavoi, 2012). The application of N and P, along with varying K doses, increased maize yields from 2-6 Mg $ha^{-1}$ in Bungoma County and from 3-12 Mg $ha^{-1}$ in Trans Nzoia County. Poor water availability can significantly restrict the duration of the cropping season and, consequently, reduce yields. Beyond this obstacle, K application can be a very useful means to achieve significantly higher yields. However, K dose should be better split and delivered over the duration of the season or through slow-release fertilizers, as demonstrated by the SRN application. The accurate K dose, type of K fertilizer, as well as the liming requirements must be evaluated separately for each location according to the local soil properties, and in consideration of the economic benefits.

## Acknowledgements

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**The paper "Potassium Application Enhances Maize Productivity in Kenya" also appears on the IPI website.**

# Research Findings

Paddy rice demonstration plot in Uttar Pradesh, India. The difference in the height and number of leaves between the plants on the left (with potash applied) and the plot on the right (without) is clear. Photo by Potash for Life.

## Fertilizing Indian Rice Plots with Potash: Results from Hundreds of Locations Across the States of Andhra Pradesh, Chhattisgarh, Madhya Pradesh, Telangana, Uttar Pradesh and West Bengal

**Bansal, S.K.**(1)*, **P. Imas**(2), **and J. Nachmansohn**(3)

### Abstract

Agriculture forms the backbone of India's economy; however, declining soil fertility is directly impacting crop productivity. The appropriate application of fertilizer is a key factor in enhancing soil fertility and productivity and for overcoming potassium (K) depletion, which has been shown to have clear negative effects on India's rice production.

In order to evaluate the response of rice to muriate of potash (MOP), and to demonstrate to farmers the increased yield and profitability obtained when fertilizing rice plots with MOP, a large-scale trial project was launched in 2013: Potash for Life

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(PFL). The methodology was straight forward - two identical rice plots side by side, with the only difference being that one of them was fertilized with additional MOP. The results were very clear: virtually every trial showed a yield increase in response to the MOP addition, and the average yield increase was significant, ranging between approximately 6 and 15%.

It was concluded that the soil status of plant available K is significantly lower than plant demand in the six project states of Andhra Pradesh, Chhattisgarh, Madhya Pradesh, Telangana, Uttar Pradesh and West Bengal. This means that MOP fertilization is necessary in these states in order to improve agricultural practices and optimize yields. At this stage of research, we recommend that local MOP application standards should follow those performed in this trial. However, further trials and research are necessary to fine tune high-precision recommendations at a location-specific level.

## Introduction

Agriculture is forming the backbone of the Indian economy in spite of concerned efforts towards industrialization in the last three decades. As such, agriculture contributes a high share of the net domestic product in India (FAO, 2018).

India's economy has experienced remarkable progress during recent decades. To a large extent due to overall growth in industrial production, IT exports, agricultural production and exports, foreign investments and enhanced inward remittances of funds by expatriates. In spite of that, 70% of the population still live in rural areas and are dependent on agriculture (FAO, 2018). The ever-increasing demand for food, feed, and fibres, and the limitation of arable land, necessitate not only the practices of preserving, managing, and enriching the natural resources, but also the up-scaling of land-use-efficiency. Soil forms the basis for any crop production activity and is the most precious natural resource. Declining soil fertility is one of the primary factors that directly affect crop productivity. Therefore, soil fertility management is crucial in order to ensure productivity and nutritional security, while maintaining soil health and sustainability (Prasad and Power, 1997).

Subsequently, fertilizer-use is a key factor in order to ensure soil fertility and productivity. Fertilizers are one of the costly inputs in agriculture. Still, if used correctly they can be one of the most profitable (FAO, 2005).

It's a fact that imbalanced and incorrect use of fertilizers not only afflicts nutrient use efficiency, but that it can also cause deterioration in soil quality (Wallace, 2008).

Therefore, balanced fertilizer use must be promoted, as it's an absolutely necessary way to prevent both soil fertility decline from too low use, and soil quality deterioration from over-use or imbalanced use.

In an effort to promote balanced use, the project "Potash for Life (PFL)" was launched in 2013 in response to recent negative developments in potash use in India, and to support profitable agriculture. PFL is a collaborative project between Indian Potash Limited (IPL) and ICL Fertilizers. One important crop in the PFL project is rice.

The rice harvesting area in India is the world's largest. Rice is not only one of the most important food crops in India, serving as the staple food for 65% of the total population (FAO, 2017), it is also one of the most important cash crops as it provides income and employment for 50 million households.

The PFL project is raising awareness of the importance of muriate of potash (MOP) fertilization for rice crops, mainly through demonstration plot trials in collaboration with local farmers. The results and profitability of MOP application were clearly demonstrated to other rice producers through the trials. PFL is engaged with rice demonstration plot trials in six states: Andhra Pradesh, Chhattisgarh, Madhya Pradesh, Telangana, Uttar Pradesh and West Bengal.

### Objectives

The trials had two main objectives:

- To demonstrate to farmers the increased yield and profitability of rice obtained as a result of applying MOP in addition to the conventional use of diammonium phosphate (DAP), urea and manure.
- To evaluate the response of rice to MOP using recommended fertilizer blends on K-deficient soils.

## Materials and methods

### Experimental set-up

Verification trials were conducted in the fields of different farmers throughout the six project states. Each farmer grew rice, and for the experiments at each farm, two adjoining plots were used - one was applied with MOP and one was the control. Between the plots was a 1 m wide path. The plots within the same state were relatively similar, but not between states.

### Treatments

There were two treatments for each experiment: 1) control, where the common fertilizer practice of urea, DAP and in some cases manure was applied, and; 2) '+K treatment', where MOP was typically applied at 75 kg $ha^{-1}$ in addition to the urea, DAP and manure fertilizers. The local fertilizer recommendations varied between and throughout the states, mainly due to the variation in recommendations by the local authorities, or soil type and crop varieties, or due to variations in the soil test levels. Therefore,

**Table 1.** Fertilizer type and typical dose applied in the two treatments for the rice demonstration plot trials. The typical treatment is representative for each state, although there were deviations from them in all states.

| Fertilizer | Treatment | |
|---|---|---|
| | Control | +K |
| | ---------------kg $ha^{-1}$--------------- | |
| N (from urea + DAP) | 120 | 120 |
| $P_2O_5$ (from DAP) | 60 | 60 |
| Manure[(a)] | X[(b)] | X[(b)] |
| $K_2O$ (from MOP) | 0 | 75[(c)] |

[(a)]Manure was derived from different kinds of domesticated animals depending on location and production.
[(b)]There was no set standard for manure application. In some cases, no manure was applied and when it was, application depended on the practice of the farmer in question. The letter 'X' signifies that whatever dose and procedure of manure was applied, it was the same for both the treatment and control.
[(c)]The MOP dose in all states was the same except in Chhattisgarh, where the dose was 60 kg $ha^{-1}$, and West Bengal where the dose was either 60, 90 or 120 kg $ha^{-1}$.

MOP doses varied. The details of the variations are described in Table 1. For each demonstration plot trial, the plot size was always the same for both treatment and control. However, between plot trials the plot sizes sometimes differed among the different farms and locations; the plot sizes varied between 0.13-14 ha. Farmers used the improved rice varieties recommended for their area, and all recommended agronomic practices such as seed rates, planting distances, irrigation schedules and plant protection measures were followed according to local recommendation and relevance.

### Statistics

The statistical analyses 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. Prior to statistical analyses, the data were trimmed in order to remove any outliers.

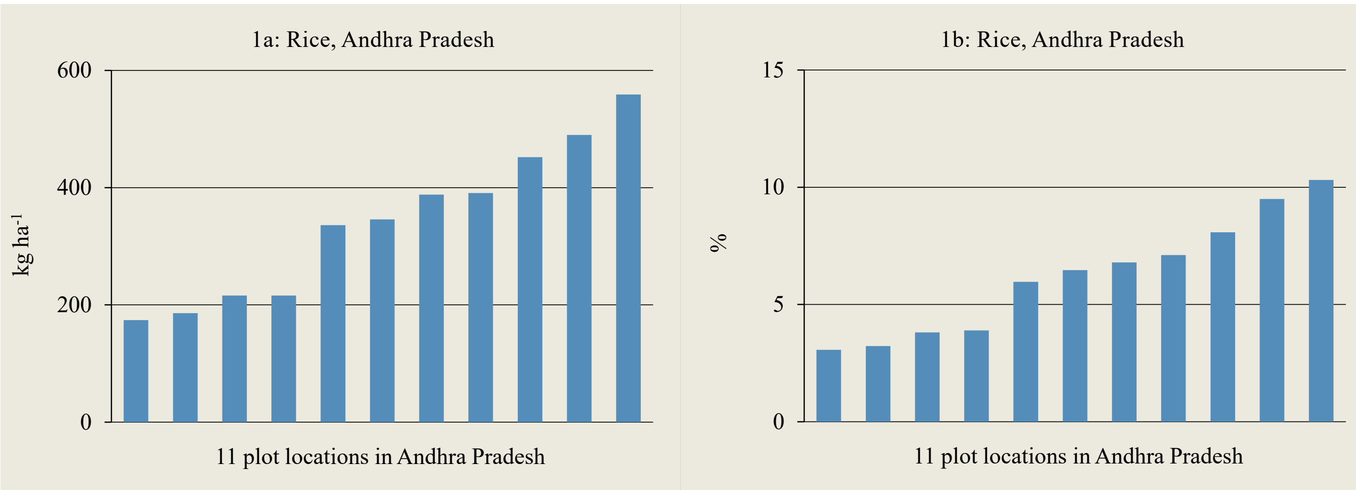
## Results

### Absolute yield increase

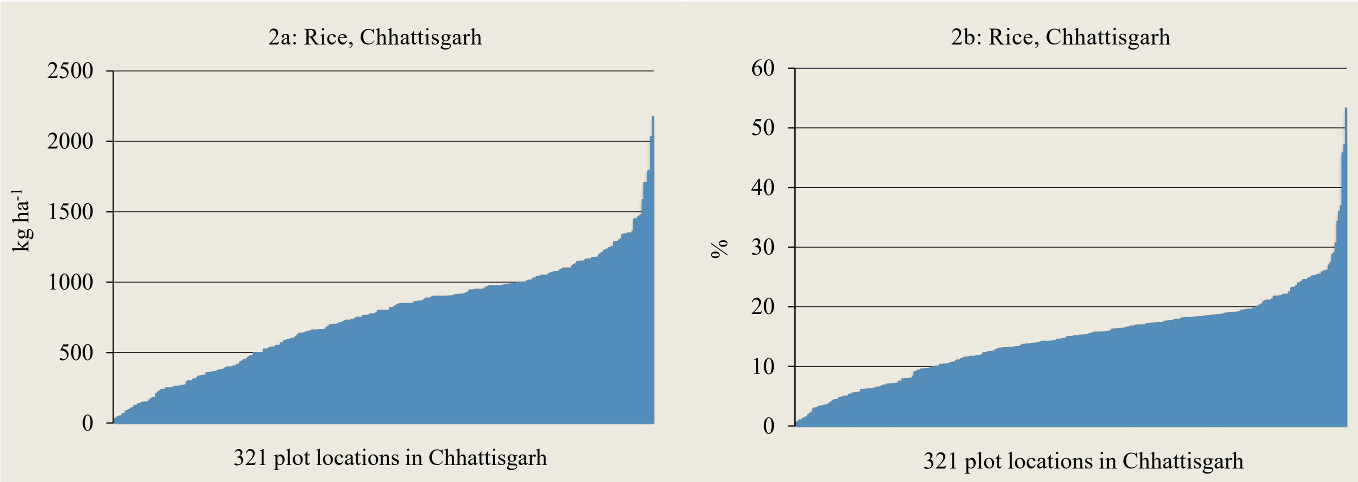
Application of MOP in addition to the common fertilizers urea, DAP and manure, gave rise to average rice yield increases of 341, 779, 509, 422 and 234 kg $ha^{-1}$, in Andhra Pradesh, Chhattisgarh, Madhya Pradesh, Telangana, Uttar Pradesh and West Bengal, respectively (Fig. 8). The range in rice yields under the control conditions and the response patterns to MOP followed similar trends for most states, even though there were some differences within and between the regions. The control rice yields predominantly ranged from 3,000 to 7,000 kg $ha^{-1}$, although they were mainly clustered above 5,000 kg $ha^{-1}$ in Andhra Pradesh and Telangana, and below 5,000 kg $ha^{-1}$ in Madhya Pradesh and Uttar Pradesh. Except for Chhattisgarh, which had its own pattern, the yield increase response patterns to MOP application ranged from roughly 100 to 700 kg $ha^{-1}$, although this increased to up to around 800 kg $ha^{-1}$ in Uttar Pradesh (Figs. 1-7). In Chhattisgarh, the yield increase response ranged evenly from 50 to 1,500 kg $ha^{-1}$, with some outlying values. Most other states also had an evenly distributed yield increase in response to MOP except for Madhya Pradesh, which had low variation in its response.

### Relative yield increase

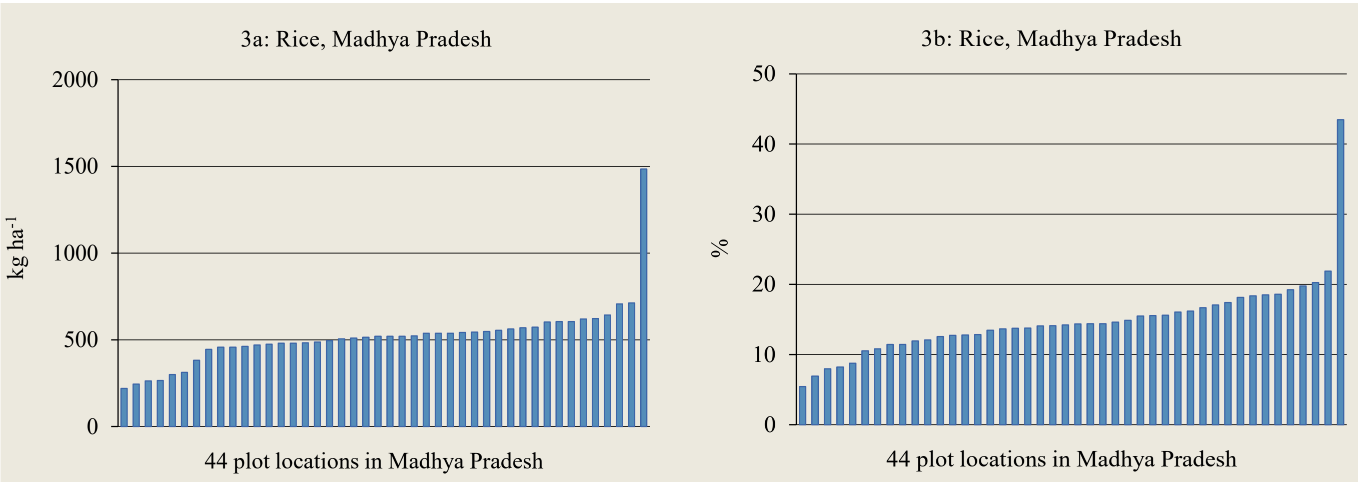
The application of MOP in addition to the common urea, DAP and manure fertilizers, gave rise to average rice



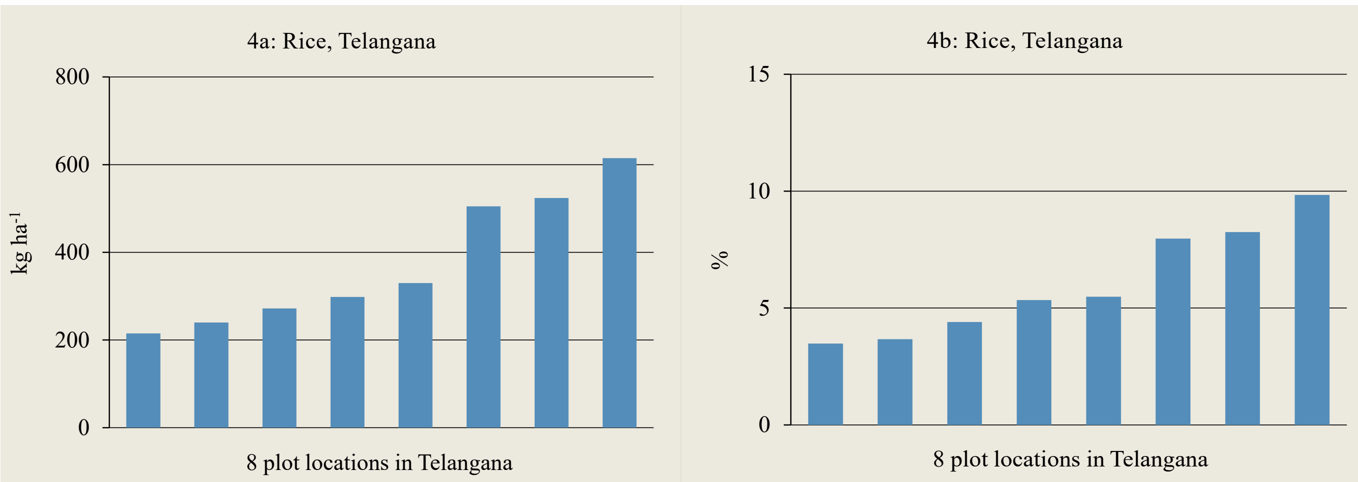

**Figs. 1a and 1b.** Yield increase in rice plots fertilized with MOP in comparison to control plots with no MOP fertilization for 11 plot pairs across Andhra Pradesh. The plots were harvested in 2015.



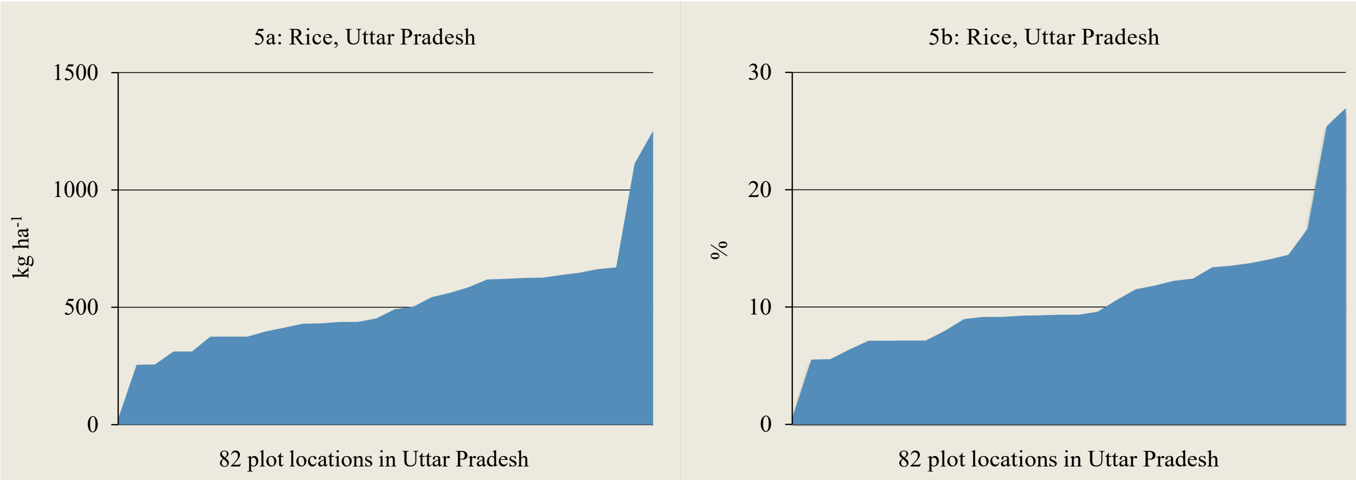

**Figs. 2a and 2b.** Yield increase in rice plots fertilized with MOP in comparison to control plots with no MOP fertilization for 321 plot pairs across Chhattisgarh. The plots were harvested in 2014, 2015 and 2016.



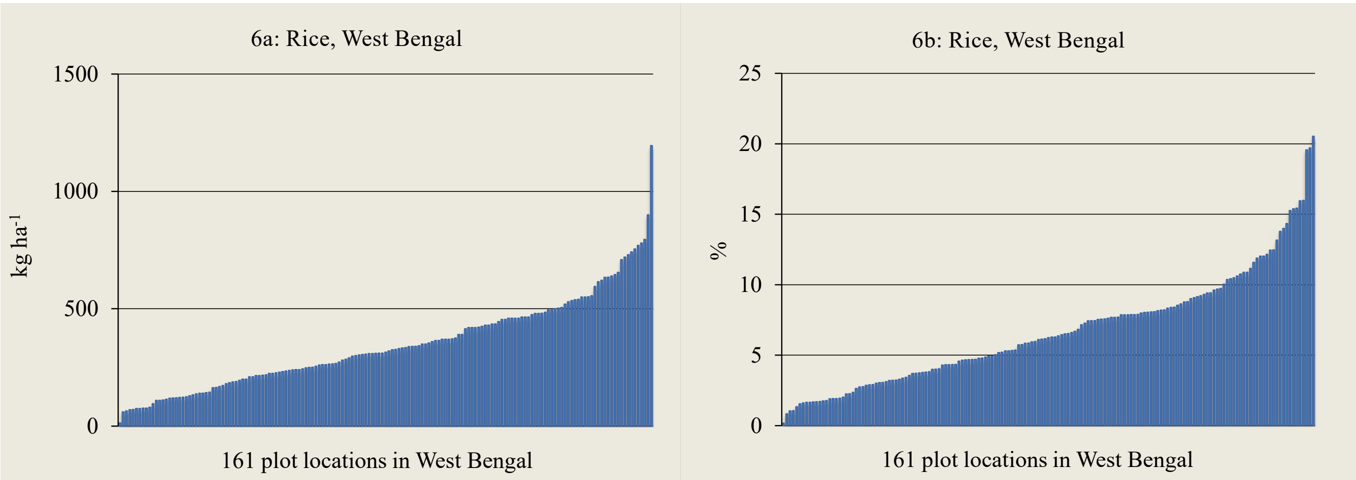

**Figs. 3a and 3b.** Yield increase in rice plots fertilized with MOP in comparison to control plots with no MOP fertilization for 44 plot pairs across Madhya Pradesh. The plots were harvested in 2016.




**Figs. 4a and 4b.** Yield increase in rice plots fertilized with MOP in comparison to control plots with no MOP fertilization for 8 plot pairs across Telangana. The plots were harvested in 2016.




**Figs. 5a and 5b.** Yield increase in rice plots fertilized with MOP in comparison to control plots with no MOP fertilization for 82 plot pairs across Uttar Pradesh. The plots were harvested in 2015 and 2016.




**Figs. 6a and 6b.** Yield increase in rice plots fertilized with MOP in comparison to control plots with no MOP fertilization for 161 plot pairs across West Bengal. The plots were harvested in 2014, 2015 and 2016.

yield increases of 6, 15, 15, 6, 10 and 7% in Andhra Pradesh, Chhattisgarh, Madhya Pradesh, Telangana, Uttar Pradesh and West Bengal, respectively (Fig. 10). The patterns of yield increase response to MOP application ranged roughly between: 2 and 10% in Andhra Pradesh and Telangana; 5 and 20% in Madhya Pradesh and Uttar Pradesh: 2 and 20% in West Bengal; and 2 and 30% in Chhattisgarh, with some outlying values up to around 50% (Fig. 9). Except for Madhya Pradesh, in which most data were relatively close to the median, there was a steady increase in yield increase response for MOP between the highest and the lowest response value in all states.

## Discussion

On average, the additional MOP brought about significant increases in rice yields across all six Indian states (Fig. 8 and Fig. 10). These results indicate that, in general, the soils of the experiment locations have undergone nutrient depletion and lack plant available K. Consequently, MOP fertilization practices seem to have considerable potential to increase rice productivity in India. However, the diversity in yields obtained for both the control and '+K treatment', within, as well as between regions, calls for careful dissection before any recommendations are disseminated.

The diversity in control yields is not surprising, considering the huge scope of the demonstration plot trials, as well as the geographic heterogeneity of the locations across and within the six states. Considering the variety in altitude, rainfall, temperature and disease presence, as well as the genetic diversity between the cultivars used in the experiment, and the different

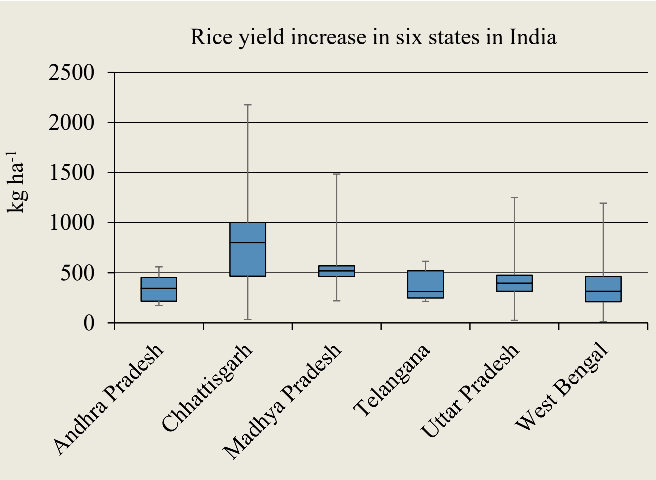



**Fig. 7.** Box plot diagram of rice yield increase across demonstration plots fertilized with MOP, in comparison to control plots with no MOP fertilization, for six states in India. The crops were harvested in 2014, 2015 and 2016. For each box plot, the middle line represents the median. The lower and upper edges of the box represent the first and third quartile respectively, and the end of the bars indicate the maximum and minimum values.

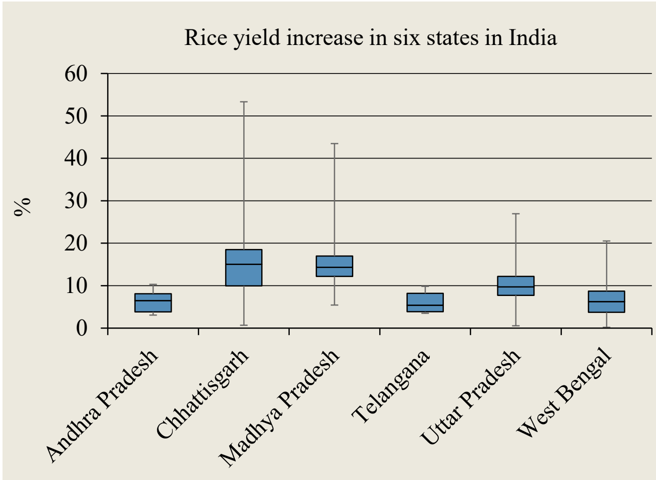



**Fig. 9.** Box plot diagram to show the relative rice yield increase in demonstration plots fertilized with MOP, in comparison to control plots with no MOP fertilization, in six states in India. The crops were harvested in 2014, 2015 and 2016. For each box plot the middle line represents the median value; the lower and upper edges of the box represent the first and third quartile respectively, and the end of bars indicate the maximum and minimum values.

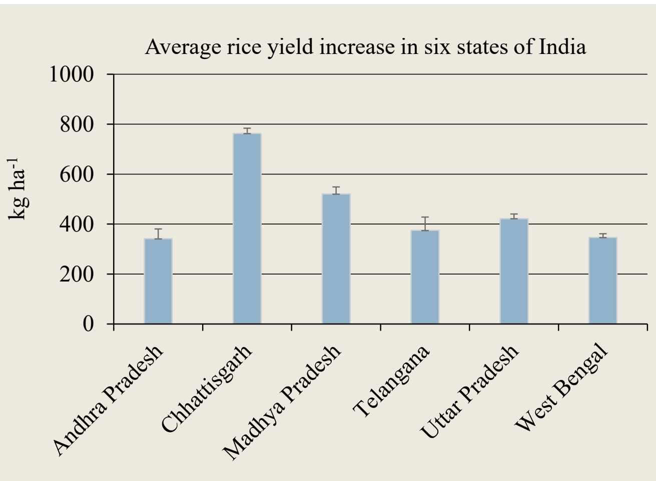



**Fig. 8.** Mean absolute yield increase in the six project states in India. The error bars signify the standard error.

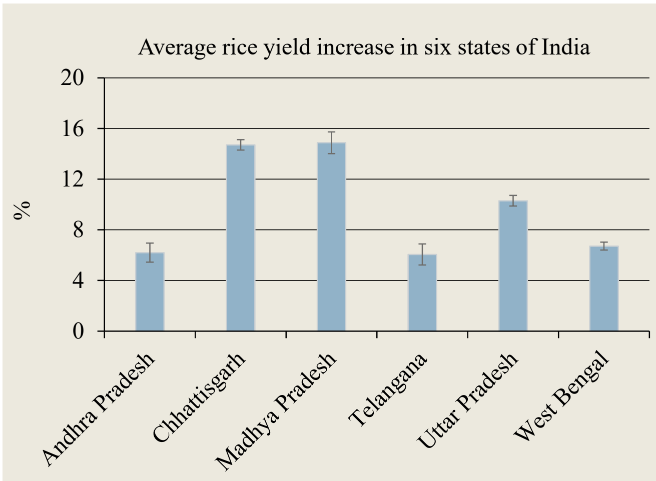



**Fig. 10.** Mean percentage yield increase in the six project states in India. The error bars signify the standard error.

soil types present throughout the locations, the control yield variation between 3,000 to 7,000 kg $ha^{-1}$ is actually reasonably narrow. Furthermore, the variation in yield increase response was even more moderate. As seen in Fig. 7 and Fig. 9, the distribution of yield increase response to MOP indicates a clear trend for each state. Combined with the stable average values obtained (Fig. 8 and Fig. 10), these results provide strong evidence that the response patterns are due to region-specific soil K status, and the local practices of nutrient balancing and fertilizer management.

One interesting pattern in the variation of the MOP response was that in most regions, the yield increase was linearly distributed within the response range. This suggests a significant natural variability of K depletion within the response range, which in turn, opens up the discussion for MOP dosage levels. An increased MOP dose might lift the average response closer to the upper limit in the response range and perhaps decrease response variation.

Furthermore, in spite of the differences between the states, the results are surprisingly similar throughout the experiment in terms of growth response to MOP application. This suggests that the levels of plant available K present in the soil is a common governing factor for the outcome: that these levels are relatively


PFL agronomist Sunil Aarya (left) with farmer at the paddy demonstration plot in Khadda, Kushinagar, Uttar Pradesh, India. Photo by Potash for Life.


This rice plant from a demonstration plot in Rudlapur, Maharajganj district, Uttar Pradesh, India shows a clear difference between a plant with potash applied (right) and one without (left). The plant grown with potash has larger and stronger roots, and more panicles resulting in a higher yield. Photo by Potash for Life.

similar for all six states; and that this factor is clearly affected by balanced MOP applications.

Of course, there is no way to predict crop response to MOP application at a given location other than by conducting a comprehensive soil test. Using the information from such a test, a relevant and tailored approach can be developed to include a whole package of solutions. On the other hand, the consistently stable rice yield increases obtained during this study, indicate a high probability that an overwhelming majority of farmers within the six project states would obtain significantly higher yields as a result of following the MOP application practices of this trial. Further, to finalize nutrient balances at field scale by means of comprehensive soil testing would likely be expensive and unfeasible for local smallholding farmers.

Raising awareness of balanced fertilizer use, and correct suggestions of MOP application rates based on empirically verified large-scale trials, could gradually improve the existing practices within local mixed farming systems. The fine tuning of dosage and nutrient balancing at the local field level would then be cost and resource effective, and could provide a safe path to food security, profitability and sustainability, at a regional scale.

## Conclusions

The plant available K in the soil is significantly lower than plant demand for all six states. MOP fertilization is necessary in these states to improve agricultural practices and optimize yields. The results show indications of clear trends, patterns and similarities throughout the six states for rice production. Therefore, the amount of MOP used in this trial could serve as a substantiated starting point for future recommendations to rice farmers. However, the variations in the MOP response give reason to investigate a higher MOP dose, as well as ways to fine tune the recommendations at the field scale, either through trial-and-error or through comprehensive soil tests.

## Acknowledgements

Indian Potash Limited (IPL) and its regional officers and field staff are gratefully thanked for their active participation and kind help. Field staff of the project 'Potash for Life' (PFL) and participating farmers are highly thanked for successfully conducting the demonstrations. Special thanks are due to ICL Fertilizers for extending financial assistance for the project. Grateful thanks also go to the Managing Director of IPL, and the Chairman of PFL, for all the support, kind advice and guidance in successful implementation of the project activities.

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**The paper "Fertilizing Indian Rice Plots with Potash: Results from Hundreds of Locations Across the States of Andhra Pradesh, Chhattisgarh, Madhya Pradesh, Telangana, Uttar Pradesh and West Bengal" also appears on the IPI website.**

# Events

## IPI Events

December 2018

### IPI-CAU-ICL Training on “Balanced Nutrition through Israeli Fertigation Technology”

**Report of the second phase of a two-part training program for students from the China Agricultural University (CAU), which took place from 17-20 December 2018 at the CAU campus in Beijing. The program was developed by the International Potash Institute (IPI), in conjunction with CAU and Israel Chemicals Ltd. (ICL), to enhance students' understanding and practical knowledge of balanced soil nutrition through fertigation.**

Participants and trainers at CAU campus in Beijing. Photo by IPI.

Sixteen undergraduate, postgraduate and PhD students from CAU were selected to take part in the fertigation training course, which combined theory classes with practical field work. The aim of the program was to enable participants to become valued agri-professionals, better-equipped to advise farmers on appropriate fertigation practices for a range of crops.

More specifically, the goals of the course included:

- Broadening the knowledge of professionals advising farmers and instructing them on methods for disseminating knowledge to farmers;
- Enabling participants to deliver their knowledge in a clear manner;
- Bridging the gap between theoretical and practical farm management to share best practice;
- Expanding participants' understanding of state-of-the-art technological advances in soil science and irrigation, information management, precision agriculture and remote-sensing technologies.

The first phase of the course was held over 4 days in May 2018 at the CAU experimental station in Quzhou, in the Hubei province of China. This initial phase included theory sessions and practical tasks, with content focusing on: crop water requirements; fertilizer calculation; leaf nutrient diagnosis; irrigation technology and layout; drip irrigation; design for dripper pressure compensation; irrigation scheduling; and principles and practicalities of fertigation.

The second phase of the course was completed through individual work. Each of the participants undertook a study regarding fertigation for a crop of their choice across different provinces of China. The selected crops included greenhouse tomatoes (Hebei), lettuce (Hebei), apples (Zhjiang), citrus (Sichuan) and grapes (Qianya). The studies examined how crops respond to fertigation when cultivated in pots, in protected environments and in fields, and measured crop yield and quality, as well as labor requirements.

The course content for the second phase consisted of:

- Fertilizer application methods;
- Garlic fertigation trial;
- Fertigation and fertilizer application;
- Nitrogen application efficiency;
- Phosphate and potassium application;
- Soaked Speedling tray in enriched fertilizer solution pre-planting;
- Phosphate application in pepper after soil sterilization;
- The principles of soil and leaf sampling;
- Physical properties of fertilizers;
- Fertilizer solutions.

This course proved to be a successful pilot for the provision of wide-scale fertigation training for student agriculturalists in China. Further training is planned for 2019, and the course is anticipated to become something that students and fertilizer company professionals would pay for, in order to be fully equipped to provide fertigation guidance and advice to Chinese farm businesses.

# Events (cont.)

IPI event

**November 2019**


**The 13th IPI-CAU-ISSAS International Symposium will take place in Kunming, China, 6-8 November 2019. This event on "Potash and Polyhalite: Potassium, Sulphur, Magnesium and Calcium for Efficient Balanced Plant Nutrition" will be jointly organized by IPI, CAU, and ISSAS, with NATESC and China Potash Association as secondary partners.**

This symposium will be of interest to soil and plant nutrition scientists, agronomists, and extension officers from universities and research organizations, government offices, and agri-businesses who share an interest in improving food production and quality. Invited speakers will include scientists from China and abroad.

**Main Themes:**

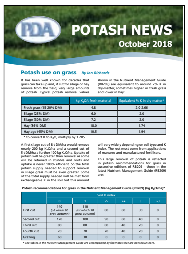
- Potassium Management in Different Cropping Systems;
- Polyhalite as a Multi-Nutrient Fertilizer;
- Effect of Polyhalite Application on the Yield and Quality of Different Crops;
- Role of S, Mg and Ca Nutrients in Plant Nutrition;
- Potassium and Biotic and Abiotic Stresses;
- Loss of Soil Fertility and Stagnation of Agricultural Production;
- Nutrient Mining and Input-Output Balances at Farm and Regional Levels.

More details on the symposium will be published shortly. Visit the event website for regular updates on the symposium at https://events.ipipotash.org/.

For further information contact IPI's Coordinator for China, Mr. Eldad Sokolowski (eldad.sokolowski@icl-group.com) or IPI's Scientific and Communications Coordinator, Dr. Patricia Imas (patricia.imas@icl-group.com).

# Publications

## Publications by the PDA




**Potash Use on Grass**

POTASH News, October 2018.

It has been well known for decades that grass can take up and, if cut for silage or hay remove from the field, very large amounts of potash. Typical potash removal values shown in the Nutrient Management Guide (RB209) are equivalent to around 2% K in dry-matter, sometimes higher in fresh grass and lower in hay. Read more on the PDA website.

*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

## in the Literature

**Follow us on Twitter on:** https://twitter.com/IPI_potash
**Follow our Facebook on:** https://www.facebook.com/IPIpotash?sk=wall

### Quantity-Intensity Relations of Potassium in Representative Coastal Soils of Eastern India

Ranajit Panda, and S.K.Patra. 2018. Geoderma 332:198-206. DOI: https://doi.org/10.1016/j.geoderma.2018.07.014.

**Abstract:** Quantity-intensity (Q/I) isotherms were used to evaluate the dynamics of $K^+$ in twelve coastal soils of eastern India. The activity ratio of $K^+$ ($AR_e^K$) and corresponding changes in labile $K^+$ ($\pm\Delta K$) at equilibrium increased with increasing $K^+$ concentrations. The equilibrium activity ratio of $K^+$ ($AR_e^{0K}$) varied between $0.09 \times 10^{-3}$ and $7.50 \times 10^{-3}$ (mol $L^{-1})^{1/2}$. The labile $K^+$ ($K_L$) ranged from 0.265 to 0.4 cmol $kg^{-1}$ constituting 43.8 to 204.5% of 1N $NH_4OAc$ extractable $K^+$. The readily available ($K_0$) and fixed $K^+$ ($K_X$) varied from 0.082 to 0.290 and 0.041 to 0.278 cmol $kg^{-1}$ contributing 22.8 to 84.5 and 15.5 to 77.2% towards $K_L$, respectively. The potential buffering capacities for $K^+$ ($PBC^K$) fluctuated from 16.2 to 85.7 cmol $kg^{-1}$(mol $L^{-1})^{-1/2}$. The $K^+$ potential ranged from 2.38 to 10.76 cmol $kg^{-1}$(mol $L^{-1})^{-1/2}$. The free energy of $K^+$ exchange ($-\Delta G$) ranged from −5533 to −2906 calories $mol^{-1}$ indicating deficient to adequate in available

$K^+$. The $AR_e^{0K}$, $K_0$, $K_X$ and $-\Delta G$ had significant positive correlations with pH, CEC, available and reserves soil $K^+$, while there were inverse relationships between $PBC^K$ and these soil parameters. A significant positive correlation was found between $AR_e^{0K}$ and $K_0$, $K^+$ saturation, $-\Delta G$ and significant negative correlation with $K_X$ and $PBC^K$. Significant positive correlations were observed between $K_X$ and $K_L$ and $PBC^K$ and significant negative correlations with $AR_e^{0K}$, $-\Delta G$ and $K^+$ saturation. $PBC^K$ had significant negative correlations with $K_0$, $-\Delta G$ and $K^+$ saturation. The study provided useful information for understanding $K^+$ dynamics in coastal soils and make significant contribution to operational $K^+$ management.

### Fruit Yellow-Shoulder Disorder as Related to Mineral Element Uptake of Tomatoes Grown in High Temperature

Yiting Zhang, KatsumiSuzuki, Houcheng Liu, Akira Nukaya, and Yoshikazu Kiriiwa. 2018. Scientia Horticulturae 242:25-29. DOI: https://doi.org/10.1016/j.scienta.2018.06.087.

**Abstract:** In order to reduce yellow-shoulder (YS) disorder by regulating nutrient solution in high temperature, effects of potassium (K) and phosphorus (P) supplementation on YS index were investigated. Experiments were conducted in an optimum temperature condition under 20°C, and in a high temperature condition under 31°C. Nutrient solution of EC 0.9 dS $m^{-1}$ ($PO_4$-P 1.5 me $L^{-1}$, K 3.0 me $L^{-1}$), EC 0.9 + P ($PO_4$-P 4.6 me $L^{-1}$, K 3.0 me $L^{-1}$), EC 0.9 + K ($PO_4$-P 1.5 me $L^{-1}$, K 5.8 me $L^{-1}$), and EC 0.9 + P + K ($PO_4$-P 4.6 me $L^{-1}$, K 5.8 me $L^{-1}$) were used. Each tomato (*Solanum lycopersicum* L. 'CF Momotaro York') plant was grown in 250 mL pot combining three trusses and high-density planting. Results showed that K uptake amount was significantly higher at EC 0.9 + P + K than at EC 0.9, EC 0.9 + P and EC 0.9 + K. K uptake efficiency was higher at EC 0.9 + P than that at EC 0.9, although the application concentration of K were identical in them. YS disorder was more severe in 31°C than 20°C temperatures condition in the case of nearly similar uptake of K per plant. The YS index showed a significantly negative linear correlation with K uptake ($R^2$ = 0.81, $P$ < 0.01) in 31°C, which was not found in 22°C or other mineral elements. These results indicated that the K uptake was significantly improved. YS disorder was correspondingly reduced by increasing P or/and K concentration in 31°C high temperature condition. In conclusion, we recommended the nutrient solution formula (EC 0.9 + P)/(EC 0.9 + P + K) to reduce the YS disorder in high temperature growing season, because its K uptake efficiency was improved as compared with EC 0.9 + P + K.

### Management Practices of Macronutrients for Potato for Smallholder Farming System at Alluvial Soil (Entisols) of India

Lalita Rana, Hirak Banerjee, Sudarshan Kumar Dutta, Krishnendu Ray, Kaushik Majumdar, and Sukamal Sarkar. 2017. Archives of Agronomy and Soil Science 63(14):1963-1976. DOI: 10.1080/03650340.2017.1317922.

**Abstract:** In the present study, seven fertilizer treatments [$T_1$, 50% NPK; $T_2$, 100% NPK (Recommended dose of fertilizer, 200–65.4–124.5 kg N-P-K $ha^{-1}$); $T_3$, 150% NPK; $T_4$, 100% PK; $T_5$, 100% NK; $T_6$, 100% NP and $T_7$, control (zero NPK)] with four replications were assessed in the new alluvial soil zone (Entisols) of West Bengal, India. The objectives of the study were to generate information on potato productivity, profitability, indigenous nutrient supply and net gain/loss of NPK in post-harvest soil. Plants grown under higher NPK supply resulted in higher tuber yield and there were significant ($p \leq 0.05$) reductions in total yield with nutrient omissions. Nutrient-limited yields were 19.78, 2.83 and 1.77 t $ha^{-1}$ for N, P and K, considering total tuber yield (28.24 t $ha^{-1}$) obtained under 100% NPK as targeted yield. Indigenous nutrient supply of N, P and K were estimated at 24.1, 22.34 and 110.22 kg $ha^{-1}$, respectively that indicates higher K-supplying capacity of experimental soil as compared to N and P. Net income (US$1349 $ha^{-1}$ $year^{-1}$) and B:C ratio (1.91) was highest with 100% NPK, and further addition of NPK (150%) resulted in decrease on net return (US$1193 $ha^{-1}$ $year^{-1}$) and B:C ratio (1.73).

### The High-Affinity Potassium Transporter EpHKT1;2 from the Extremophile *Eutrema parvula* Mediates Salt Tolerance

Akhtar Ali, Irfan Ullah Khan, Masood Jan, Haris Ali Khan, Shah Hussain, Muhammad Nisar, Woo Sik Chung, and Dae-Jin Yun. 2018. Front. Plant Sci. DOI: https://doi.org/10.3389/fpls.2018.01108.

**Abstract:** To survive salt stress, plants must maintain a balance between sodium and potassium ions. High-affinity potassium transporters (HKTs) play a key role in reducing $Na^+$ toxicity through $K^+$ uptake. *Eutrema parvula* (formerly known as *Thellungiella parvula*), a halophyte closely related to *Arabidopsis*, has two *HKT1* genes that encode EpHKT1;1 and EpHKT1;2. In response to high salinity, the *EpHKT1;2* transcript level increased rapidly; by contrast, the *EpHKT1;1* transcript increased more slowly in response to salt treatment. Yeast cells expressing EpHKT1;2 were able to tolerate high concentrations of NaCl, whereas EpHKT1;1-expressing yeast cells remained sensitive to NaCl. Amino acid sequence alignment with other plant HKTs showed that EpHKT1;1 contains an asparagine residue (Asn-213) in the second pore-loop domain, but EpHKT1;2 contains an aspartic acid residue (Asp-205) at the same position. Yeast cells expressing EpHKT1;1, in which Asn-213 was substituted with Asp, were able to tolerate high concentrations of NaCl. In contrast, substitution of Asp-205 by Asn in EpHKT1;2 did not enhance salt tolerance and rather resulted in a similar function to that of AtHKT1 ($Na^+$ influx but no $K^+$ influx), indicating that the presence of Asn or Asp determines the mode of cation selectivity

of the HKT1-type transporters. Moreover, *Arabidopsis* plants (Col-*gl*) overexpressing *EpHKT1;2* showed significantly higher tolerance to salt stress and accumulated less $Na^+$ and more $K^+$ compared to those overexpressing *EpHKT1;1* or *AtHKT1*. Taken together, these results suggest that EpHKT1;2 mediates tolerance to $Na^+$ ion toxicity in *E. parvula* and is a major contributor to its halophytic nature.

### Maize-Nutrient Response Functions for Eastern and Southern Africa

Wortmann, C. S., C. Senkoro, A.R. Cyamweshi, C.Kibunja, D. Nkonde, M. Munthali, P. Nalivata, L.N. Nabahungu, and K. Kaizzii. 2018. Agron. J. 110(5):2070-2079. DOI: 10.2134/agronj2018.04.0268.

**Abstract:** Information is scarce for maize (*Zea mays* L.) response to nutrient application for many production areas in tropical Africa. Research was conducted to determine macronutrient response functions and to diagnose Mg-S-Zn-B deficiencies. Site-year × N-rate interactions within countries often accounted for little variation in yield relative to the N-rate effect. Country mean grain yield responses to N-rate were curvilinear to plateau, but linear in Malawi. Although mean yields differed, the response to N was similar for Kenya, Tanzania, and Zambia with a mean yield increase of 0.94 Mg $ha^{-1}$ due to 50 kg $ha^{-1}$ N compared with 1.59 Mg $ha^{-1}$ for Malawi and Rwanda. Response to N was related to yield with no fertilizer applied ($r = 0.40$). Only Rwanda had mean responses to P and K with respective yield increases of 0.99 and 0.22 Mg $ha^{-1}$ due to 15 kg $ha^{-1}$. Application of Mg-S-Zn-B caused a mean yield increase of 0.73 Mg $ha^{-1}$ in Rwanda but had no effect in other countries. Application of affordable fertilizer to twice as much land at 50% compared with 100% of the economically optimum rate results in mean gains of 50% for production and agronomic efficiency and 72% for profit/cost ratio. Soil test results were not related to response to applied nutrients but historical yield appears to be weakly predictive of N response. The determined country-level P and K response functions can be widely applied, except for Kenya, in consideration of other available information. The response to Mg-S-Zn-B in Rwanda needs further investigation.

### Socioeconomic Factors Determining Fertilizer Use in China for Different Crops: Same Factors, Different Effects

Wang, Y., L.Y. Khor, and K. Siddig. 2018. Agron. J. 110(5):1813-1819. DOI: 10.2134/agronj2018.01.0031.

**Abstract:** Studies on the socioeconomic determinants of fertilizer use intensity usually analyze the total fertilizer use for all crops as a whole or focus only on fertilizer use for the main crop in the region. This article examines if the determinants of fertilizer use are consistent across different crops. Four years of panel data were collected from annual household surveys in Hebei province, China. The data include only households who practice wheat–maize rotation to generate an identical sample for comparing the determinants of fertilizer use in wheat and maize production ($N = 1467$). A fixed-effects regression is used to estimate the effects of socioeconomic factors on the intensity of fertilizer use for wheat and maize, respectively, while controlling for unobserved effects. The results indicate that there is inconsistency in the determinants of fertilizer use intensity between the two crops. Labor availability, crop share in food consumption, and farming diversity affect fertilizer use intensity for wheat and maize differently. These findings suggest that crop type matters when examining the socioeconomic determinants of fertilizer use and that current and future fertilizer policies should take crop differences into consideration, for example when identifying potential target groups in fertilizer subsidy programs and development projects where fertilizer is distributed.

### Fertilizer Recommendations for Switchgrass: Quantifying Economic Effects on Quality and Yield

Popp, M. P., A. J. Ashworth, P. A. Moore, P. R. Owens, J. L. Douglas, D. H. Pote, A. A. Jacobs, K. R. Lindsay, and B. L. Dixon. 2018. Agron. J. 110(5):1854-1861. DOI: 10.2134/agronj2018.04.0273.

**Abstract:** Switchgrass (*Panicum virgatum* L.) is a native, perennial warm-season grass suited for biomass production for renewable fuels and also fodder on marginal soils. To develop fertilizer recommendations, yield responses to and nutrient removal in harvest biomass associated with five levels of macronutrients of N, P, and K on Leadvale silt loam (fine-silty, siliceous, semiactive, thermic Typic Fragiudults) with a fragipan at 14 to 97 cm at a mid-southern US location were examined. Feed quality was assessed using crude protein (CP) and total digestible nutrient (TDN) concentration to assess feasibility in beef cow (*Bos taurus*) rations. Nitrogen affected economic performance to a larger extent than P and K. Profit-maximizing K use rivaled that of N use, whereas P use was low and thereby limited sustainable poultry litter application. Hay ranged between 7 and 9% CP and 51% ± 0.5% TDN in response to harvest time and nutrient application rate. Cattle producers would find such hay suitable for maintaining dry cows without need for supplemental feed. Profitability of hay production and fertilizer recommendations varied largely with changes in switchgrass price and fertilizer cost. As such, a supplemental spreadsheet tool was developed for research outreach purposes to provide output price- and input cost-specific fertilizer recommendations for switchgrass hay with attendant quality impacts. Overall, breakeven prices were lower using inexpensive litter in comparison with synthetic fertilizers and ranged from approximately US$40 to US$60 $Mg^{-1}$ in this

study. Therefore, switchgrass hay compared favorably in cost to traditional hay averaging US$126 $Mg^{-1}$ over the study period.

### Sidedressing Potassium and Nitrogen on Corn

Miller, R.D. 2017. The Fluid Journal 25(4):Issue 98 (https://fluidfertilizer.org/wp-content/uploads/2017/11/F17-A1.pdf).

**Abstract:** Summary: Results of a Midwestern population study across five sites show optimum yields were obtained with planted corn populations of 32k-36k plants $ac^{-1}$ based on 30" rows in the Midwest. Higher populations resulted in reduced number of plants with ears and lower grain yields. Side dress nitrogen (N) was site and year specific with an average response of 30 bu $ac^{-1}$ to 50 lbs N $ac^{-1}$ on the most responsive sites. Sidedress response to potassium (K) was limited, and the average response to sidedress applied K was 10-12 bu $ac^{-1}$ with 50 lbs K $ac^{-1}$. K source product studies showed K acetate combined with N showed significant grain yield response. Cluster analysis of corn ear leaf nutrients collected at growth stage R1-R2 from 112 grower fields from 2011 to 2016 across six states, indicate leaf K levels <1.9% are indicative of lower yields and that K deficient fields show increased magnesium (Mg) accumulation resulting in lower ear leaf K:Mg ratios. Across five years low ear leaf K clusters averaged 45.2 bu $ac^{-1}$ less grain yield than those with >2.0 leaf K. Established N, K, Mg DRIS ratio norms for corn leaves are an effective tool in diagnosing corn K deficiencies, their impact on grain yield, and addressing long-term K fertility management of corn.

### Corn Era Hybrid Macronutrient and Dry Matter Accumulation in Plant Components

Woli, K.P., J.E. Sawyer, M.J. Boyer, L.J. Abendroth, and R.W. Elmore. 2018. Agron. J. 110(5):1648-1658. DOI: 10.2134/agronj2018.01.0025.

**Abstract:** As corn (*Zea mays* L.) hybrids change over time, and with increased use of different plant components for feed, bedding, and energy production, it is important to know macronutrient distribution within plants and how nutrient concentration and accumulation varies during plant development. This field study was conducted in 2007 and 2008 to evaluate dry matter (DM) biomass, macronutrient concentration, and macronutrient content in corn plant fractions (stalk, leaf, tassel, ear shoot, cob, and grain) across developmental stages with two hybrids from 1960 and 2000 eras. Concentrations of N, P, and K were generally lower in all plant fractions for the 2000 compared to 1960 era hybrids, except P concentration in stalks and grain and K concentration in leaves and ear shoots. In contrast, N, P, and K content was consistently higher in 2000 era hybrids for whole plants, leaves, and grain; a reflection of greater DM production. Nitrogen, P, K, and DM content in tassels was lower for 2000 than 1960 era hybrids. From the 1960s to 2000s, hybrid development brought about an increase in plant biomass and grain yield resulting in greater total nutrient content. However, macronutrient concentrations in vegetative plant fractions and grain decreased, thus moderating increase in plant total and grain nutrient content. This research shows the importance for analysis of newer hybrid vegetative and grain biomass on an ongoing basis to provide reliable estimates of macronutrient uptake patterns and removal with harvest of specific vegetative material and grain.

### How to Monitor Potassium Fertilization in Grapevines

Brase, R. 2010. Growing Produce.

**Introduction:** Monitoring grapevine nutrition and undertaking appropriate fertilization is important in maintaining healthy vines and maturing grapes of a good quality. This is especially challenging with the diversity of soils and climates where grapevines are grown in the U.S. While grapevines require a number of different nutrients to maintain health and production, the nutrient needed in the largest quantity is potassium (potash).

### Production of Low-Potassium Content Melon through Hydroponic Nutrient Management using Perlite Substrate

Md. Asaduzzaman, Md. Raihan Talukder, Hideyuki Tanaka, Makoto Ueno, Mikiko Kawaguchi, Shozo Yano, Takuya Ban, and Toshiki Asao. 2018. Front. Plant Sci. DOI: https://doi.org/10.3389/fpls.2018.01382.

**Abstract:** Chronic kidney disease patients are restricted to foods with high potassium content but our daily diets including melon are rich in potassium. Therefore, we investigated the production of low-potassium melon through hydroponic nutrient management in soilless culture using perlite substrate during autumn season of 2012, 2014 and spring season of 2016. In the first study, melon plants were supplied with 50% standard 'Enshi' nutrient solution until first 2 weeks of culture. In 3rd and 4th week, amount of applied potassium was 50, 75, 100, and 125% of required potassium nitrate for each plant per week (based on our previous study). It was found that, melon plants grown with 50% of its required potassium nitrate produced fruits with about 53% low-potassium compared to control. In the following study, four cultivars viz. Panna, Miyabi shunjuukei, Miyabi akifuyu412, and Miyabi soushun banshun309 were evaluated for their relative suitability of low-potassium melon production. Results showed insignificant difference in fruit potassium content among the cultivars used. Source of potassium fertilizer as potassium nitrate and potassium sulfate and their restriction (from 1 or 2 weeks after anthesis) were also studied. There were no influences on fruit potassium content and yield due to sources of potassium fertilizer and restriction timings. In our previous studies, it was

evident that potassium can be translocated from leaves to fruits at maturity when it was supplied nutrient without potassium. Thus, we also studied total number of leaves per plant (23, 24, 25, 26, and 27 leaves per plant). It was evident that fruit potassium, yield, and quality were not influenced significantly due to differences in number of leaves per plant. These studies showed that restriction of potassium nitrate in the culture solution from anthesis to harvest could produce melon fruits with low-potassium (>20%) content compared to potassium content of greenhouse grown melon (340 mg/100 g FW). Quality testing and clinical validation of low-potassium melon also showed positive responses compared to greenhouse grown melon.

## Species-Wide Variation in Shoot Nitrate Concentration, and Genetic Loci Controlling Nitrate, Phosphorus and Potassium Accumulation in *Brassica napus* L.

Alcock, T.D., L. Havlickova, Z. He, L. Wilson, I. Bancroft, P.J. White, M.R. Broadley, and N.S. Graham 2018. Front. Plant Sci. DOI: https://doi.org/10.3389/fpls.2018.01487.

**Abstract:** Large nitrogen, phosphorus and potassium fertilizer inputs are used in many crop systems. Identifying genetic loci controlling nutrient accumulation may be useful in crop breeding strategies to increase fertilizer use efficiency and reduce financial and environmental costs. Here, variation in leaf nitrate concentration across a diversity population of 383 genotypes of *Brassica napus* was characterized. Genetic loci controlling variation in leaf nitrate, phosphorus and potassium concentration were then identified through Associative Transcriptomics using single nucleotide polymorphism (SNP) markers and gene expression markers (GEMs). Leaf nitrate concentration varied over 8-fold across the diversity population. A total of 455 SNP markers were associated with leaf nitrate concentration after false-discovery-rate (FDR) correction. In linkage disequilibrium of highly associated markers are a number of known nitrate transporters and sensors, including a gene thought to mediate expression of the major nitrate transporter NRT1.1. Several genes influencing root and root-hair development co-localize with chromosomal regions associated with leaf P concentration. Orthologs of three ABC-transporters involved in suberin synthesis in roots also co-localize with association peaks for both leaf nitrate and phosphorus. Allelic variation at nearby, highly associated SNPs confers large variation in leaf nitrate and phosphorus concentration. A total of five GEMs associated with leaf K concentration after FDR correction including a GEM that corresponds to an auxin-response family protein. Candidate loci, genes and favorable alleles identified here may prove useful in marker-assisted selection strategies to improve fertilizer use efficiency in *B. napus*.

## Potassium Nutrition Affects Anthracnose on Annual Bluegrass

Schmid, C.J., B.B. Clarke, and J.A. Murphy. 2018. Potassium Nutrition Affects Anthracnose on Annual Bluegrass. Agron. J. 110(6):2171-2179. DOI: 10.2134/agronj2018.03.0147.

**Abstract:** Potassium fertilization can improve stress tolerances in turfgrass; however, its effect on turfgrass diseases is inconsistent and not well understood. A 3-yr field study was initiated to determine the effect of K fertilization rate and K source on anthracnose disease of annual bluegrass turf. Potassium chloride and $K_2SO_4$ were applied at K rates of 54, 109, and 218 kg ha$^{-1}$ yr$^{-1}$ as a 2 × 3 factorially arranged randomized complete block design with four replications. Potassium nitrate and $K_2CO_3$ were also included at the 218 kg K ha$^{-1}$ yr$^{-1}$ rate, as well as an untreated check. Nonlinear regression models were used to estimate critical concentrations of K in the mat layer and tissue with respect to anthracnose severity. All K treatments reduced disease severity compared to the untreated check (no K); however, KCl was less effective than the other sources when applied at the 218 kg K ha$^{-1}$ yr$^{-1}$ rate. The Cate–Nelson regression model predicted that K values less than 43 mg kg$^{-1}$ in the mat layer (Mehlich 3 extractant) and 20 g kg$^{-1}$ in leaf tissue will increase anthracnose severity of annual bluegrass (ABG). This study provides evidence that K fertilization can reduce anthracnose severity and that the severity of this disease can be correlated with mat and tissue K concentrations. Thus, it is important to monitor K in ABG turf and to maintain sufficient levels to reduce disease severity and improve turfgrass quality.

## Hydrogen Sulfide Mediates $K^+$ and $Na^+$ Homeostasis in the Roots of Salt-Resistant and Salt-Sensitive Poplar Species Subjected to NaCl Stress

Nan Zhao, Huipeng Zhu, Huilong Zhang, Jian Sun, Jinchi Zhou, Chen Deng, Yuhong Zhang, Rui Zhao, Xiaoyang Zhou, Cunfu Lu, Shanzhi Lin, and Shaoliang Chen. 2018. Front. Plant Sci. DOI: https://doi.org/10.3389/fpls.2018.01366

**Abstract:** Non-invasive micro-test techniques (NMT) were used to analyze NaCl-altered flux profiles of $K^+$, $Na^+$, and $H^+$ in roots and effects of NaHS (a $H_2S$ donor) on root ion fluxes in two contrasting poplar species, *Populus euphratica* (salt-resistant) and *Populus popularis* (salt-sensitive). Both poplar species displayed a net $K^+$ efflux after exposure to salt shock (100 mM NaCl), as well as after short-term (24 h), and long-term (LT) (5 days) saline treatment (50 mM NaCl, referred to as salt stress). NaHS (50 µM) restricted NaCl-induced $K^+$ efflux in roots irrespective of the duration of salt exposure, but $K^+$ efflux was not pronounced in data collected from the LT salt stress treatment of *P. euphratica*. The NaCl-induced $K^+$ efflux was inhibited by a $K^+$ channel blocker, tetraethylammonium chloride (TEA) in *P. popularis* root samples, but $K^+$ loss increased with a specific inhibitor of

plasma membrane (PM) $H^+$-ATPase, sodium orthovanadate, in both poplar species under LT salt stress and NaHS treatment. This indicates that NaCl-induced $K^+$ loss was through depolarization-activated $K^+$ channels. NaHS caused increased $Na^+$ efflux and a corresponding increase in $H^+$ influx for poplar roots subjected to both the short- and LT salt stress. The NaHS-enhanced $H^+$ influx was not significant in *P. euphratica* samples subjected to short term salt stress. Both sodium orthovanadate and amiloride (a $Na^+/H^+$ antiporter inhibitor) effectively inhibited the NaHS-augmented $Na^+$ efflux, indicating that the $H_2S$-enhanced $Na^+$ efflux was due to active $Na^+$ exclusion across the PM. We therefore conclude that the beneficial effects of $H_2S$ probably arise from upward regulation of the $Na^+/H^+$ antiport system ($H^+$ pumps and $Na^+/H^+$ antiporters), which promote exchange of $Na^+$ with $H^+$ across the PM and simultaneously restricted the channel-mediated $K^+$ loss that activated by membrane depolarization.

## Potassium Influence on Soil Aggregate Stability

Yotsapon Phocharoen, Surachet Aramrak, Natthapol Chittamart, and Worachart Wisawapipat. 2018. Communications in Soil Science and Plant Analysis 49(17):2162-2174. DOI: 10.1080/00103624.2018.1499752.

**Abstract:** Improving soil aggregate stability (SAS) is important for crop production and environmental protection. Here we aim to quantify the effects of potassium (K) on SAS and to examine SAS as a function of potassium adsorption ratio (PAR) and cation ratio of soil structural stability (CROSS). The soils were treated with the incremental K and analyzed for their aggregate stability, clay dispersion, PAR, and CROSS. The influence of K on SAS, therefore, was tested statistically and fitted functionally. The results showed that K decreased clay dispersion and improved SAS. Also, SAS as a function of PAR fit an inverse exponential regression. Based on the coefficients of determination ($R^2$) of the obtained functions, SAS can be explained by PAR with the accuracy above 94%. Increasing CROSS according to K also caused higher SAS, implying that K is considered as a flocculating inducer for kaolinitic tropical soils.

## The *Arabidopsis thaliana* $K^+$-Uptake Permease 5 (AtKUP5) Contains a Functional Cytosolic Adenylate Cyclase Essential for $K^+$ Transport

Al-Younis, I., A. Wong, F. Lemtiri-Chlieh, S. Schmöckel, M. Tester, C. Gehring, and L. Donaldson. 2018. Front. Plant Sci. DOI: https://doi.org/10.3389/fpls.2018.01645.

**Abstract:** Potassium ($K^+$) is the most abundant cation in plants, and its uptake and transport are key to growth, development and responses to the environment. Here, we report that Arabidopsis thaliana $K^+$ uptake permease 5 (AtKUP5) contains an adenylate cyclase (AC) catalytic center embedded in its N-terminal cytosolic domain. The purified recombinant AC domain generates cAMP *in vitro*; and when expressed in *Escherichia coli*, increases cAMP levels *in vivo*. Both the AC domain and full length AtKUP5 rescue an AC-deficient *E. coli* mutant, *cyaA*, and together these data provide evidence that AtKUP5 functions as an AC. Furthermore, full length AtKUP5 complements the *Saccharomyces cerevisiae* $K^+$ transport impaired mutant, *trk1 trk2*, demonstrating its function as a $K^+$ transporter. Surprisingly, a point mutation in the AC center that impairs AC activity, also abolishes complementation of *trk1 trk2*, suggesting that a functional catalytic AC domain is essential for $K^+$ uptake. AtKUP5-mediated $K^+$ uptake is not affected by cAMP, the catalytic product of the AC, but, interestingly, causes cytosolic cAMP accumulation. These findings are consistent with a role for AtKUP5 as $K^+$ flux sensor, where the flux-dependent cAMP increases modulate downstream components essential for $K^+$ homeostasis, such as cyclic nucleotide gated channels.

## Potassium Application Alleviates Grain Sterility and Increases Yield of Wheat (*Triticum aestivum*) in Frost-Prone Mediterranean-Type Climate

Ma, Q., R. Bell, and B. Biddulph. 2019. Plant Soil 434(1-2):203-216. DOI: https://doi.org/10.1007/s11104-018-3620-y.

**Abstract:**
Aims: Frost is a major risk factor for grain production in Australian farming systems and appears to be increasing in severity and occurrence due to changing climate. In this study we assessed the role of potassium (K) and micronutrients in alleviating floret sterility (FS) and yield loss in wheat crops subject to frost.
Methods: Field experiments with K application in 2015 and 2016 were conducted in frost-prone, low soil K fields in the grain belt of Western Australia. Following frost events the heads reaching anther dehiscence were tagged and FS was measured 5-6 weeks later. We also measured leaf K concentration, photosynthesis and antioxidant activity, and grain yield.
Results: In 2015 K supply decreased FS from 32% at nil K to 24% at 80 kg K $ha^{-1}$. In 2016 the FS values varied from 30 to >95%. Although there was no effect of K on FS at extreme frosts (FS >95%), applying 20-80 kg K $ha^{-1}$ reduced FS by 10-20% and increased yield by 0.2-0.4 t $ha^{-1}$ at less severe frosts. The decrease in FS was associated with increasing leaf K concentrations in the range 1.5-2.6%, higher photosynthesis and less oxidative stress at anthesis, but K supply did not provide extra protection from frost damage at leaf K > 2.6%. Foliar micronutrients at booting and heading did not affect FS in either year due to adequate micronutrient levels in the topsoil.
Conclusions: Improved plant K status can increase grain set and yields in wheat under frost, likely by maintaining physiological functions such as cell osmoregulation, plant photosynthesis and anti-oxidant systems. Plant K requirement in frost prone parts of

the landscape is greater than in the areas with low risk of frost damage.

### It Is Not All About Sodium: Revealing Tissue Specificity and Signalling Roles of Potassium in Plant Responses to Salt Stress

Wu, H., X. Zhang, J.P. Giraldo, and S. Shabala. 2018. Plant Soil 431(1-2):1-17. DOI: https://doi.org/10.1007/s11104-018-3770-y.

**Abstract:**
Background: Salinity is a global issue threatening agricultural production systems across the globe. While the major focus of plant salinity stress tolerance research has been on sodium, the transport and physiological roles of $K^+$ in plant salt stress response has received less attention. This review attempts to bridge this knowledge gap.
Scope: The major emphasis is on newly proposed $K^+$ signalling roles and plant salt tolerance cell- and tissuespecificity. In addition to summarizing the importance of $K^+$ retention for plant salt tolerance, we focus onaspects that were not the subject of previous reviews including (1) the importance of HAK/KUP family of transporters in $K^+$ uptake in salt stressed plants and its possible linkage with $Ca^{2+}$ and ROS signalling; (2) control of xylem $K^+$ loading in salt stressed plants, control of phloem $K^+$ recirculation in salt stressed plants and the potential importance of plant's ability to efficiently coordinate $K^+$ signals between root and shoot; (3) the buffering capacity of the vacuolar $K^+$ pool; and (4) mechanisms of restoring the basal cytosolic $K^+$ levels by coordinated activity of tonoplast $K^+$-permeable channels.
Conclusions: Overall, this review emphasises the need to fully understand the newly emerging roles of $K^+$ and regulation of its transport for improving salinity stress tolerance in plants.

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

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

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

### Effects of Rice (*Oryza sativa* L.) Cultivation and Soil Type on Potassium Mobilization and Transformation Behavior

Zhu, D.D., L.P. Zhan, R.H. Cong, and X.K. Li. 2018. Canadian Journal of Soil Science 98(3):500-507. DOI: https://doi.org/10.1139/cjss-2018-0029.

**Abstract:** To understand the chemical behavior of potassium (K) in soil, rhizobox experiments were conducted to study the effects of K uptake by cultivated rice and soil type on K migration and transformation in soils. The aim of this study was to guide reasonable application of K fertilizer in different soil types. The results showed that at the maximum tillering stage, the migration distances of water-soluble K (Sol-K) were 6 and 5 cm, the depletion of exchangeable K (Ex-K) was 7 and 4 cm, and depletion of nonexchangeable K (Nonex-K) was 1 and 5 cm, respectively, in yellow cinnamon soil (YCS) and fluvo-aquic soil (FS). With the growth of rice, the migration distances of Sol-K showed little difference between YCS and FS. Throughout the season, the contributions of Sol-K, Ex-K, and Nonex-K to K uptake in YCS were 12.0%, 40.0%, and 48.0%, respectively, whereas their contributions in FS were 25.7%, 25.8%, and 48.5%, respectively. K uptake by rice was linearly related to the concentration of different forms of K in soils ($R^2 = 0.687^*$). In conclusion, soil type significantly affected K mobilization and transformation behavior. This indicated that the location of K fertilizer addition in the root zone should differ with soil type.

### Effects of Potassium Fertilization on Late Potato Blight and Yield - Short Communication

Kowalska J., and D. Drożdżyński. 2018. Plant Protect. Sci. 54:87-91. DOI: https://doi.org/10.17221/79/2017-PPS.

**Abstract:** Potato yields and infestation by *P. infestans* are related to the supply of potassium. Potassium was applied as soil fertilisation combined with split foliar applications or only as split foliar treatments at a maximum dose of 150 kg/ha $K_2O$ in both strategies, Lord and Ditta cultivars were used. Additionally, water spraying was included as an alternative treatment in order to maintain uniform moisture in the rows of plants. Plants fertilised with foliar spraying only were more infested than plants fertilised with combined methods. The fertiliser increased the protection impact of copper treatments against *P. infestans*. This may suggest a possible synergistic effect in reducing the symptoms of the disease, however not always statistically significant in both cultivars. Plants sprayed with water but without soil application of fertiliser showed a statistically significantly higher infestation

rate, both in Lord and Ditta cultivars, compared to plants with soil application of fertiliser but without watering.

## A Long-Term Evaluation of Differential Potassium Fertilization of a Creeping Bentgrass Putting Green

Bier, P.V., M. Persche, P. Koch, and D.J. Soldat. 2018. Plant Soil 431(1-2):303-316. DOI: https://doi.org/10.1007/s11104-018-3765-8.

**Abstract:**
Aims: The objective of this research was to evaluate bentgrass quality, growth, and disease incidence over a range of soil and tissue potassium levels.
Methods: 'Penn A4' creeping bentgrass (*Agrostis stolonifera* L.) on a sand root zone was maintained as a putting green. The treatments included four levels of liquid potassium sulfate, ranging from 0 to 249 kg $ha^{-1}$ $yr^{-1}$ K and one level of granular gypsum at a rate of 100 kg $ha^{-1}$ $yr^{-1}$ Ca.
Results: No differences in vegetative or quality parameters were observed over the 6 year study period. Tissue K, Mehlich-3 extractable K, and Microdochium patch infection were all affected by treatment, with high-K treatments being greater than control and Ca treatments in all three instances. Near-daily turfgrass harvest resulted in much greater K removal than was estimated to be available from the pools extracted by Mehlich-3 and 1 *M* $HNO_3$, suggesting that K became plant-available from more recalcitrant pool.
Conclusion: Traditional soil testing methods may be inadequate for determining plant-available K in sand root zones. Total soil K analysis of the 0-K treatment indicated an increase in K during the study period, likely as a result of regular additions of sand via topdressing. Weathering of mineral K likely provided sufficient K to compensate for the lack of fertilizer.

## Avocado Fertilization: Matching the Periodic Demand for Nutrients

Silber, A., A. Naor, H. Cohen, Y. Bar-Noy, N. Yechieli, M. Levi, M. Noy, M. Peres, D. Duari, K. Narkis, and S. Assouline. 2018. Scientia Horticulturae 241:231-240. DOI: https://doi.org/10.1016/j.scienta.2018.06.094.

**Abstract:** The main objective of this study was to assess the seasonal nutrients requirement of 'Hass' avocado trees grown in lysimeters, especially during flowering and the early period of fruit development that may affect later on the fruitlet abscission and determine crop yield. The experimental design included three fertigation treatments applying a fixed nutrient solution at three different starting dates of fertigation: (a) T1 - continuous fertigation, including macro nutrients (N-P-K) and micronutrients application, all over the year; (b) T2 - no fertilization (only irrigation) until 15 March, and fertigation as T1 since then; (c) T3 - no fertilization (only irrigation) until 15 May, and fertigation as T1 since then. Absence of fertilization during the winter period induced leaf-chlorosis while healthy, dense and plenteously green leaves characterized the fertilized trees (T1). The beneficial effect of early fertigation on fruit yield was statistically significant, mostly because of higher fruit number. Leaf analyses are commonly used in the avocado industry as a guide for fertilization yet; fruits rather than leaves are the main products of avocado orchards. Consequently, fruit rather than leaf analyses should determine fertilization management. Based on fruit growth data and nutrient concentration in the fruit, the N, P and K quantities removed by 'Hass' avocado fruit yield of 30 t $ha^{-1}$ were 120, 25 and 240 kg $ha^{-1}$. Taking into account common efficiency consideration (nutrient quantities removed by fruit yield divided by quantities added), the annual quantities of N, P and K required for attaining high quality avocado yield are 250-300, 80-120 and 500-600 kg $ha^{-1}$, respectively. Thus, fertilization rate together with nutrient combination should be modified in order to insure optimal fruit development.

## Changes in Mineral Nutrient Concentrations and C-N Metabolism in Cabbage Shoots and Roots Following Macronutrient Deficiency

Jwakyung Sung, Hyejin Yun, Seunga Back, Alisdair R. Fernie, Yangmin X. Kim, Yejin Lee, Seulbi Lee, Deogbae Lee, and Jaekwang Kim. 2018. J. Plant Nutr. Soil Sci. 181(5):777-786. DOI: https://doi.org/10.1002/jpln.201800001.

**Abstract:** The responses of metabolic networks to mineral deficiency are poorly understood. Here, we conducted a detailed, broad-scale analysis of macronutrient concentrations and metabolic changes in the shoots and roots of cabbage (*Brassica rapa* L. ssp. *pekinensis*) plants in response to N, P, K, Ca, and Mg deficiency in nutrient solution. To standardize individual macronutrient-deficient treatments, the concentrations of the other nutrients were maintained via substitution with other ions. Individual nutrient deficiencies had various effects on the uptake and accumulation of other mineral nutrients. Phosphorus deficiency had relatively little effect on other mineral nutrient levels compared to the other treatments. Cation deficiency had little effect on N and P concentrations but had a somewhat negative effect on the uptake or concentrations of the other nutrients. Primary metabolic pathways, such as energy production and amino acid metabolism, were greatly affected by mineral nutrient deficiency. Compared to the control treatment, soluble sugar levels increased under -N conditions and decreased under -Ca and -Mg conditions. The levels of several organic acids involved in glycolysis and the TCA cycle decreased in response to -N, -P, or -K treatment. The levels of most amino acids decreased under - N treatment but increased under -P, -K, -Ca, or -Mg treatment. Mineral depletion also led to the activation of alternative biochemical pathways resulting

in the production of secondary metabolites such as quinate. Notable changes in metabolic pathways under macronutrient deficiency included (1) a quantitative increase in amino acid levels in response to Mg deficiency, likely because the restriction of various pathways led to an increase in protein production and (2) a marked increase in the levels of quinate, a precursor of the shikimate pathway, following cation (K, Ca, and Mg) deficiency. These findings provide new insights into metabolic changes in cabbage in response to mineral deficiency and pave the way for studying the effects of the simultaneous deficiency of more than one macronutrient on this crop.

### A Review on Soil Potassium Scenario in Vertisols of India

Gurav, P.P., S.K. Ray, P.L. Choudhari, A.K. Biswas, and A.O. Shirale. Open Access J. Sci. 2(1):89-90. DOI: 10.15406/oajs.2018.02.00051

**Abstract:** Potassium is an essential element for plant growth and production. The Vertisols are generally rich in available potassium reserves for supplying potassium to plant. In present agriculture scenario the negative balance of potassium goes on increasing because crops remove more K than N and P. Under such condition there is need to focus on K fertility status of soil. On the other hand, there is an anomaly regarding crop response to applied potassium in some Vertisols of India. This review paper provides information important to the understanding of soil potassium status and its behavior in Vertisols.

### Potassium Humate Improves Physio-Biochemical Attributes, Defense Systems Activities and Water-Use Efficiencies of Eggplant under Partial Root-Zone Drying

Howladar, S.M. 2018. Scientia Horticulturae 240:179-185. DOI: https://doi.org/10.1016/j.scienta.2018.06.020.

**Abstract:** Partial root-zone drying (PRD) applied in an alternate strategy (PRDalt) can regulate plant physiological and antioxidative defense system responses, and it is considered as an irrigation water-saving method. The current study was carried out using pot experiments to elucidate the potential role of potassium humate (KH) in integration with PRDalt in regulating eggplant physiological and defense systems responses, and irrigation water-saving. PRDalt significantly reduced the plant growth and yield, leaf photosynthetic gas exchange, leaf relative water content (RWC) and membrane stability index (MSI), while significantly increased leaf and root contents of malondialdehyde (MDA), hydrogen peroxide ($H_2O_2$), and leaf and root activities of enzymatic and non-enzymatic antioxidants compared to Full irrigation (control; FI). Integrative application of PRDalt + KH increased water-use efficiencies; $WUE_{fw}$ (calculated as g fruits $L^{-1}$ applied water) by 97.9% and $WUE_{pt}$ (calculated by dividing the net photosynthetic rate by transpiration rate) by 20.3% compared to the controls. It also further increased leaf and root activities of enzymatic and non-enzymatic antioxidants, while controlled the contents of MDA and $H_2O_2$, and maintained plant growth and yield, leaf photosynthetic gas exchange, RWC and MSI at the same levels in plants of FI. Results of this study recommend using the integrative strategy of PRDalt + KH to confer the same eggplant growth and yield of the FI control and save about 50% of irrigation water.

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

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

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

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**IPI is expanding it's activities:**
**We are pleased to announce new Coordinators**

### IPI Scientific and Communications Coordinator: Dr. Patricia Imas

Dr. Patricia Imas, has over 20 years' experience working with farmers, dealers, extension workers, researchers and state officials. She has been active in the area of plant nutrition and crop fertilization for over 30 years. Her international experience includes agricultural research, extensions programs and consultancies worldwide, especially in Argentina, China and India.

By training, Dr. Imas is an Agronomic Engineer from the Faculty of Agronomy, University of Buenos Aires, Argentina. She completed her MSc and PhD at the Department of Soil and Water Sciences, Faculty of Agricultural, Food and Environmental Quality Sciences, The Hebrew University of Jerusalem, Israel. Her MSc thesis focused on the "Relationship between Yield and Transpiration under Different Nutrition Conditions", and her PhD thesis, supervised by Prof. U. Kafkafi, on "Chemical and Biological Processes in the Rhizosphere Affecting Phosphorus Mobility and Uptake Conditions".

Dr. Imas has published papers in peer review journals, served as an editor for IPI proceedings, and presented IPI research projects at international events. She developed and implemented regular training programs for dealers and farmers and produced numerous leaflets and brochures on plant nutrition and balanced fertilization.

Dr. Imas is the representative of Dead Sea Works Ltd. at the Technical Secretariat of IPI. At IPI, she was also previously a coordinator for India, China and Argentina.

As IPI Scientific and Communications Coordinator, she is in charge of IPI publications, website, and organization of IPI international events, as well of the development of improved media and communication tools for the institute.

The extensive and in-depth knowledge of crop nutrition, knowledge transfer, and the work of the International Potash Institute that Dr. Imas possesses will make her an essential, and highly valuable, member of the IPI team.

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### IPI Coordinator for Large-Scale Global Agronomy Projects: Cristian Terrones

Mr. Cristian Terrones is an experienced agronomist and newly appointed coordinator for IPI's agronomy projects. He specialized in soil science, plant nutrition and data analysis.

For the past three years, Mr. Terrones has worked as an agronomist for ICL Specialty Fertilizers in the Netherlands. During this time, he has been actively involved in providing agronomic technical assistance to the company's clients in Africa and the Middle East. Mr. Terrones has comprehensive soil chemistry knowledge, and experience in enhancing the cultivation of a wide range of crops, including covered and open field vegetables, extensive arable crops, and tropical and sub-tropical fruit trees.

Mr. Terrones gained his BSc in agronomy from the Pan-American Agricultural University Zamorano in Honduras, where he specialized in soil science. He later gained his MSc in soil quality from Wageningen University in the Netherlands.

His expertise will be invaluable in the coordination of IPI's projects in large-scale global initiatives.

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### IPI Coordinator for the UK and Ireland: Scott Garnett

Mr. Scott Garnett has been in the fertilizer industry for 20 years, analyzing the growing technics for many different crops, worldwide. He has worked in California, for instance, focusing on almond and pistachio production, and Asia, to enhance tropical fruit production. Most of his work, however, has focused on the potato industry.

Mr. Garnett has worked for ICL in the UK for six years. During that time, he worked closely with independent advisors, agro-dealers and farmers within the UK and Ireland. He has held the positions of specialty fertilizer manager for the UK and Ireland, as well as senior agronomist for specialty fertilizers for Europe. Mr. Garnett is now lead agronomist for the development of ICL's FertilizerpluS range for the UK and Ireland, which mainly concerns the development of potassium and sulfur fertilizers for UK crops.

Mr. Garnett holds a BSc in agronomy from Myerscough University in the UK, where he specialized in plant physiology and soil science. Prior to joining ICL, Mr. Garnett worked with bio-science companies looking at the movement of calcium within crops, and for one of the largest producers of potassium nitrate. He has also held the position of advisor to the soft fruit industry in the UK.

Such extensive expertise will be invaluable in the coordination of IPI's projects and extension programs in the UK.

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