e-ifc

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

No. 59 | March 2020

INTERNATIONAL POTASH INSTITUTE
SINCE 1952
Optimizing Crop Nutrition

Editorial

Dear readers,

The COVID-19 pandemic has caused widespread disruption to businesses across the world and halted production for many industries, but farmers have continued to work hard so that we can all continue to eat. Farmers are essential workers and, by planting, hoeing, pruning, fertilizing and harvesting fields, orchards and vineyards, they have been able to maintain food supply systems.

At IPI, we want to send our thanks to the farmers and everyone who works along the food chain around the world for keeping the global food supply chain going. Our respect goes to all those who, from sunrise to sunset, nourish the crops that nourish us all.

In the current *e-ifc* edition, we present two papers on experiments with polyhalite: one from Brazil for soybean and the second from Israel on lettuce.

In addition, we are pleased to announce the launch of the first global IPI photo contest 2020 on "Capturing nutrient deficiencies in crops". This contest is in memory of our dear colleague Ricardo Melgar, who strongly believed in the power of people to promote crop stories.

I wish you an enjoyable read and stay safe!

Dr. Patricia Imas
IPI Scientific and Communications Coordinator

Photo cover page: Avocado flowering in an experiment in Israel. Photo by N. Cohen Kadosh.

Research Findings

Photo 1. Overview of soybean experiment site at Rio Verde Foundation, Brazil. Photo by the authors.

Evaluation of Potassium and Sulfur Fertilizers for Soybean in Brazil

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Abstract

Soybean production in several regions of Brazil is carried out on soils with medium to low sulfur (S) levels, which may be corrected using fertilizer. Several S fertilizers have been examined, some of which contain S in sulphate form and others in its elemental form. Polyhalite, a fertilizer comprised of sulphate, calcium (Ca), magnesium (Mg), and potassium (K), was shown to correct Ca, Mg, and S deficiencies, but could not always fully supply crops' K requirements. PotashpluS®, a new granular blend of polyhalite and potassium chloride (KCl), was evaluated as the sole K and S sources for soybean production and compared to alternative S fertilizers common in Brazil. The experiment took place at Rio Verde Foundation, Mato Grosso state, Brazil. The experiment included six fertilizer treatments in a completely randomized block design with four replications. Two treatments: Mono-ammonium phosphate (MAP)+PotashpluS®, and MAP+single superphosphate (SSP)+KCl, both comprising sulphate as their sole S source, showed greater response potential and gave rise to significantly higher yields (10%) compared with common fertilizers where the partial or total S supply was in the elemental

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form. PotashpluS® broadcast pre-planting was as efficient as the SSP applied in the planting furrow. Further research is needed to verify all potential benefits of PotashpluS® for soybean, as well as other crop species.

Keywords: Calcium; *Glycine max.* L.; magnesium; polyhalite; PotashpluS®.

Introduction

Brazil is one of the largest soybean (*Glycine max.* L.) producers in the world, with an annual production of about 120 million tonnes of grain. In the 2018/2019 season, the total harvested area reached 35.8 million ha with a mean grain yield of about 3,300 kg ha^{-1} (CONAB, 2019).

Soybean crops have a high potassium (K) requirement; the production of one tonne of grain requires 43 kg of K. Overall K uptake required for the production of 3,500 kg soybean grain and 9,500 kg total biomass ha^{-1} during a cropping season has been determined as 172 kg ha^{-1}, equivalent to 207 kg K_2O ha^{-1} (Bender *et al.*, 2015). The authors also estimated soybean's requirements for other essential macronutrients such as calcium (Ca), magnesium (Mg), and sulfur (S). To produce similar soybean grain yields and biomass, a crop required 113, 50, and 19 kg ha^{-1} of Ca, Mg, and S, respectively.

Management of K fertilization in Brazil must consider several serious edaphic challenges. In many regions, soils are acidic; K+ ions fail to compete with H+ ions and adsorb to the surface of the soil particles. Consequently, these K+ ions are rapidly leached away from the rhizosphere, necessitating additional K application doses in order to meet crop requirements. Under such circumstances, K fertilizers with a lower risk of salinization are desirable. Furthermore, fertilizers with slower solubility rates are particularly advantageous in order to reduce K leaching.

Insufficient Ca and Mg levels in the relevant soil profile were detected in several regions in Brazil (Caires *et al.*, 2000; Vale, 2016). This phenomenon has been associated with the use of limestone broadcast aimed at alleviating soil acidity. Instead of penetrating into subsurface soil layers in forms available to plant roots (soluble ions), Ca and Mg remain associated with carbonate anions, concentrated on the soil surface as an insoluble limestone layer. Subsequently, root distribution is restricted to the upper soil layer. The inadequate root system fails to support plant water requirements during drought periods, often occurring within the rainy season. This scenario was suggested as a possible reason for the drastic reduction in soybean production (Roldão, 2015).

Soybean production in several regions of Brazil often takes place in areas with medium to low soil S status. In such cases, there is a considerable potential to improve soybean crop performance through S application. Several sources were utilized to enrich the soil with S, some were in the form of sulphate, and others in the elemental form.

In recent years, a new supplementary fertilizer, polyhalite, was introduced to Brazil. Polyhalite is comprised of K_2O (14%), Ca (12%), Mg (3.6%), and S (19%). Due to reduced levels of sodium and chloride, this fertilizer has a lower salinity rate compared to KCl (Fried *et al.*, 2019), in addition to gradual nutrient solubility (Yermiyahu *et al.*, 2017; Yermiyahu *et al.*, 2019). Studies have demonstrated the effect of applying polyhalite to crops, including soybean (Vale and Serio, 2017; Bernardi *et al.*, 2018; Pittelkow *et al.*, 2018).

One of a new generation of polyhalite fertilizers, PotashpluS®, has been introduced recently and is available to soybean farmers in Brazil and parts of the world. While primarily a potash and sulphate fertilizer, it also contains essential Mg and Ca, and supplies all K and S crop requirements in a single application. The formula is 37% K_2O, 9% S (24% SO_3), 3% MgO and 8% CaO. Encapsulated in the same granule, nutrient segregation is avoided, even when fertilizer is broadcast at pre-planting. Sulfur, Mg and Ca are all in sulphate (SO_4) form, ensuring high availability to plants.

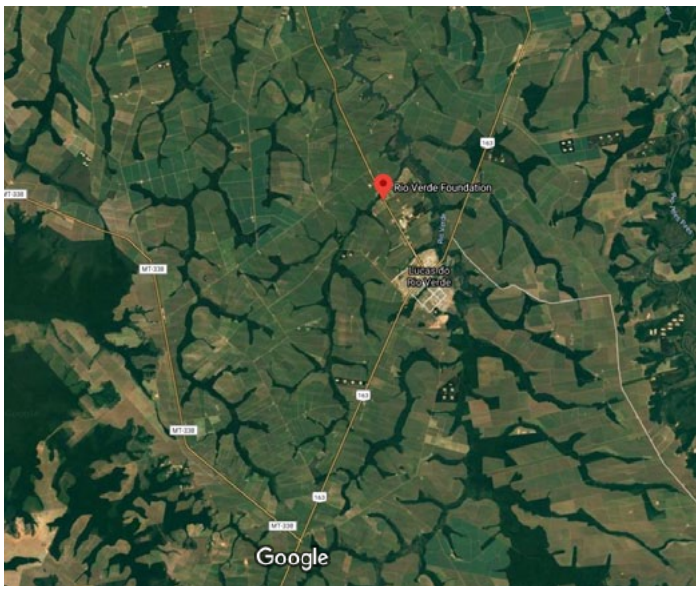
The objective of the present study was to evaluate the effect of applying the new compact fertilizer combination of KCl with polyhalite as a source of K and S, and to compare it with other S-donor fertilizers commonly used in soybean production in Brazil.

Materials and methods

The experiment was carried out at the Rio Verde Research and Technological Development Foundation, located between the geographic coordinates 13°00'27"S - 55°58'07"W and 12°59'34"S - 55°57'50"W, at an average altitude of 387 meters, in the city of Lucas do Rio Verde, Mato Grosso state, Brazil (Map 1). The region is comprised of the Cerrado biome and its predominant climate is Aw type (Tropical Savannah) according to the Köppen-Geiger classification (Peel *et al.*, 2007), presenting two well-defined seasons: rainy, from October to April; and drought, from May to September.

The soil of the experiment site was a Typic Hapludox, or a dystrophic Red-Yellow Latosol, as defined in the Brazilian system of soil classification (Embrapa, 2013). The pre-experiment physical and chemical soil properties are shown in Table 1.

The interpretation of soil fertility as it relates to soybean production, characterized according to critical levels defined by Embrapa (2014), indicated that phosphorus (P), copper (Cu), iron (Fe) and zinc (Zn) contents were high, while S, Ca and manganese



Map. 1. Location of the trials, Rio Verde Foundation, Brazil. *Source:* Google maps.

Table 1. Texture and chemical properties of the local topsoil (depth of 0-20 cm) used in the soybean experiment.

Soil property	Quantity	Units
Sand	465	g kg^{-1}
Silt	75	g kg^{-1}
Clay	460	g kg^{-1}
pH ($CaCl_2$)	4.6	
Organic matter	21	g dm^{-3}
Cation exchange capacity (CEC)	6.9	$cmol_c$ dm^{-3}
Basic saturation (V%)	32	
Phosphorus, as $P_{Mehlich}$	13.5	mg dm^{-3}
K	0.1	$cmol_c$ dm^{-3}
Ca	1.8	$cmol_c$ dm^{-3}
Mg	0.3	$cmol_c$ dm^{-3}
S, as SO_4	11	mg dm^{-3}
B	0.2	mg dm^{-3}
Cu	1.0	mg dm^{-3}
Fe	52	mg dm^{-3}
Mn	4	mg dm^{-3}
Zn	1.8	mg dm^{-3}

(Mn) contents were medium. Potassium, Mg, boron (B) and organic matter contents were classified as low, showing the potential for fertilization.

The experiment took place in the 2018/2019 season. Soybean crop (cultivar M 8372 IPRO) was sown on 19 October 2018, under no-tillage on residual straw from a second corn crop. Seeds were treated with Standak Top insecticide at a dose of 2.0 ml kg^{-1} of seeds.

The experiment design was completely randomized blocks with six treatments distributed in four repetitions. Each plot consisted of 10 seeding lines at a spacing of 0.45 x 13.0 meters, in a total area of 58.5 m^2 per plot and 234 m^2 per treatment. Detailed description of the treatments employed is given in Table 2.

The rates of N, P_2O_5 and K_2O applied in all treatments were 17, 80 and 80 kg ha^{-1}, respectively, while the rate of S was 20 kg ha^{-1}, adjusted according to the blends of the fertilizers used in the experiment.

Two K sources were tested: KCl (60% K_2O), and PotashpluS® (37% K_2O; 5.7% Ca; 1.8% Mg and 9.2% S). Four S sources were examined: single superphosphate (SSP) (18% P_2O_5, 16% Ca, 8% S); pastille elemental S (90% S); PotashpluS®; and a composite granulated NPK fertilizer (8% N, 40% P_2O_5, and no K) that also contained 3.2% Ca and 9.3% S (3.5% S-SO_4 and 5.8% elemental S). The fertilizer MAP (11% N and 52% P_2O_5) was the standard source of P in all treatments, excluding treatment three (MAP+SSP+KCl), where the P_2O_5 rate was adjusted with a blend of MAP and SSP, and in treatment six (NPK+KCl), which received all P from the composite fertilizer. In treatment three, the adjustment of N rate was made using urea fertilizer (45% N).

All phosphate sources (MAP, SSP, and NPK 8-40-0), as well as the pastille elemental S were applied in the planting furrow. KCl and PotashpluS® were broadcast pre-planting, one day before sowing.

Climate data, starting 10 days before sowing until harvest, are presented in Fig. 1. A 13-day period of restricted soybean development occurred during mid-December, characterized by very low precipitation, and coincided with

Table 2. Description of treatments tested in the soybean experiment in Lucas do Rio Verde, Mato Grosso state, Brazil. Rio Verde Foundation, 2018-2019.

Treatment	Pre-planting broadcast		Applied at sowing				
	KCl (MOP)	PotashpluS®	MAP	Urea	NPK 8-40-0	SSP	PES
	kg ha^{-1}						
MAP	-	-	154	-	-	-	-
MAP+KCl	134	-	154	-	-	-	-
MAP+SSP+KCl	134	-	69	20	-	245	-
MAP+PES+KCl	134	-	154	-	-	-	22
MAP+PotashpluS®	-	217	154	-	-	-	-
NPK 8-40-0+KCl	134	-	-	-	200	-	-

Abbreviations: MAP: mono-ammonium phosphate; KCl: potassium chloride; MOP: muriate of potash; SSP: single superphosphate; PES: pastille elemental sulfur; NPK: composite N-P-K fertilizer with determined N-P_2O_5-K_2O.

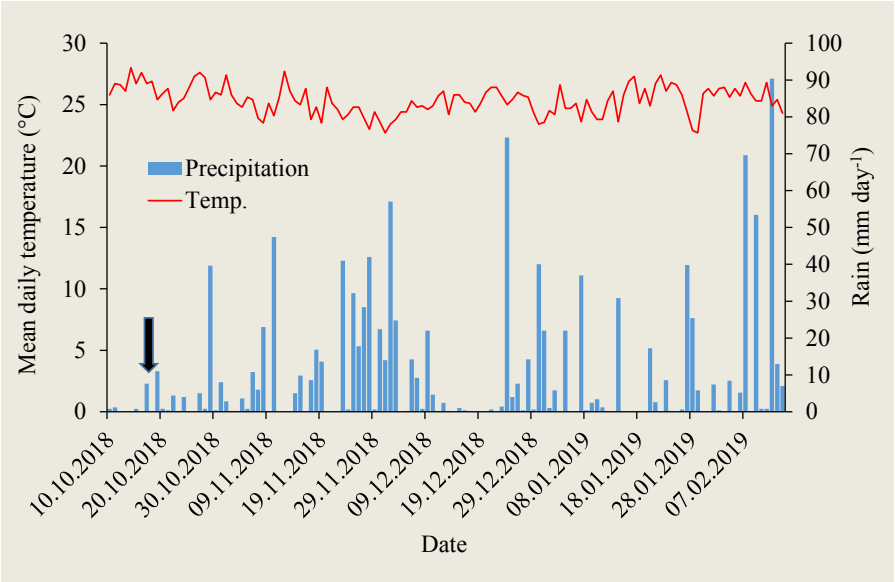


Fig. 1. Mean daily temperature and rainfall occurred from 10 days before sowing (black arrow) until harvest during the soybean experiment at Rio Verde Foundation, 2018-2019. Accumulated rainfall during the period was 1.197 mm.

final vegetative and early reproductive crop phases.

Harvest took place on 14 February 2019, and the crop duration was 118 days. Disease, pest, and weed controls were performed according to the technical recommendations for the crop. Crop performance was evaluated throughout the season, including phenological follow-up and sampling, as described below.

Initial and final plant population (IPP and FPP, respectively; plants ha^{-1}) were determined at crop phenological stages V3 and R9 (8 November 2018 and 8 February 2019, respectively) by counting two linear meters of two rows twice per experimental plot in order to estimate plant emergence and establishment rates. Foliar nutrient status was recorded at crop phenological stage R1 (bloom initiation). Twenty trifoliate leaves per experiment plot were randomly sampled, including petioles. Samples were put in tagged paper bags and delivered to the laboratory for macro and micronutrient analyses that were carried out according to Embrapa (2014). Plant height (PH) and first pod insertion height (FPIH), and the distances from soil surface to plant apex and to the first pod peduncle, were determined using two random plants per plot at phenological stage R9 (8 February 2019).

At harvest, grain yield (kg ha^{-1}) was determined for each treatment by manual sampling of all plants within a 4 m length from two central lines, twice in each experiment plot. Grain moisture content was determined and yield was adjusted according to the standard commercial moisture content of 13%. Additionally, weight of 1,000 grains was determined as a commercial quality parameter.

Data of each evaluated attribute were subjected to analysis of variance by applying the F test ($P < 0.05$); means were then compared by the Scott-Knott test ($P < 0.05$) using the statistical analysis program Sisvar 5.6 (Ferreira, 2008).

Results and discussion

Fertilization treatments did not affect the phenological course of the soybean crop. At bloom initiation, N and S concentrations in indicative trifoliate leaves were slightly below the Embrapa standard range for soybean (Embrapa, 2014); P and Ca levels were at the lower edge of this range, Mg at its middle, while K concentrations were

Table 3. Macro- and micronutrient concentrations in soybean indicative leaves at bloom initiation as a function of the evaluated fertilization treatments at Rio Verde Foundation, 2019.

Treatment	Macronutrients						Micronutrients				
	N	P	K	Ca	Mg	S	B	Cu	Fe	Mn	Zn
	g kg^{-1} DM						*mg kg^{-1} DM*				
MAP	39.7	3.2	24.2b	6.9	5.3	1.9	29.0	5.1	149.5	27.0	25.6
MAP+KCl	39.2	3.2	26.4a	6.7	5.1	1.8	31.4	5.1	151.9	29.4	25.6
MAP+SSP+KCl	38.5	3.1	25.4a	6.6	5.0	1.8	30.9	6.2	144.6	27.0	25.9
MAP+PES+KCl	39.2	3.1	25.7a	6.4	5.2	1.9	29.3	5.8	149.5	31.9	26.5
MAP+PotashplusS®	39.3	3.0	25.8a	6.6	5.0	2.0	29.7	5.9	144.6	39.2	28.7
NPK 8-40-0+KCl	40.0	3.0	22.5b	6.5	5.1	1.9	28.4	5.5	147.0	29.4	27.2
Mean	39.3	3.1	25.0	6.6	5.1	1.9	29.8	5.6	147.9	30.7	26.6
Covariance	2.82	6.1	6.13	5.2	5.5	5.2	11.2	27.4	9.24	25.4	10.7
Significance	NS	NS	*	NS	NS	NS	NS	NS	NS	NS	NS
Embrapa std. range	45-55	2.5-5.0	17-25	3.5-20	2.5-10	2-4	20-55	6-14	50-350	20-100	20-50

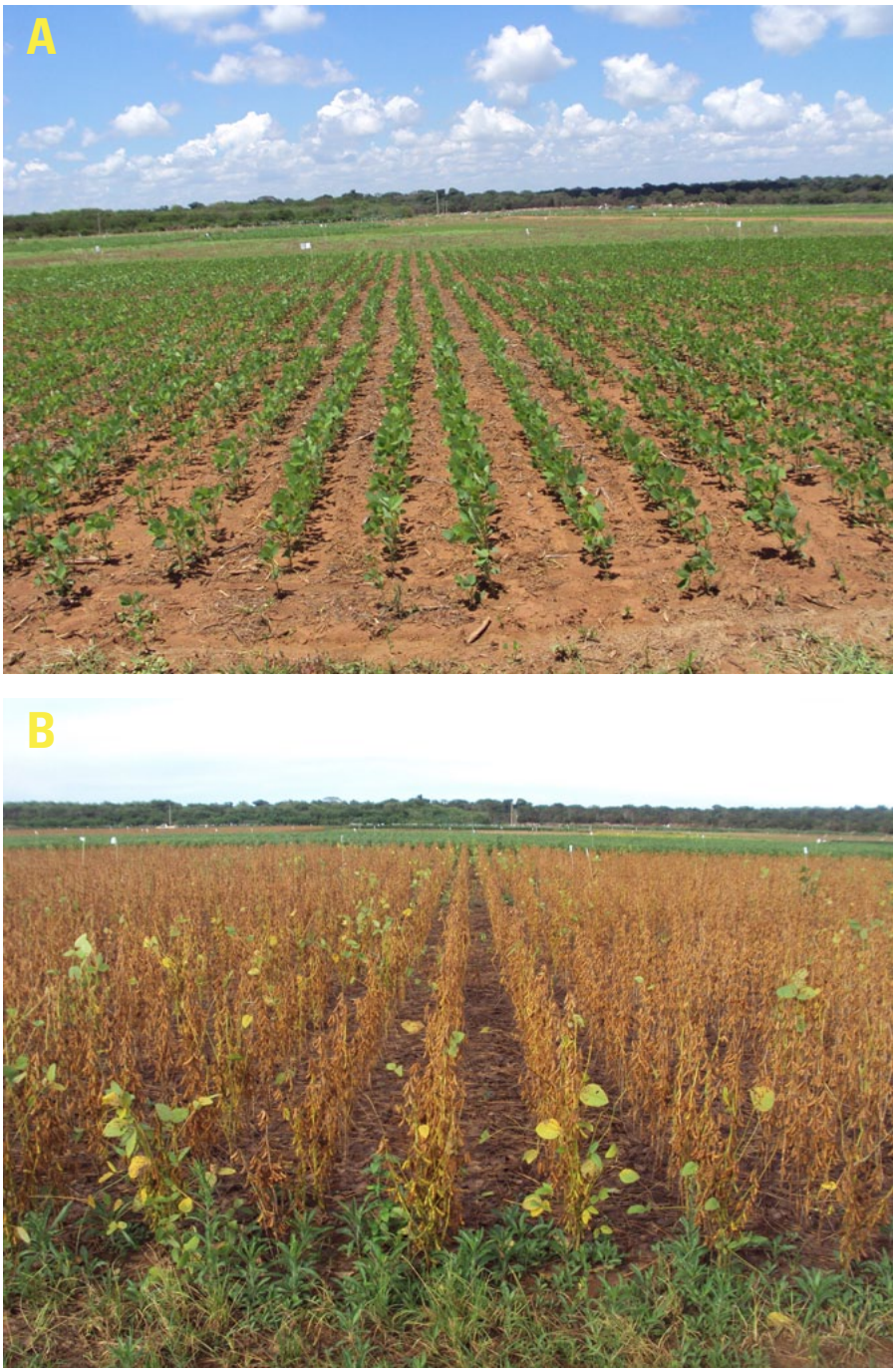
Means followed by the same letters do not differ from each other.*Significant by the Scott-Knott test ($P < 0.05$).

at the upper edge or above this standard range (Table 3). Although beyond any risk of deficiency, K concentration was significantly lower with the MAP and the NPK+KCl treatments, compared to the other four treatments. While these results could be easily justified for the MAP treatment, which did not included any external K source, the case of the sixth treatment (NPK 8-40-0+KCl) was less clear. The low N concentration in the leaves throughout this experiment may indicate a serious N deficiency that, in consequence, might have restricted the uptake of other nutrients. Closure of this gap may lead to overall improvement of the nutrient status in soybean crops. Under these circumstances, the performance of PotashpluS® as a K-donor to soybean plants was comparable to that of KCl (Table 3).

Among micronutrients examined, Cu concentrations were below the Embrapa standard range, indicating deficiency levels. With the exception of Fe, the remaining micronutrients tended to be at the lower edge of the Embrapa (Table 3), supporting the assumption that crop development may be restricted to some extent if the supply of N is too low.

Plant emergence, as indicated by IPP evaluated at phenological stage V3 (Photo 2) was very slightly affected by the fertilization treatments, showing a tendency to increase in response to improved S and K supply (Table 4). This tendency became significant towards the end of the cropping season, with greater numbers of persisting plants under MAP+SSP+KCl and MAP+PotashpluS® fertilizers (Table 4), suggesting an advantage for SSP and PotashpluS® as sulphate sources. An addition indication of better crop performance was provided by the slight, though insignificant tendency of PH to increase under these two treatments. FPIH varied between treatments, expressing no clear influence by the different fertilizer treatments; however, as all measurements were above 10 cm, the parameter did not affect mechanical harvesting (Table 4).

The small, not always significant, advantages observed in crop development parameters for treatments MAP+SSP+KCl and MAP+PotashpluS® were augmented to establish a significant effect on soybean grain yield (Fig. 2). Although all other treatments supported yields that met the



Photos 2 A-B. Visual appearance of the soybean experiment at phenological stages V3 (A) and R9 (B). While no differences between treatments occurred at V3 stage, slight but significant differences in FPP were recorded at R9 stage (Table 4). Photos by the authors.

Table 4. PH, FPIH, IPP, FPP and grain weight of soybean as a function of the evaluated fertilization treatments at Rio Verde Foundation, 2019.

Treatment	PH	FPIH	IPP	FPP	Grain weight
	----------*cm*----------		-----*1,000 plants ha*$^{-1}$-----		*g 1,000*$^{-1}$ *grains*
MAP	68.0	19.6	202.8	188.8b	178.3
MAP+KCl	69.8	16.1	200.7	181.9b	182.6
MAP+SSP+KCl	71.6	18.5	208.3	193.8a	182.7
MAP+PES+KCl	72.6	15.6	209.7	188.0b	185.6
MAP+PotashpluS®	72.0	18.2	204.9	194.8a	185.0
NPK 8-40-0+KCl	74.5	20.9	203.4	190.4b	183.9
Mean	71.4	18.2	205.0	189.6	183.0
COV	5.92	17.5	7.4	3.64	2.22
Significance	NS	NS	NS	*	NS

Means followed by the same letters do not differ from each other. *Significant by the Scott-Knott test (P <0.05).

local common average of 3,500 kg ha^{-1} (Bender *et al.*, 2015), these two treatments obtained a significant yield increase of about 10%. Sulfur supply through fertilizers harboring all nutrients in the form of sulphate, such as SSP and PotashpluS®, demonstrated significantly higher productivity over those comprising a blend of sulphate and mineral S (NPK 8-40-0+S). Moreover, the lowest yields were obtained when S was applied in an elemental form (MAP+PES+KCl) or was not applied at all (Fig. 2). These results confirm that S is essential to obtain reasonable soybean yields, and that the delivery of this nutrient in the elemental form is less effective (Pittelkow *et al.*, 2018).

This is due to the rapid solubility and, hence, availability of the nutrient in the sulphate form, while the elemental form requires a long time to become available to plants (Horowitz and Meurer, 2006). Thus, S application in the mineral form is impractical in most cases, where immediate effects are desired for a current crop.

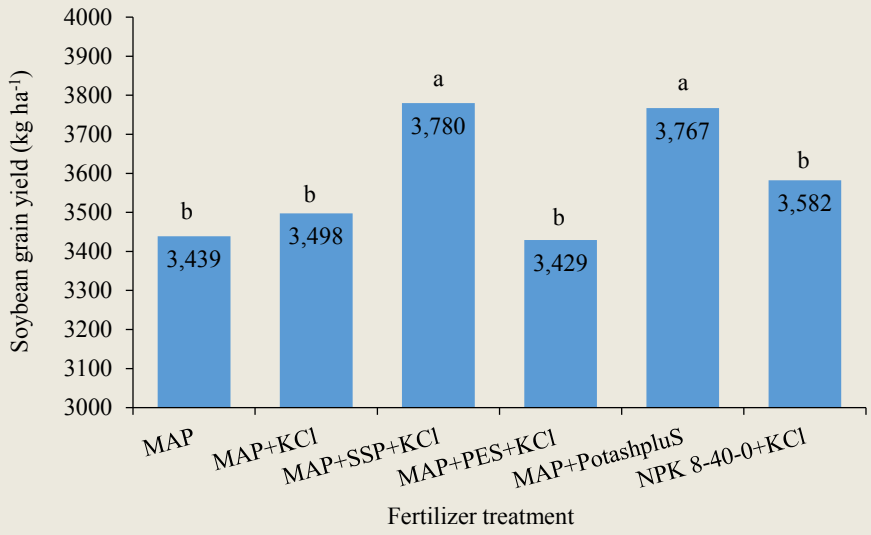


Fig. 2. Effects of fertilizer treatments on soybean grain yield at Rio Verde Foundation, 2019. Means followed by the same letters do not differ from each other.

Partial replacement of KCl by polyhalite, as performed through PotashpluS®, was expected to reduce salinity problems that emerge from high KCl application doses (Bernardi *et al.*, 2018). Nevertheless, no evidence could be observed in the present study regarding such effects. This might have been due to some changes made during the experiment in KCl application practices, such as spreading it over the whole area rather than directly to the sowing line. The anticipation that uptake of Ca and Mg would be enhanced through PotashpluS® application was not fulfilled (Table 3). Whether the yield increase recorded under the PotashpluS® treatment was due to better distribution of the root system in the soil profile requires further research.

Practically, the use of PotashpluS® holds some benefits to large-scale soybean farmers when compared to SSP, even in cases of comparable yields. The soybean-sowing window in the Brazilian Cerrado is quite short, and the farmer's challenge is to make it between mid-October and mid-November. The use of low-concentration P fertilizers requires more frequent refill of the spreading machines, and reduces the planting capacity, thus delaying the operation. Therefore, farmers often sow a considerable proportion of their fields out of the optimum window. Soybean, as a C3 plant species, is sensitive to photoperiod, thus synchronization between day-length and phenological events is crucial for obtaining an acceptable yield (Meotti *et al.*, 2012; Sentelhas *et al.*, 2015). PotashpluS® application is significantly faster than SSP and, therefore, increases the proportion of areas sown on time, leading to a higher yield potential.

Conclusions

The competence of PotashpluS®, a granular blend of polyhalite and KCl, to supply all K and S requirements of soybean crop in a single application was examined in Brazil. PotashpluS®, and MAP+SSP+KCl, both comprising sulphate as their sole S source, showed greater response potential and gave rise to significantly higher yields compared with

fertilizers, where the partial or total S supply is in the elemental form. PotashpluS®, broadcast pre-planting, was as efficient as SSP applied in the planting furrow. However, the full promise of PotashpluS®, which also contains considerable amounts of the essential nutrients Ca and Mg, remains unclear in the present study, probably due to serious N deficiency. Further research is needed to verify the potential benefits of PotashpluS® for soybean as well as other crop species.

Acknowledgements

The authors acknowledge the field technicians of the Rio Verde Foundation for their support in setting up and conducting the research, and the International Potash Institute (IPI) for its financial support.

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The paper "Evaluation of Potassium and Sulfur Fertilizers for Soybean in Brazil" also appears on the IPI website.

Research Findings

Photo 1. Romaine lettuce grown on perlite mixed with standard polyhalite. Doses ascending from 0-37.5 g L^{-1}, from left to right. Photo by L. Peled-Lichter.

Effects of Polyhalite Fertilizers on Lettuce Development on a Soilless Culture

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Abstract

Lettuce production on a soilless culture served as a model system to test polyhalite as a potential sole donor of potassium (K) and calcium (Ca), separately. Polyhalite is available as a new commercial fertilizer marketed as Polysulphate® (ICL Fertilizers, Cleveland, UK). It is a natural hydrated sulfate of K, Ca, and magnesium (Mg) with the formula: $K_2Ca_2Mg(SO_4)_4 \cdot 2H_2O$. Two experiments were carried out, both using perlite 212 as a solid phase and final fertigation solutions as a liquid phase. The winter experiment (Eshel HaNassi, 11/11/19-14/01/20) tested standard Polysulphate (PSS) at 0, 12.5, 25, and 37.5 g L^{-1} perlite, while nitrogen (N), phosphorus (P) and micronutrients were provided via fertigation throughout the experiment, with no Ca or Mg donor other than PSS. The summer experiment (Hula farm, Northern R&D, 05/06/2019-09/07/2019) examined granular Polysulphate (PSG) at 0, 0.25, 0.50, and 0.75 g L^{-1} perlite, while N-P-K and $MgSO_4$ were supplied via fertigation with no Ca donor other than PSG. In the winter experiment, the rising PSS rate gave rise to enhanced root development and consequent increase in lettuce biomass. The elevated PSG rate in the summer experiment had a small positive effect on lettuce biomass. No symptoms of Ca deficiency (tip-burn) occurred, including in the control. The ability of polyhalite to provide all K requirements of a crop throughout the season was clearly demonstrated for lettuce; however, it largely depended on the crop duration and the amount of PSS embedded in the growth medium. Obviously, enrichment of the growth medium with PSG can ensure sufficient available Ca to satisfy lettuce requirements and guarantee high produce quality. Nevertheless, developing an accurate PSG application rate should be subject to thorough fine-tuning, taking local properties of the water and growth medium into consideration. Moving from a model to conventional cropping systems, economic evaluations of polyhalite application would always be necessary.

Keywords: Calcium; granular Polysulphate; *Lactuca sativa* L.; potassium; slow-release; standard Polysulphate.

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Introduction

Lettuce (*Lactuca sativa* L.) is a staple leafy vegetable for human consumption and an economically important food crop worldwide. In 2018, 1.27 million ha of lettuce and chicory (combined) were harvested worldwide, with a total production of more than 27 million tons (FAOSTAT, 2019). Although often regarded as being low in nutritional value, lettuce's nutrient composition, depending on type and growing conditions, can be equivalent to other 'nutritious' vegetables (Kim *et al.*, 2016b). Lettuce contains several minerals important for human health such as iron (Fe), zinc (Zn), calcium (Ca), phosphorus (P), magnesium (Mg), manganese (Mn), and potassium (K), in addition to other health-promoting bioactive compounds (Kim *et al.*, 2016a; b). Epidemiological studies have reported a correlation between fresh vegetable consumption and reduced risk of chronic diseases (Rodriguez-Casado, 2016).

Field production of lettuce is restricted to short seasons by a number of temperature-related physiological effects that include tip-burn, loose head, leaf discoloration, and bolting, as well as susceptibility to various diseases (Maynard and Hochmuth, 2007). Therefore, greenhouse production plays an increasing role in lettuce production, allowing the manipulation of environmental conditions such as temperature, light, and nutrients (Barbosa *et al.*, 2015).

Being a short-cycle leafy vegetable crop, lettuce displays a simple model for developing and testing innovative cultivation approaches. Among these, a large array of soilless culture technologies has been employed, given the advantage of fully controlled crop water status and mineral nutrition (Soundy *et al.*, 2001; Barbosa *et al.*, 2015; Mandizvidza, 2017; Ainun *et al.*, 2018; Djidonou and Leskovar, 2019). Hydroponic approaches are highly productive; however, challenged by very sophisticated technologies such as on-line control of temperature, pH, and balanced mineral nutrition, as well as water recycling and disinfection practices, they are significantly costly (Barbosa *et al.*, 2015).

An ideal growth medium should be highly porous, with a wide pore-size distribution range, providing maximum water retention and aeration, simultaneously. Additionally, it should be chemically inert, enabling full control of nutrient composition and balance in the liquid phase. Perlite, an inorganic, expanded alumino-silicate of volcanic origin, fulfills these prerequisites (Markoska *et al.*, 2018; Reka *et al.*, 2019) and, furthermore, it can be easily reused (Giuffrida and Consoli, 2016). Therefore, perlite is commonly used throughout the world for soil amendment and as a principal component of soilless growing mixtures. Crop mineral nutrition on perlite must be accurate and should include all essential macro- and micronutrients. Employing liquid composite fertilizers through fertigation seems an ultimate solution. In addition, this type of culture systems sets an ideal stage for the evaluation of new fertilizers and alternative sources of various nutrients.

Polyhalite is available as a new commercial fertilizer marketed as Polysulphate® by ICL Fertilizers, Cleveland, UK, is a natural hydrated sulfate of K, Ca, and Mg with the formula: $K_2Ca_2Mg(SO_4)_4{\cdot}2H_2O$. The purity of Polysulphate® is very high (95% polyhalite) with <5% sodium chloride (NaCl) and traces of boron (B) and iron (Fe) at 300 and 100 ppm, respectively. The typical analysis of polyhalite for S, K, Mg and Ca is 48% sulfur trioxide (SO_3), 14% potassium oxide (K_2O), 6% magnesium oxide (MgO), and 17% calcium oxide (CaO), respectively. Polyhalite, which may serve as a suitable fertilizer by supplying four nutrients, is less water soluble than the more conventional fertilizers and may conceivably provide a slower release of nutrients (Barbarick, 1991; Yermiyahu *et al.*, 2017; Yermiyahu *et al.*, 2019). A number of studies comparing polyhalite to other K and Mg fertilizers have shown that polyhalite is at least as effective as potassium sulfate (K_2SO_4) as a source of K, and at least as effective as potassium chloride (KCl) plus magnesium sulfate ($MgSO_4$) as a source of K and Mg (Barbarick, 1991). Calcium, the less soluble nutrient in polyhalite (Yermiyahu *et al.*, 2019), can provide available Ca at rates equivalent to those of gypsum (Bernardi *et al.*, 2018).

Lettuce crops require significant amounts of nitrogen (N) (Broadley *et al.*, 2000; Soundy *et al.*, 2001; Fu *et al.*, 2017; Conversa and Elia, 2019; Djidonou and Leskovar, 2019). Potassium is another macronutrient vital to plant growth, yield, and quality; it is involved in the regulation of stomatal conductance and photosynthesis, photophosphorylation, transport of photoassimilates from source to sink tissues via the phloem, enzyme activation, turgor maintenance, and stress tolerance (Marschner, 2012). Research associated with adequate and elevated levels of K on lettuce yield and quality is quite limited and inconclusive. Some studies found that K in a nutrient solution did not affect lettuce yield and quality (Bres and Weston, 1992; Fallovo *et al.*, 2009; Hoque *et al.*, 2010). In contrast, Soundy *et al.* (2001) demonstrated that increasing K concentration in a nutrient solution enhanced lettuce root growth. More recently, Barickman *et al.* (2016) showed that elevating K fertilizer levels resulted in an optimum pattern of lettuce biomass production and a linear increase in the leaf sucrose content. Maximum yield and produce quality were reached at K levels of about 200 kg ha^{-1}, presumably due to the consistent decline of Ca, Mg, and S uptake, as well as reduced micronutrient contents (Fe, B, Zn, Cu, and Mn) under further increasing K application rates.

Calcium is essential for cell membrane and cell wall construction (Marschner, 2012). In addition, this nutrient is an intracellular second messenger involved in the regulation of biosynthetic pathways and hormonal expression (de Freitas *et al.*, 2016).

Calcium application can alleviate postharvest disorders and enhance produce quality of many fruit and vegetable species (de Freitas *et al.*, 2016). In lettuce, lack of Ca in the youngest leaves causes membrane failure and cytoplasm leakage leading to tip-burn symptoms (Saure, 1998; Lim and White, 2005). Fallovo *et al.* (2009) concluded that in lettuce, marketable yield, shoot biomass and leaf area index were unaffected by nutrient solution composition; however, a high proportion of Ca in the nutrient solution increased the quality attributes, in particular Ca, chlorophyll, glucose and fructose concentrations. In contrast, excess Ca/cation ratios in the nutrient solution might be antagonistic to the uptake of P, K, and Mg (Mandizvidza, 2017).

The main objective of the present study was to evaluate polyhalite as a possible supplemental solid fertilizer for lettuce, using a greenhouse soilless production as a principal model system. Polyhalite is available as both a powder (Polysulphate standard; PSS) and a granular (Polysulphate granular; PSG) product. Two experiments were carried out: the first was aimed to examine PSS as the sole K donor fertilizer, and the second tested the ability of very low PSG doses to provide lettuce with sufficient Ca.

Materials and methods

Two experiments were carried out. The first one took place at Eshel Hanassi Youth Village and high school, located in the Western Negev district of Israel, and the second at Hula Orchard Farm of Northern R&D in the Northern Galilee, Israel.

The first experiment was aimed at evaluating PSS as a sole K source. Romaine lettuce seedlings were planted on perlite 212 (Agrekal HaBonim Ltd., Israel) in 4-L pots on 11/11/2019. Plants were grown under controlled greenhouse conditions. Treatments included four levels of PSS: 0 (control), 12.5, 25, and 37.5 g L^{-1} that were thoroughly mixed with the perlite before planting. A final fertigation solution was prepared in a large container, using liquid ammonium nitrate 21% (ICL Haifa, Israel), phosphoric acid 85% (ICL Haifa, Israel), and Super Koretin (ICL Haifa, Israel) for micronutrients. All components were dissolved in water to produce 110, 30, and 3 ppm of N, P, and Fe, respectively, in the fertigation solution, used for all treatments throughout the growing season. Drip irrigation was exercised once a day until 30% drainage was reached. Harvest took place on 14/01/2020; plant length and weight were determined, as well as the number of leaves. Representative plants were photographed with the pots. Plants were then carefully rooted out; roots were washed and cleaned of perlite, measured, and photographed.

The second experiment aimed to evaluate PSG as a sole source of Ca. Romaine lettuce seedlings were planted on perlite 212 in 4-L pots, two seedlings per pot, on 05/06/2019. Plants were grown under controlled greenhouse conditions. Treatments included four levels of PSG: 0 (control), 0.25, 0.50, and 0.75 g L^{-1} that were thoroughly mixed with the perlite before planting. Water used for irrigation was desalinated using reverse osmosis at Zemach experimant station to a level of 0.6 meq Ca L^{-1}. Plants in all treatments were fertigated throughout the experiment with 'Shefer 5:3:8' (ICL Haifa, Israel) at 60 ppm N, and 200 ppm $MgSO_4$. Irrigation was scheduled three times a day, 10 minutes per irrigation (approx., 1 L day^{-1}). Harvest took place on 09/07/2019, 35 days after planting. At harvest, fresh above-ground biomass was determined. Plants were oven-dried at 70°C and dry biomass was determined. Leaf samples were taken, nutrient (Mg, Ca, K, and S) concentrations were determined at Zemach laboratories, and nutrient uptake was calculated.

Both experiments were designed in complete random blocks, with six replications consisting of five pots each.

Results

A significant response in lettuce growth to the perlite enrichment with PSS was recorded when the PSS dose was above 25 g L^{-1} (Fig. 1A), although a clear positive tendency could be observed throughout the scale of the application dose (Photo 2). The increment in the lettuce fresh weight was due to both greater numbers of leaves per plant (Fig. 1B) and leaf size, indicated by plant height (Fig. 1C). In contrast, the SPAD index, which measures chlorophyll density and, indirectly, indicates N content, was higher in the control leaves and consistently declined with the rising PSS dose (Fig. 1D).

Perlite enrichment with PSS significantly promoted the development of the lettuce root system (Fig. 2). Root length varied considerably and, therefore, displayed clear but statistically non-significant differences (Fig. 2A). Nevertheless, root biomass was obviously greater with the rising PSS dose (Fig. 2B).

In the second experiment, although smaller in two degrees of order than the PSS dosage in the first experiment, PSG displayed significant effects on lettuce fresh and dry biomass were recorded (Fig. 3). Yet, the effects were much weaker, adding no more than 25% to the fresh biomass, and even less to the dry plant biomass. Moreover, the influence of PSG seemed to decrease at the highest dose tested, 0.75 g PSG L^{-1}. While K, Mg, and S were supplied in fertigation via composite N-P-K fertilizer and $MgSO_4$, Ca was provided solely by PSG. Certainly, Ca concentration was significantly higher under PSG enrichment; however, no response was observed to the nutrient dose (Fig. 3C). Furthermore, control plants accumulated a considerable level of Ca, apparently in the absence of an available Ca source. Calcium uptake, a function of Ca concentration and plant biomass at harvest, followed the response pattern of fresh biomass to the PSG dose, but the differences between treatments were not significant (Fig. 3D).

The presence of PSG in the growth medium had no significant

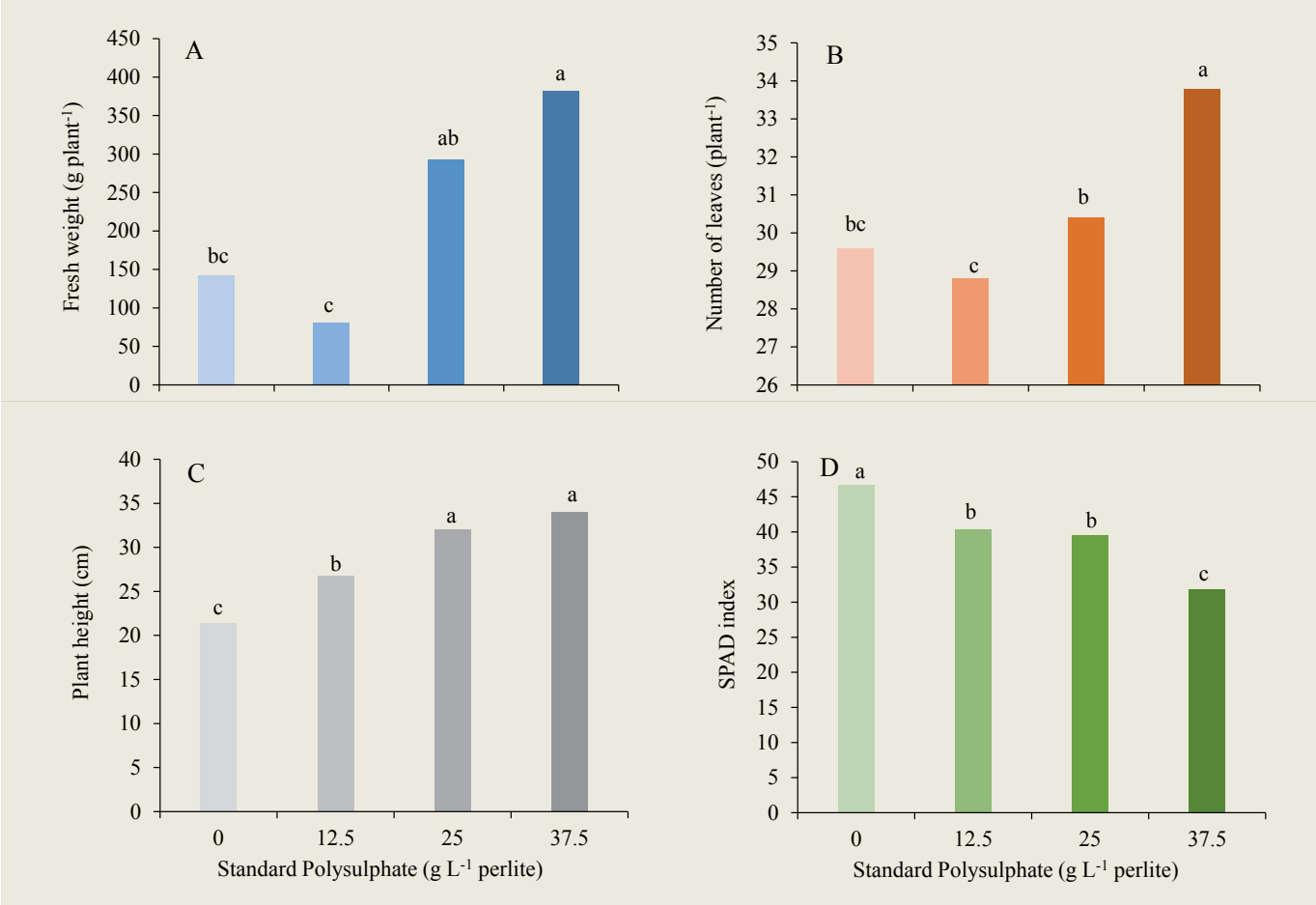

Fig. 1A-D. Effects of standard Polysulphate (PSS) concentration in the growth medium (perlite) on plant fresh biomass (A); number of leaves (B); plant height (C); and, SPAD index (D) at harvest. Similar letters indicate no significant differences between treatments at $p < 0.05$.

Photo 2. Effect of PSS concentration in the growth medium (perlite) on lettuce plant size and appearance before harvest. Photos by the authors.

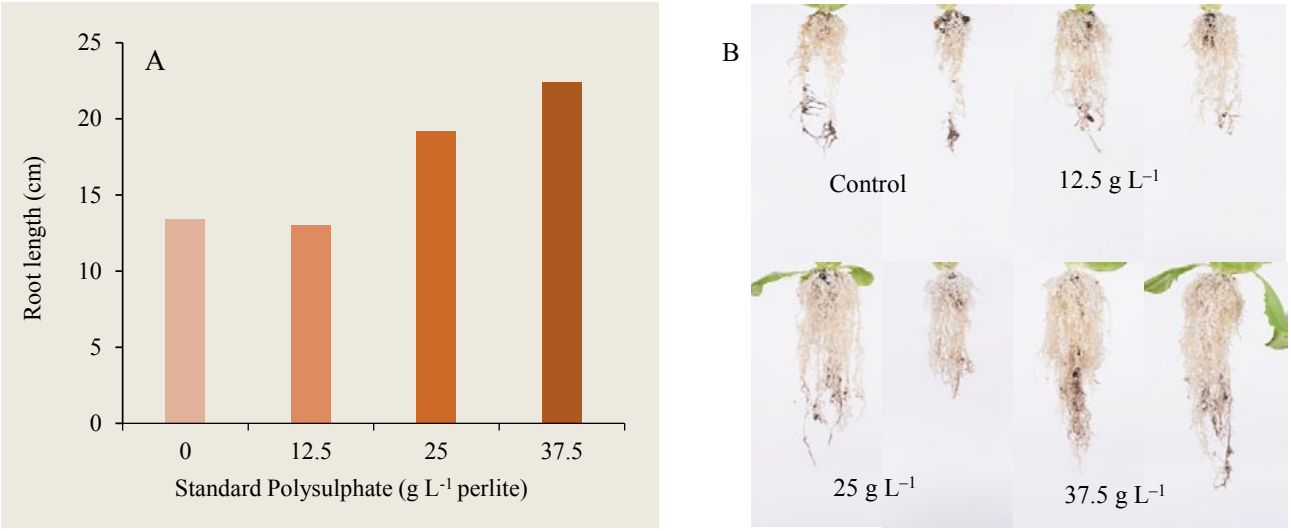

Fig. 2A,B. Effects of standard Polysulphate concentration in the growth medium (perlite) on the root length (A), and overall appearance (B) at harvest.

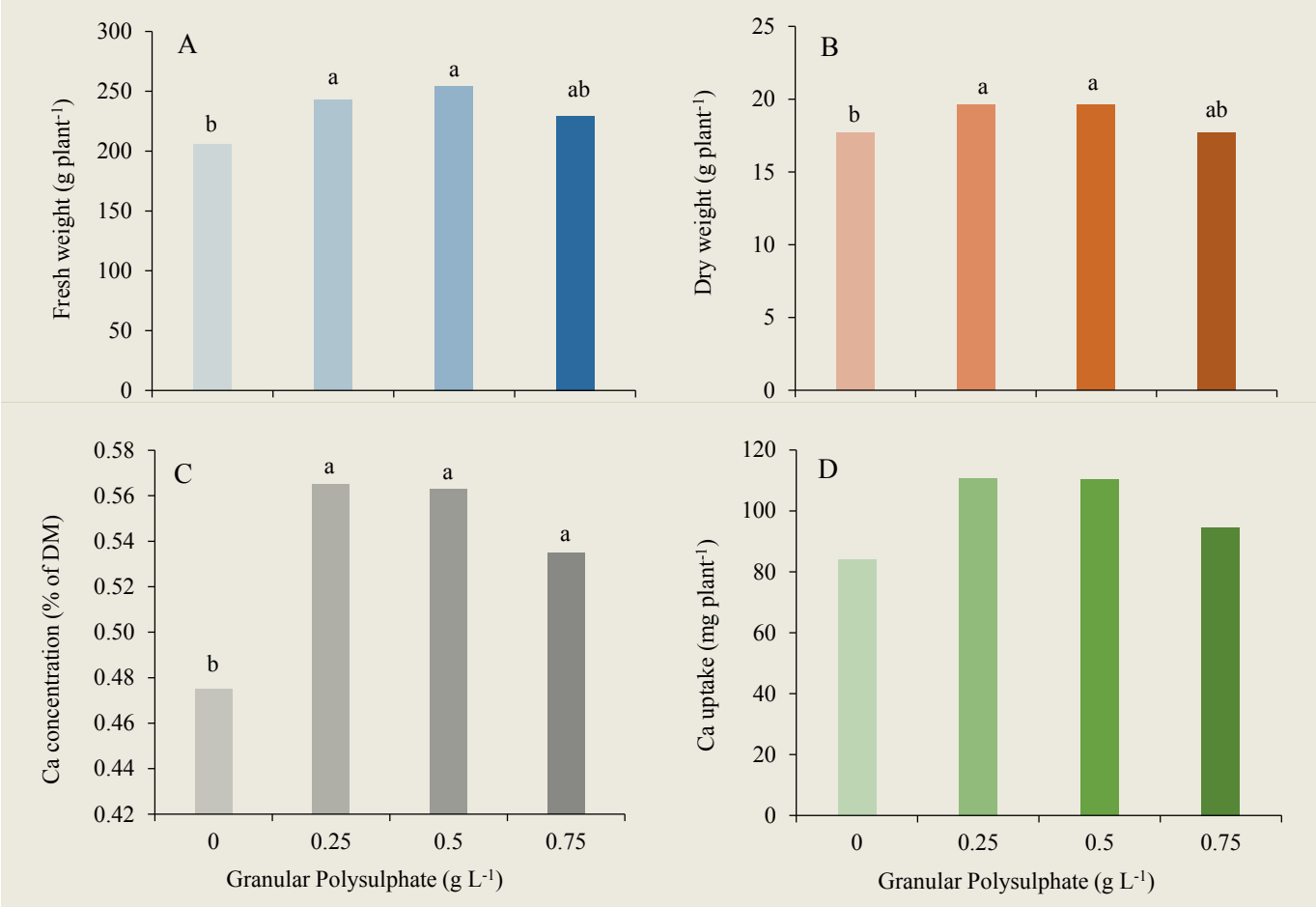

Fig. 3A-D. Effects of granular Polysulphate (PSG) concentration in the growth medium (perlite) on plant fresh weight (A); plant dry weight (B); calcium concentration (C); and calcium uptake (D). Similar letters indicate no significant differences between treatments at $p < 0.05$.

Table 1. Effects of PSG concentration in the growth medium on nutrient (S, Mg, and K) concentration in leaves and uptake, determined at harvest.

PSG	Nutrient concentration			Nutrient uptake		
	S	Mg	K	S	Mg	K
g L^{-1} perlite	----------%----------			----------*mg plant^{-1}*----------		
0	0.133b	0.525	4.33	111.5b	92.8	766
0.25	0.165a	0.498	4.17	183.1a	97.7	818
0.50	0.161a	0.423	4.24	177.8a	82.8	830
0.75	0.160a	0.465	4.37	151.6ab	82.2	772

Similar letters indicate no significant differences between treatments at p <0.05.

effect on leaf K and Mg concentrations, or on the uptake of the nutrients (Table 1) that were supplied through fertigation. In contrast, leaf S content and uptake significantly increased under PSG treatments, but similar to Ca, with no correlation with the PSG dose (Table 1).

Discussion

Significant progress has been made recently in understanding the role of K^+ in root growth, development of root system architecture, cellular functions, and specific plant responses to K^+ shortage. There is evidence linking K^+ transport with cell expansion, membrane trafficking, auxin homeostasis, cell signaling, and phloem transport, all of which place K^+ among the important general regulatory factors of root growth (Sustr *et al.*, 2019). In general, when plant roots encounter a low K^+ region they often stop growth (Gruber *et al.* 2013; Kellermeier *et al.* 2013). Li *et al.* (2017) suggested that under low K^+ conditions, the auxin transport towards the root tip is blocked, and root growth subsequently stops. It is not surprising, therefore, that in the present study the most straightforward response of lettuce to a lack of K^+ was a significantly poorer root system (Fig. 2B). Polyhalite, applied as PSS at 25-37.5 g L^{-1} perlite, gave rise to a remarkable increase in root biomass. The enhanced size and, presumably, the consequent boosted function of the greater root system promoted an increase in the number and size of the leaves (Fig. 1), realizing commercially equivalent levels of lettuce yield and quality. The declining SPAD value recorded in response to increasing PSS dose (Fig. 1D) can be associated with excess N, which accumulated in the leaves under growth inhibition due to the K deficiency.

In this experiment, polyhalite served as the sole K donor, while N, P, and micronutrients were supplied through the fertigation system. PSS competence to fulfill lettuce K requirement was demonstrated, with no observable negative side effects on produce quality. In addition, PSS was the sole supplier of Mg and S, two essential nutrients; no deficiency symptoms occurred for these nutrients, indicating the potential role of PSS as an Mg and S donor. Nevertheless, the majority of vegetable or leafy species have much longer crop cycles compared to lettuce. Thus, and in spite of the relatively slower nutrient release rate of polyhalite (Yermiyahu *et al.*, 2017), significantly larger PSS doses might be required for conventional cropping systems.

In the second experiment, the ability of PSG to supply lettuce Ca requirements was examined while the other macro- and micronutrients were supplied through fertigation. Usually, excess Ca application would not promote significantly greater biomass (Maynard and Hochmuth, 2007; Pinto *et al.*, 2014; Ainun *et al.*, 2018); however Ca deficiency might cause tip-burn, browning of the younger leaves, which is a substantial quality drawback that particularly occurs under high temperature and evaporative demands (Bres and Weston, 1992; Saure, 1998; Mandizvidza, 2017; Sublett *et al.*, 2018). In the present study, a slight increase in lettuce fresh and dry biomass did occur, but this was not proportional with the PSG dose (Figs. 3A, 3B). No tip-burn problems occurred; however, bolting, quite natural in the warm conditions that prevailed during the experiment, necessitated an early harvest. The results of a successive experiment, where the PSG dose was raised and the irrigation water was further purified, were very similar, although Ca uptake was lower (data not shown). These results suggest that in the lettuce production system described, Ca is not a limiting factor. It may be questionable whether similar conclusions would prevail under elevated N application rates and a more favorable temperature range. Under such conditions, lettuce growth rates are expected to increase significantly (Broadley *et al.*, 2000; Fu *et al.*, 2017; Conversa and Elia, 2019; Djidonou and Leskovar, 2019), increasing Ca demand, and consequently, for the required Ca availability in the growth medium. Another question may be raised due to the Ca content and uptake values in the control of the second experiment (Figs. 3C, 3D), where apparently no Ca donor was applied; what was the exact Ca source in that system?

A possible candidate is the irrigation water used; although desalinated, it contained Ca at 0.6 meq L^{-1}. Unfortunately, no direct measurements of water uptake were carried out during the experiment. Roughly calculated, the irrigation water delivered a total of 175 mg Ca plant^{-1}, much greater than actually taken up by the plants (Fig. 3D). It is well known that nutrient uptake in hydroponic systems is substantially more efficient than in conventional soil cultures and, hence, much lower nutrient concentrations are required (Soundy *et al.*, 2001; Barbosa *et al.*, 2015; Ainun *et al.*, 2018). Conversely, the recently estimated water uptake rates of lettuce (Barbosa *et al.*, 2015) do not support the uptake of the complete amount of Ca provided solely by the irrigation water. In addition, the greater Ca uptake demonstrated by plants treated with PSG clearly indicate that this supplementary

fertilizer took part in the Ca supply to these plants. Theoretically, PSG potentially held a reservoir of 60-180 mg Ca plant^{-1}; nevertheless, Ca occurs in polyhalite in the form of gypsum, and its solubility is very slow (Yermiyahu, 2019). It would be more realistic, then, to assume that only a small portion of the Ca held in PSG became available during the experiment.

In conclusion, the ability of polyhalite to provide all the K requirements of a crop throughout the season, which was clearly demonstrated for lettuce, largely depends on the crop duration and the amount of PSS embedded in the growth medium. Obviously, enrichment of the growth medium with PSG can ensure sufficient available Ca to satisfy lettuce requirements and guarantee high produce quality. Nevertheless, developing an accurate PSG application rate should be subject to thorough fine-tuning, taking local properties of the water and growth media into consideration. Economic evaluations will always be necessary when moving from the soilless model presented here to conventional cropping systems.

Acknowledgements

The authors thank the pupils (Adi Biton; Noa Frenkel; Gaya Alon) and team (M. Sapir and E. Nagadi) of Eshel Hanassi Youth Village and high school, who contributed a lot of time and effort carrying out experiment. We also want to thank MIGAL staff, Zlil Baras and Menashe Levi for executing experiment 2.

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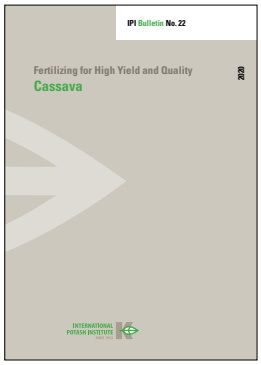
The paper "Effects of Polyhalite Fertilizers on Lettuce Development on a Soilless Culture" also appears on the IPI website.

Publications

IPI Bulletin No. 22

Fertilizing for High Yields and Quality: Cassava

By John Okoth Omondi. 2020. 54 p.



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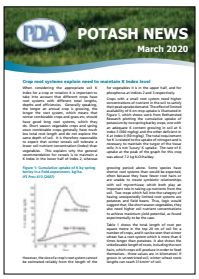

Crop Root Systems Explain Need to Maintain K Index Level

POTASH News, March 2020

When considering the appropriate soil K Index for a crop or rotation it is important to take into account that different crops have root systems with different total lengths, depths and efficiencies. Generally speaking, the longer an annual crop is growing, the longer the root system, which means that winter combinable crops and grass etc, should have good long root systems, which they do. Short season vegetable crops and spring sown combinable crops generally have much less total root length and do not explore the same depth of soil. It is therefore reasonable to expect that winter cereals will tolerate a lower soil nutrient concentration (Index) than vegetables. This explains why the general recommendation for cereals is to maintain a K Index in the lower half of Index 2, whereas for vegetables it is in the upper half, and for phosphorus at Indices 2 and 3 respectively. 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.

IPI Funded Research

Economic Benefit of Potassium Use in Potato-Cereal Crop Rotation

Evan Rroço, Adrian Doko, Witold Grzebisz, Pavel Čermák, György Füleky, and Thomas Popp. 2019. Albanian J. Agric. Sci.18(2-3):74-82.

Abstract: Crop production is among others an economic activity, and farmers should have a profit from the fertilizers use. To test the profitable use of fertilizers in different climatic and soil conditions, a five years' experiment was set up in the Czech Republic (CZ), Poland (PL), and in Albania (AL) in a rotation scheme with potato, as the main crop, preceding winter wheat and winter barley. In all the experimental sites, potato was the crop that reacted better to K fertilization, showing the highest profit compared with the other crops. The benefit of the farmers using fertilizers in the potato-cereal rotation reached than 11.200 Euro ha^{-1} in Albania and 3.000 and 4.100 Euro ha^{-1} for The Czech Republic and Poland, respectively. The beneficial

profitable effect of K fertilization was recorded also in the second year after its application, in turn increasing economic benefits in barley production. The highest benefit was achieved when the requirements of the main crop, i.e. potato was fully covered by application of three essential nutrients, i.e. N, P and K. The balanced application of the three nutrients, not only affected positively the yields, but also contributed to increase the farmers' incomes.

Potassium Fertilization as a Driver of Sustainable Management of Nitrogen in Potato (*Solanum tuberosum* L.)

Witold Grzebisz, Witold Szczepaniak, and Jan Bocianowski. 2020. Field Crops Research 254:107824. DOI https://doi.org/10.1016/j.fcr.2020.107824.

Abstract: The objectives of the present study were to assess and demonstrate the role of potassium fertilizer management on nitrogen use efficiency (NUE), and to select the most suitable set of NUE indicators. A series of six field experiments was conducted during 2009-2014. A principal trial factor was crop rotation (CR), potatoes - winter wheat - winter barley (1st CR/ lupine – cover crop/2nd CR). The experimental design was composed of four K rates (0, 80, 160, 240 kg K_2O ha^{-1}) and two N rates (120, 160 kg N ha^{-1}). The marketable yield (MY) ranged from 20 to 49 Mg ha^{-1}. The amount of K in tubers at harvest (Ka) was significantly associated with the MY. K_a, largely governed by the interaction between CR and K rate, was also linked to Partial Factor Productivity of fertilizer nitrogen (PFP_N) and Agronomic Nitrogen Efficiency (ANE). The results suggest that the K rate should be oriented to the realization of a specific production strategy, depending on environmental factors (water shortage), and N use efficiency. It was documented that increased K_a might be a crucial factor for controlling N productivity, subsequently decreasing its rates. At the optimum K fertilizer rate, N rates can be significantly reduced.

Efficacy of Fertilizing Method for Different Potash Sources in Cotton (*Gossypium hirsutum* L.) Nutrition under Arid Climatic Conditions

Hussain, M,. A.F. Tariq, A. Nawaz, M. Nawaz, A. Sattar, S. Ul-Allah, and A. Wakeel. 2020. PLoS ONE 15(1):e0228335. DOI: https://doi.org/10.1371/journal.pone.0228335.

Abstract: Precise choice of potassium (K) source and application method does matter for its cost-effectiveness. This study was aimed to evaluate the best source and method of K fertilizer application to improve cotton productivity and profitability under an arid climate. Three different K sources (KNO_3, K_2SO_4 and KCl) were applied at 100 kg ha^{-1} by four methods, i.e. a) basal application, b) side dressing, c) fertigation and d) foliar application of 2% K_2SO_4. The highest productivity and profitability were recorded with K_2SO_4 applied as foliar application. Total boll weight per plant was similar in foliar applied K_2SO_4 and basal application of KNO_3. Better boll opening in foliar applied K_2SO_4, perhaps, played decisive role for increased seed-cotton yield. For basal application and side dressing, KNO_3 produced the highest seed-cotton yield, but the benefit cost ratio was better for foliar applied K_2SO_4. In crux, foliar application of K_2SO_4 might be opted to improve the seed cotton yield, fiber quality and net returns under the arid climate. However, soil K application through K_2SO_4 and/ or KNO_3 is essential to balance the K removal from soil.

Scientific Abstracts in the Literature

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Potassium Fertilization Affects Alfalfa Forage Yield, Nutritive Value, Root Traits, and Persistence

Jungers, J.M., D.E. Kaiser, J.F.S. Lamb, J.A. Lamb, R.L. Noland, D.A. Samac, M.S. Wells, and C.C. Sheaffer. 2019. Agron. J. 111(6):2843-2852. DOI: https://doi.org/10.2134/agronj2019.01.0011.

Abstract: Potassium (K) is a critical macronutrient for alfalfa growth; however, reports of the effects of K fertilization on alfalfa yield, quality, and persistence have been inconsistent. Five K fertilizer rates ranging from 0 to 403 kg K ha^{-1} were applied to eight alfalfa cultivars during the establishment year (2011) and three subsequent production years (2012-2014) at three locations varying in baseline soil test potassium (STK) levels. Alfalfa yield, nutritive value, and STK were measured annually. During the final year, stem density and belowground traits were quantified. Forage yield, nutritive value, and root traits varied by cultivar, but there were no interactions between cultivar and K rate. Crown rot varied by cultivar but was not affected by K rate. Averaged across cultivars, the effect of K on yield varied by location and stand age. At the site with the lowest baseline STK values, K fertilizer had a positive quadratic effect on yield, which plateaued at a K rate of 296 kg K ha^{-1}. There was no effect of K on yield at the site with the greatest baseline STK. Potassium fertilizer reduced forage nutritive value and increased forage K concentration. Aboveground and belowground biomass K concentration increased with K fertilizer at rates beyond those that maximized yield, indicating luxury consumption of K. However, mineralization of soil K resulted in a net increase in

STK after accounting for K removal during harvest. Potassium removal rates that resulted in maintained STK were 167, 227, and 268 kg K ha^{-1} yr^{-1} at three locations.

Evaluation of Potassium Application on Tomato Performance and Rhizosphere Bacterial Communities under Negative Pressure Irrigation of Greenhouse-Grown

Xiang Gao, Shuxiang Zhang, Xiujuan Zhao, and Huaiyu Long. 2020. J. Plant Nutr. 43(3):317-326. DOI: 10.1080/01904167.2019.1683862.

Abstract: The study investigated the response to five levels of potassium (K) fertilizer addition on tomato (*Solanum lycopersicum* L.) performance and soil bacterial communities by negative pressure irrigation (NPI) over two consecutive years. The application of K fertilization positively affected tomato performance under NPI, as indicated by increased yield, quality, growth, and nutrients' contents of tomato compared with no K addition treatment. High-throughput sequencing of the rhizosphere soil revealed that K additions significantly affected in the bacterial diversity indices according to Chao1, Ace, and Shannon. K addition significantly increased the relative abundance of *Gemmatimonadetes* and decreased the level of *Planctomycetes*. There were very prominent increases in the levels of the genus *Opitutus*, but reduced the content of *Sphingomonas* and *Bdellovibrio* compared with no K addition treatment. Furthermore, application of 150 kg K ha^{-1} (K150) was considered to be beneficial for plant growth and rhizosphere bacterial diversity of tomato. The tomato yield under K150 was considerably increased by 58% and 47% compared with no K addition treatment in 2016 and 2017, respectively. The K150 showed the highest K fertilizer utilization efficiency compared with other K treatments, with K contribution rate and K agronomic efficiency reaching 36.7 and 62.9 as well as 32.0 and 53.6 in 2016 and 2017, respectively. Therefore, these findings also demonstrate that K application under NPI not only promotes yield and quality of tomato fruits but also positively affects the rhizosphere microbiome.

The Importance of Cl^- Exclusion and Vacuolar Cl^- Sequestration: Revisiting the Role of Cl^- Transport in Plant Salt Tolerance

Honghong Wu, and Zhaohu Li. 2019. Front. Plant Sci. DOI: https://doi.org/10.3389/fpls.2019.01418.

Abstract: Salinity threatens agricultural production systems across the globe. While the major focus of plant researchers working in the field of salinity stress tolerance has always been on sodium and potassium, the transport patterns and physiological roles of Cl^- in plant salt stress responses are studied much less. In recent years, the role of Cl^- in plant salinity stress tolerance has been revisited and has received more attention. This review attempts to address the gap in knowledge of the role of Cl^- transport in plant salinity stress tolerance. Cl^- transport, Cl^- exclusion, vacuolar Cl^- sequestration, the specificity of mechanisms employed in different plant species to control shoot Cl^- accumulation, and the identity of channels and transporters involved in Cl^- transport in salt stressed plants are discussed. The importance of the electrochemical gradient across the tonoplast, for vacuolar Cl^- sequestration, is highlighted. The toxicity of Cl^- from $CaCl_2$ is briefly reviewed separately to that of Cl^- from NaCl.

Enhancement of Potato Shelf Life: Role of Pre-Harvest Potassium Application

Zakaria Alam, Md. Azizul Hoque, Sanjida Akter, Md. Mazadul Islam, and Avijit Biswas. 2019. Sustainable Food Production 6:24-32. DOI: https://doi.org/10.18052/www.scipress.com/SFP.6.24.

Abstract: An experiment was conducted at the research field in Gazipur, Bangladesh during winter season of 2014-2015 to determine the effect of different potash fertilizer rates as pre-harvest application viz. K_1 (0 kg-K_2O/ha), K_2 (150 kg-K_2O/ha), K_3 (175 kg-K_2O/ha) and K_4 (200 kg-K_2O/ha) on storability of different potato varieties (V_1= Cardinal, V_2=Courage, V_3=Diamant, V_4=Granola) under natural condition. The potato tubers were stored in a well ventilated room of day and night temperature of (25-30°C) and (20-25°C), respectively. Result revealed that after 135 days of storage, lowest cumulative weight loss was recorded in Granola (12.66%) followed by Courage (21.50%), Diamant (30.84%) and Cardinal (30.84%). The cumulative weight loss was minimum (10.66%) in Granola variety after 135 days of natural storage where the pre-harvest potassium application rate was @ 200 kg-K_2O/ha.

Tissue-Specific Regulation of Na^+ and K^+ Transporters Explains Genotypic Differences in Salinity Stress Tolerance in Rice

Liu, J., S. Shabala, L. Shabala, M. Zhou, H. Meinke, G. Venkataraman, Z. Chen, F. Zeng, and Q. Zhao. 2019. Front. Plant Sci. DOI: https://doi.org/10.3389/fpls.2019.01361.

Abstract: Rice (*Oryza sativa*) is a staple food that feeds more than half the world population. As rice is highly sensitive to soil salinity, current trends in soil salinization threaten global food security. To better understand the mechanistic basis of salinity tolerance in rice, three contrasting rice cultivars - Reiziq (tolerant), Doongara (moderately tolerant), and Koshihikari (sensitive) - were examined and the differences in operation of key ion transporters mediating ionic homeostasis in these genotypes were evaluated. Tolerant varieties had reduced Na^+ translocation from roots to shoots. Electrophysiological and quantitative reverse transcription PCR experiments showed that tolerant genotypes possessed 2-fold higher net Na^+ efflux capacity in the

root elongation zone. Interestingly, this efflux was only partially mediated by the plasma membrane Na^+/H^+ antiporter (*OsSOS1*), suggesting involvement of some other exclusion mechanisms. No significant difference in Na^+ exclusion from the mature root zones was found between cultivars, and the transcriptional changes in the salt overly sensitive signaling pathway genes in the elongation zone were not correlated with the genetic variability in salinity tolerance amongst genotypes. The most important hallmark of differential salinity tolerance was in the ability of the plant to retain K^+ in both root zones. This trait was conferred by at least three complementary mechanisms: (1) its superior ability to activate H^+-ATPase pump operation, both at transcriptional and functional levels; (2) reduced sensitivity of K^+ efflux channels to reactive oxygen species; and (3) smaller upregulation in *OsGORK* and higher upregulation of *OsAKT1* in tolerant cultivars in response to salt stress. These traits should be targeted in breeding programs aimed to improve salinity tolerance in commercial rice cultivars.

The Effect of Potassium Applications on Fruit Yield and Some Quality Characteristics of Sweet Chestnut (*Castanea sativa* mill.)

Toprak, S. 2019. Int. J. Agric. For. Life Sci. 3(2):295-300.

Abstract: This research was performed to determine the effects of potassium applied on the soil to different doses on the yield and yield components of sweet chestnut grown in conditions in the Bursa province in 2012 and 2013. In this context, 0, 500, 1,000, 1,500 and 2,000 g K $tree^{-1}$ doses were applied to the tree canopy soil at 0-30 cm depth in April. According to the results of the study, the highest fruit yield, total protein, and sugar were recorded averagely 26 kg $tree^{-1}$, 10.7 and 13.7 g 100 g^{-1} respectively in 1,500 g K $tree^{-1}$ dose in application years. The highest starch content in fruit was determined as average 34.5 g 100 g^{-1} in 1,000 g K $tree^{-1}$ dose. As a result of this research, the amount of potassium fertilizer to be applied to the Sarıaşılama variety of chestnut trees at the age of 20 years were determined as 1,500 g K $tree^{-1}$.

Response of Medical Cannabis (*Cannabis sativa* L.) Genotypes to K Supply Under Long Photoperiod

Saloner, A., M.M. Sacks, and N. Bernstein. 2019. Front. Plant Sci. DOI: https://doi.org/10.3389/fpls.2019.01369.

Abstract: Potassium is involved in regulation of multiple developmental, physiological, and metabolic processes in plants, including photosynthesis and water relations. We lack information about the response of medical cannabis to mineral nutrition in general, and K in particular, which is required for development of high-grade standardized production for the medical cannabis industry. The present study investigated the involvement of K nutrition in morphological development, the plant ionome, photosynthesis and gas-exchange, water relations, water use efficiency, and K use efficiency, comparatively for two genotypes of medical cannabis, under a long photoperiod. The plants were exposed to five levels of K (15, 60, 100, 175, and 240 ppm K). Growth response to K inputs varied between genotypes, revealing genetic differences within the Cannabis sativa species to mineral nutrition. Fifteen ppm of K was insufficient for optimal growth and function in both genotypes and elicited visual deficiency symptoms. Two hundred and forty ppm K proved excessive and damaging to development of the genotype Royal Medic, while in Desert Queen it stimulated rather than restricted shoot and root development. The differences between the genotypes in the response to K nutrition were accompanied by some variability in uptake, transport, and accumulation of nutrients. For example, higher levels of K transport from root to the shoot were apparent in Desert Queen. However, overall trends of accumulation were similar for the two genotypes demonstrating competition for uptake between K and Ca and Mg, and no effect on N and P uptake except in the K-deficiency range. The extent of accumulation was higher in the leaves > roots > stem for N, and roots > leaves > stem for P. Surprisingly, most micronutrients (Zn, Mn, Fe, Cu, Cl) tended to accumulate in the root, suggesting a compartmentation strategy for temporary storage, or for prevention of access concentrations at the shoot tissues. The sensitivity of net-photosynthetic rate, gas exchange, and water use efficiency to K supply differed as well between genotypes. The results suggest that growth reduction under the deficient supply of 15 ppm K was mostly due to impact of K availability on water relations of the tissue and transpiration in Royal Medic, and water relations and carbon fixation in Desert Queen.

Controlled-Release Nitrogen Fertilizer Improved Lodging Resistance and Potassium and Silicon Uptake of Direct-Seeded Rice

Shugang Zhang, Yuechao Yang, Weiwei Zhai, Zhaohui Tong, Tianlin Shen, Yuncong C. Li, Min Zhang, Gilbert C. Sigua, Jianqiu Chen, and Fangjun Ding. 2019. Crop Sci. 59(6):2733-2740. DOI: https://doi.org/10.2135/cropsci2018.12.0765.

Abstract: Lodging is a severe problem for rice (*Oryza sativa* L.) because it interferes with mechanical harvesting, and potentially results total crop loss. This study investigated whether a controlled-release urea (CRU) could reduce lodging, improve the uptake of K and Si, and yields of direct-seeded rice. The 2-yr field experiment included four rates of CRU (120, 180, 240, and 360 kg N ha^{-1}), each provided in one application; a conventional urea fertilizer provided in four applications (360 kg N ha^{-1} total); and a control with no N fertilizer. Results indicated that the N release rates from the CRUs were matched well to N

uptakes by rice plants; hence, N use efficiencies were improved. Concentrations of K and Si in rice tissues were much higher for treatments with the full and reduced rates of CRU than for the full rate urea treatment. Lodging of rice only appeared to occur in the urea treatment. Microscopic examination revealed that cells of rice stems provided with CRU treatments were more resistant to lodging than stem cells from plants in the urea treatment.

Yield and yield attributes of wheat as influenced by potassium application in irrigated area of agro ecological zone of Karor, Pakistan

Ghulam Abbas, M. Anjum Ali, Tahir Mehmood, Waseem Abbas, Shoaib Kaleem, Zafar Abbas, and Marghub Amer. 2019. Sci. Int. (Lahore) 31(6):943-946. ISSN 1013-5316.

Abstract: Potassium (K) deficient soils of Pakistan are the foremost reason for the truncated yield of wheat. Application of the recommended dose of K to get potential yield is a sustainable strategy to combat this issue. The present experiment was conducted to investigate the effect of Potassium (K) on the yield and yield factors of the wheat cultivar Shafaq-2008. This study, binge over the gap between the optimum level of K fertilizer and the wheat variety. By using Randomized Complete Block Design (RCBD), thrice replicated treatments K0:0 (control), K1:15, K2:30 and K3:45 Kg K ha^{-1} were tested. Results revealed that the highest grain yield of wheat was recorded as 4,412.70 kg ha^{-1} with a dose of 45 kg K ha^{-1}. Furthermore, 51.58 percent of the increased yield was observed as compared to control (3,885.40 kg K ha^{-1}) where no fertilizer was applied.

Potassium Fertilizer Management on Rice Cultivation

Khin Pyone Nwe, Kyaw Ngwe, Swe Swe Mar, and Myint Thuzar. 2015. Journal of Agricultural Research 2(2):70-77.

Abstract: The purpose of the present study was to evaluate the effect of potassium on growth and yield of rice and to find out the best suited scheme/timing of potassium fertilizer application for rice crop. With this regard, pot experiments with Shwe Thwe Yin rice variety were conducted at the screen house of Department of Soil and Water Science, Yezin Agricultural University during the dry and wet seasons of 2014. In this investigation, a recommended dose of potassium fertilizer (37 kg ha^{-1}) was tested in 7 different treatments i.e. T1 (all potash applied as basal), T2 (all potash applied at 25 DAT), T3 (all potash applied at 45 DAT), T4 (½ potash applied as basal and remaining ½ at 25 DAT), T5 (½ potash applied as basal and remaining ½ at 45 DAT), T6 (½ potash applied at 25 DAT and remaining ½ at 45 DAT), and T7 (1/3 potash applied as basal, 1/3 at 25 DAT and remaining 1/3 at 45 DAT) and no potash application was used as T8 (Control). Based on the two strong investigations, yield, yield components and nutrient use efficiency were responded to different application time of potassium fertilizer. T6 (½ potash applied at 25 DAT and remaining ½ at 45 DAT) and T2 (all potash applied at 25 DAT) produced more grain yield in both seasons. Least value of yield was achieved in the treatment T8 (Control) and T1 (all potash applied as basal) ranked at second. The maximum partial factor productivity of potassium (PFPK) was observed from T6 (½ potash applied at 25 DAT and remaining ½ at 45 DAT) and T2 (all potash applied at 25 DAT) among the treatments in both seasons. According to the results of this study, basal application of potash (traditional method) may be replaced by a late application of potash at 25 DAT (maximum tillering stage) and split application of potash in two splits ½ at 25 DAT and remaining ½ at 45 DAT may be promoted for getting maximum benefit.

Comparative effects of potassium chloride (KCl) as osmotic stressor on various growth parameters of *Lycopersicon esculentum* L.

Faheem Tariq, Abdul Basit, Izhar Ahmad, Syed Inzimam Ul Haq, Zakir Ullah, Amir Ali, Jalil Ahmed, Awais Adnan Rahim, and Muhammad Hameed Iqbal. 2019. Pure Appl. Biol. 8(3): 2065-2075.

Abstract: *Lycopersicon esculentum* L. is one of the most important crop and used as a source of vitamins. The present study was carried out to investigate the osmotic effect of KCl on tomato growth and productivity. The experiment was conducted under two different conditions i.e. tomato plants were cultivated in fields as well as in pots. In order to investigate the difference among plant cultivated under different conditions. The plants were provided with various concentration of KCl treatment i.e. 0.1 M KCl, 0.2 M KCl and 0.3 M KCl and keeping one line as control. However, the completely randomize design (CRD) with 4 replicates was used. Various agronomic characters of plants such as plant height, number of brunches per plant, number of leaflets per plants, size of branch, terminal leaflet length, terminal leaflet width, Plant fresh weight, dry weight and number of fruits per plant were studied. The results showed that with increasing concentration of potassium chloride, the plant various growth parameters increase. The plant showed maximum growth, when provided with 0.3M KCl. Similar, type of results was obtained from the tomato plants cultivated in pots. However, in case of tomato plant cultivated in pots, showed less growth as compare to field in general.

Yield and Potassium Uptake of Rice as Affected by Potassium Rate in the Middle Reaches of the Yangtze River, China

Tinghong Ye, Xinxin Xue, Jianwei Lu, Wenfeng Hou, Tao Ren, Rihuan Cong, and Xiaokun Li. 2019. Agron. J. 112(2):1318-1329. DOI: https://doi.org/10.1002/agj2.20092.

Abstract: Potassium is an essential macroelement for rice (*Oryza sativa* L.), but K deficiency in paddy ecosystems has increased widely and limited sustainable rice production in China. Two-year field trials were conducted with five K levels (0, 60, 120, 180, and 240 kg K_2O ha^{-1}, designated as K0, K60, K120, K180, and K240) in Qichun county, Hubei Province, to investigate grain yield, K uptake characteristics, and K use efficiencies of rice. The results showed that application of K increased rice yield by 9.8-29.3%, compared to K0. No significant differences were observed in rice yield among the K120, K180, and K240 treatments. The K uptake in aboveground biomass increased linearly with the K rate, while K harvest index decreased. As K uptake increased, rice yield increased linearly at first and then stabilized, showing the phenomenon of luxury consumption of K. The growth period for fast K uptake in different rice varieties and K levels was 29-67 d after transplanting, and sufficient nutrient supply is needed to ensure the increase of rice yield and growth during this period. Internal use efficiency (IUE), agronomic efficiency (AE), and physiological efficiency (PE) declined as the application rate of K increased. These results indicated that absorption and utilization of K in rice were affected by the K supply rates, and that luxury consumption occurred when K application was excessive. The luxury consumption of K by rice was mainly stored in straw.

Large Scale Demo Plot Trial Project of Potash Fertilization for Increased Yield and Profitability for Smallholder Soybean Fields in India

Nachmansohn, J., P. Imas, and S.K. Bansal. 2019. Int. J. Agr. Ext. 07(02):159-170. DOI: 10.33687/ijae.007.02.2844.

Abstract: Agriculture is the backbone of the Indian economy, in spite of concerned efforts towards industrialization in the last three decades. Therefore, the soil quality and fertility are the major factors in crop production. Declining soil fertility is one of the primary factors that directly affect crop productivity, and fertilizer-use is a key factor in order to keep soil fertility and productivity. A major factor in declining soil fertility is potassium (K) depletion, especially on smallholder farms where fertilization decisions are not based on regular soil testing. Most of the smallholder soybean producers do not have access and investment capacity to soil testing services. Therefore, there is a need to create K fertilizer recommendations based on empirically verified knowledge at India-specific scale. Such large-scale studies, in local filed conditions, are currently lacking. In order to bridge this gap, and generate proven set of directly applicable recommendations, a large-scale plot trial was launched; the Potash for Life (PFL) project. The study evaluated the K response in soybean when fertilizing with potash on K depleted soils in local variable field conditions. The aim was to (1) evaluate the effect and response consistency of K application on soybean yield, (2) to demonstrate to farmers the increased yield and profitability from K-inclusive fertilization regimes for this crop and give recommendations for transient yield increase, and (3) to raise the awareness among smallholder farmers about the importance of K fertilization. A comprehensive experiment was carried out in Madhya Pradesh (M.P.) and Maharashtra. The methodology was straight-forward; two identical plots side by side, with the only difference that one of them was fertilized with additional potash. The results showed a significant yield increase response from the potash application; the average yield increase was 244 kg ha^{-1} or 26 % in M.P., and 105 kg ha^{-1} or 36 % in Maharashtra. This entailed an average additional net profit of ₹ 6,681 INR ha^{-1} and ₹ 2,544 INR ha^{-1}, in M.P. and Maharashtra respectively. It was concluded that the soil status of plant available K is significantly lower than the plant demand for soybean production in the two states, Consequently, K fertilization is necessary in order to improve agricultural practices and optimizing yields. Ultimately, following recommendations given in this study would allow farmers to generate additional profit, which could further allow them to invest in fine-tuning fertilizer practices through the means of soil testing.

Productivity and Oil Content of Soybean as Affected by Potassium Fertilizer Rate, Time and Method of Application

Hemeid, M.M. 2020. Asian Journal of Crop Science 12:19-25. DOI: 10.3923/ajcs.2020.19.25.

Abstract: Background and Objective: The demand for soybean is on the rise worldwide for its vegetable oil and high protein seed content. One of the reasons for the reduction in the crop's area in Egypt is the high production costs, especially with the rise in fertilizer prices. Soybean requires high rates of potassium compared to other summer crops like maize. The main aim of this study was to investigate the possibility of replacing the soil applied mineral potassium fertilizer with a foliar form without affecting seed yield or oil content of seeds.

Materials and Methods: A two year study was conducted, under irrigated conditions, to study the effect of 57 and 114 kg ha^{-1} potassium (K_2O) applied to the soil and 0.58 and 1.16 kg ha^{-1} (K_2O) sprayed on plants as foliar application at two soybean growth stages (V_2-V_3 and R_2-R_3) on growth, yield and yield attributes in addition to seed oil percentage of Giza 22 and Giza 35 soybean cultivars.

Results: Results indicated the importance of K fertilization for improving yield and oil percentage of soybean. Foliar fertilization at the rate of 1.16 kg ha^{-1} applied at the R_2-R_3 stage (about 60 days after sowing), was superior in seed yield/plant and seed yield ha^{-1} as opposed to the soil application of 57 kg ha^{-1} and equivalent to 114 kg ha^{-1} applied to the soil.

Conclusion: Foliar application of potassium at the rate of 1.16 kg ha^{-1} applied at the R_2-R_3 stage of soybean can replace the recommended soil application of 57 kg K ha^{-1} under irrigated

conditions in Egypt, reducing the amount of potassium applied by 98%. This will achieve the targeted seed yield and oil percentage of soybean at much lower costs of production.

Response of Black Gram (*Vigna mungo*) to Potassium under Water Stress Condition

Swati Shahi, Rajnish Kumar, and Malvika Srivastava. 2019. Annals of Plant and Soil Research 21(1):93-97.

Abstract: To evaluate the impact of limited water availability and potassium fertilization on growth, antioxidative systems and pigment content in urad bean, plants were grown in pot culture during 2016-2017. The treatments were based on a randomized complete block design (RCBD) with three replications. Plants were supplied with four moisture regimes (400 ml, 200 ml, 100 ml and 50 ml of water). Control plants were supplied with 500 ml of water. Potassium was applied in the form of 200 ppm KCl and KNO_3. Plants were observed from 25 upto 55 days of plant growth at 10-day interval for different treatments. Decrements in growth parameters (viz. shoot length, number of leaves and fresh weight) and chlorophyll stability index were observed due to water stress, and maximum decrement was observed when plants were supplied with 50 ml water. While antioxidant enzymes (viz. POD and CAT) and carotenoid content increased with increasing level of stress (50 ml water) as compared to control. Growth parameters and CSI increased while antioxidant enzyme activity and carotenoid content decreased upon foliar treatment with KCl and KNO_3, due to maintenance of favorable internal tissue moisture. However, the effect of KNO_3 was more prominent than that of KCl.

Potassium Application Improves Grain Yield and Alleviates Drought Susceptibility in Diverse Maize Hybrids

Sami Ul-Allah, Muhammad Ijaz, Ahmad Nawaz, Abdul Sattar, Ahmad Sher, Muhammad Naeem, Umbreen Shahzad, Umar Farooq, Farukh Nawaz, and Khalid Mahmood. 2020. Plants 9(1):75. DOI: https://doi.org/10.3390/plants9010075.

Abstract: Maize (*Zea mays* L.) is an important component of global food security but its production is threatened by abiotic stresses in climate change scenarios, especially drought stress. Many multinational companies have introduced maize hybrids worldwide which have variable performance under diverse environmental conditions. The maize production is likely to be affected by a future water crisis. Potassium (K) is a well-known macronutrient which improves the performance of cereals under abiotic stresses. In this field experiment, we assessed the influence of soil applied K on the productivity of diverse maize hybrids grown under well-watered and drought stress conditions. The study consisted of three K levels viz., control (no KCl), KCl at 50 kg ha^{-1}, and KCI at 75 kg ha^{-1} factorally combined with two irrigation levels (i.e., normal recommended irrigation, well-watered condition, and half of the recommended irrigation, drought stress condition) and eight maize hybrids. Irrigation was kept in main plots, potassium in subplot, and maize hybrids in sub-subplots. The results revealed that performance of the maize hybrids was significantly influenced by all three factors, and the interaction of irrigation with potassium and irrigation with hybrids was significant; results being non-significant for all other interactions. Potassium application improved yield traits and water productivity under both normal and water stress conditions but effect was more prominent under water stress conditions than normal conditions. Potassium application also alleviated drought susceptibility of all maize hybrids. In all cases, the performance of maize hybrids was maximum under potassium application at 75 kg ha^{-1}.

Phosphorus and Potassium Uptake, Translocation, and Utilization Efficiency in Chickpea under Mediterranean Conditions

Fotiadis, S., S.D. Koutroubas, and C.A. Damalas. 2020. Nutr. Cycl. Agroecosyst. 116:313-328. DOI: https://doi.org/10.1007/s10705-020-10047-z.

Abstract: Sowing time and cultivar choice have major effects on chickpea yield in the Mediterranean climate, but the effects on nutrient requirements are not well known. Information regarding nutrient requirements and utilization efficiency by crop species is necessary to optimize nutrient management in agricultural systems. A two-year field study was conducted to examine the patterns of P and K uptake, translocation, utilization and removal across a wide-range of chickpea yield levels induced by sowing time (March and April) and cultivar [Zehavit-27 (Kabuli-type), Andros, Kassos, and Serifos (desi-type)], as well as to identify plant traits associated with efficient nutrient utilization. At all samplings throughout the growing period, P uptake was significantly correlated with that of K uptake with r values between 0.633 ($P<0.05$) and 0.983 ($P<0.01$). Both P and K uptake peaked, in terms of uptake rate and net uptake, earlier during the April sowing (early pod filling stage) compared with March sowing (late pod filling stage). Early sowing increased chickpea productivity and total nutrient uptake, but did not offer any advantage in terms of nutrient utilization efficiency. Phosphorus or K translocation to seeds were significantly correlated with P ($r=0.838$, $P<0.01$) or K ($r=0.861$, $P<0.01$) accumulation prior to the beginning of seed filling, respectively. PUtE varied from 161 to 422 kg kg^{-1} and was greater than KUtE (32-101 kg kg^{-1}). Low (leaf+stem)-P or K concentration at maturity could be considered as an indirect selection tool to enhance nutrient utilization efficiency. Seed P or K removal depended on yield level of each cultivar. For a yield level of 2000 kg ha^{-1}, 8.2 kg P ha^{-1} and 18.9 kg K ha^{-1} were removed by seed harvest.

Evaluation of Potato Yield and Nitrate Accumulationi n Potatoes Cultivated under Differentiated NPK Fertilization Conditions

Bărăscu, N., M. Matei Duda, M. Hermeziu, and S. Nițu. 2019. ProEnvironment 12(38):121-126.

Abstract: Potato is a plant with high nutrient requirements but demands a balanced fertilizer management. Because in potato crop the application of high nitrogen levels may result in a decrease in the tubers quality with implications for human health, the aim of this paper was to study the potato yield, tuber starch content and the nutritional quality of two potato varieties fertilizated with different levels of nitrogen and different NPK ratios and to find the best fertilization variants to obtain the highest yield and quality for potato tubers with reduced implications for the accumulation in the environment. Evaluation of nitrates and nitrites potato tubers content was performed on the material obtained in a polyfactorial experiment with different NPK ratios (1:1:1 and 1:0.9:2) and different doses of nitrogen (100 and 200 kg N/ha) and two different potato varieties (Christian and Roclas). The experiment was conducted within the N.I.R.D.P.S.B. Braşov experimental field, on a chernozem soil and according with the current fertilization practices in the region, under non irrigated conditions. The experiment results show that the higher NPK ratio and nitrogen dose of 200 kg N/ha determined reduction of tubers starch content and significant increases in tuber nitrates and nitrites contents at high nitrogen doses (200 kg N/ha).

Coping With Water Shortage: An Update on the Role of K^+, Cl^-, and Water Membrane Transport Mechanisms on Drought Resistance

Nieves-Cordones, M., F. García-Sánchez1, J.G. Pérez-Pérez, J.M. Colmenero-Flores, F. Rubio, and M.A. Rosales. 2019. Front. Plant Sci. DOI: https://doi.org/10.3389/fpls.2019.01619.

Abstract: Drought is now recognized as the abiotic stress that causes most problems in agriculture, mainly due to the strong water demand from intensive culture and the effects of climate change, especially in arid/semi-arid areas. When plants suffer from water deficit (WD), a plethora of negative physiological alterations such as cell turgor loss, reduction of CO_2 net assimilation rate, oxidative stress damage, and nutritional imbalances, among others, can lead to a decrease in the yield production and loss of commercial quality. Nutritional imbalances in plants grown under drought stress occur by decreasing water uptake and leaf transpiration, combined by alteration of nutrient uptake and long-distance transport processes. Plants try to counteract these effects by activating drought resistance mechanisms. Correct accumulation of salts and water constitutes an important portion of these mechanisms, in particular of those related to the cell osmotic adjustment and function of stomata. In recent years, molecular insights into the regulation of K^+, Cl^-, and water transport under drought have been gained. Therefore, this article brings an update on this topic. Moreover, agronomical practices that ameliorate drought symptoms of crops by improving nutrient homeostasis will also be presented.

Mapping and Validation of a Major Quantitative Trait Locus *qRN5a* Associated with Increasing Root Number under Low Potassium in Rice

Islam, A., Y. Zhang, G. Anis, M.H. Rani, W. Anley, X. Shen, L. Cao, S. Cheng, and W. Wu. 2020. Plant Growth Regul. 90:519-528. DOI: https://doi.org/10.1007/s10725-020-00574-8.

Abstract: Potassium (K) is an indispensable mineral constituent required for plant growth and many physiological processes. K deficiency and depletion in rice occurs frequently, resulting in limited growth, agronomical loss, and reduced yield. To investigate the genetics of low K (LK) tolerance, a set of high throughput genotyped chromosome segment substitution lines (CSSL) derived from the cross between Zhonghui9308 (ZH9308, susceptible to LK) and XieqingzaoB (tolerant to LK) was used to identify QTL for the shoot and root traits at the seedling stage. The experiment was conducted in hydroponic culture to explore the molecular basis of five seedling traits under two K conditions, LK and normal K (NK) and their ratio (LK/NK) for relative traits. A total of five QTL were identified on four chromosomes (3, 4, 5, and 6) with positive allelic effects from XieqingzaoB for root length (RL) and root number (RN) and negative allelic effects for shoot dry weight (SDW) and root dry weight (RDW). Two QTLs, *qRN5a* and *qSDW4*, were detected under LK and three QTLs, *qRL6*, *qRN5b*, and *qRDW3*, were identified under LK/NK ratio explaining 11.81% to 13.07% of total phenotypic variation. *qRN5a*, a novel QTL under LK, was validated in the F_2 (BC_5F_2) population and delimited to a 1023 Kb interval between the markers InD78 to RM18472. These findings will serve as important breeding material for further genetic characterization like fine mapping and cloning, which may be useful in molecular marker-assisted breeding.

Foliar K Application to Rainfed Wheat in a Soil Testing High K as an Option to Improve K Use Efficiency, Grain Yield and Yield Components

Limon-Ortega, A., J.P. Munguia-Lopez, and E. Espitia-Rangel. 2020. J. Plant Nutr. 43(8):1080-1090. DOI: 10.1080/01904167.2020.1724301.

Abstract: Granular application of potassium (K) in soils testing high is generally not recommended. However, the effect of foliar K on rainfed wheat (*Triticum aestivum* L.) under these soil conditions is largely unknown. The objective of this work was to identify the effect of K fertilizer on K use efficiency (KUE), grain yield and yield components of wheat. The data were collected until

2017 in an ongoing trial established in 2007 with eight treatments; two granular K rates (0 and 50 kg K ha^{-1}); two foliar N rates (0 and 3 kg N ha^{-1}); and two foliar K rates (0 and 3 kg K ha^{-1}) in a split-split plot arrangement. Treatments were applied to the same plots each season. Treatment with foliar K resulted in the highest KUE response but the effect size varied according to the accumulated precipitation during the reproductive stage. On average, KUE was enhanced in crop seasons with water constrains (<179 mm) during the growth period but the converse was true as the amount of precipitation increased. In contrast, granular K had no effect on KUE irrespective of precipitation conditions. Application of foliar K increased grain yield as compared to granular K from 2,988 to 3,089 kg ha^{-1}. This enhancement was attributed to an increased number of grains per head. Therefore, foliar K application to wheat is suitable in a soil testing high K to enhance KUE and grain yield, overall in crop seasons with water constrains.

Effects of Potassium/Sodium Fertilization and Throughfall Exclusion on Growth Patterns of *Eucalyptus grandis* W. Hill ex Maiden During Extreme Drought Periods

Chambi-Legoas, R., G. Chaix, and M. Tomazello-Filho. 2020. New Forests 51:21-40. DOI: https://doi.org/10.1007/s11056-019-09716-x.

Abstract: In Brazil, most *Eucalyptus* plantations are located in regions experiencing periods of water shortage where fertilizers are intensively used to achieve high productivity. Fertilization can affect water use. However, the effects of fertilization on tree growth patterns during extreme droughts periods remain unknown. A throughfall exclusion experiment was set up in São Paulo State-Brazil to study the effects of potassium (K) and sodium (Na) fertilization and their interaction with water supply in the growth of *Eucalyptus grandis* trees over an abnormal season of 6 months of extreme drought in comparison with that in normal seasons, as well as the differences in responsiveness to intra-annual meteorological variability. Arranged in a split-plot design, the factors were water supply (37% throughfall exclusion vs. no throughfall exclusion) and fertilization regime (K, Na, and control). Basal area growth was monitored by band dendrometers measurements at 14-day intervals over 2 years. Meteorological and soil water content data were also collected. K and Na fertilization increased the tree basal area by four and three-fold, respectively, during normal seasons. During a severe drought season, these positive effects were suppressed. However, K- and Na-fertilized trees achieved a similar cumulative basal area increment to that of the control trees. The 37% throughfall exclusion significantly decreased tree growth in all treatments only in the severe drought period, and these effects were stronger in K-fertilized trees. K-fertilized trees were highly responsive to intra-annual meteorological variability. Our results suggest that extreme drought has similar effects on *E. grandis* tree growth regardless of the K/Na fertilization regime.

Crop Residue Incorporation Combined with Potassium Fertilizer Increased Cotton Canopy Apparent Photosynthesis and Seed Cotton Yield in Barley-Cotton Rotation System

Xiaobing Lv, Zhi Wang, Linjie Ma, Nan Cao, Yali Meng, and Zhiguo Zhou. 2020. Archives of Agronomy and Soil Science. DOI: 10.1080/03650340.2020.1723160.

Abstract: The field experiment was conducted to evaluate the effects of crop residue incorporation and K fertilizer on seed cotton yield, K uptake and canopy apparent photosynthesis. Without K fertilizer, barley residue incorporation and barley-cotton residue incorporation increased seed cotton yield, total biomass, K uptake, leaf K concentration, leaf area index and canopy apparent photosynthesis in 2017 and 2018, while cotton residue incorporation increased these factors in 2018; and with 150 kg ha^{-1} K2O, barley residue incorporation and barley-cotton residue incorporation increased K uptake and leaf K concentration in 2017 and 2018, while these factors were influenced by cotton residue incorporation in 2018. Thus, the effects of crop residue incorporation on cotton growth depended on K fertilizer rate. In addition, crop residue incorporation could reduce K fertilizer input to some extent. Based on yield, barley residue incorporation and barley-cotton residue incorporation could reduce 73.7 kg ha^{-1} K_2O (49.1%) and 70.1 kg ha^{-1} K_2O (46.7%) in 2017, 53.6 kg ha^{-1} K_2O (35.7%) and 89.5 kg ha^{-1} K_2O (59.6%) in 2018, while cotton residue incorporation could reduce 38.0 kg ha^{-1} K_2O (25.4%) in 2018.

Water Relations of Two Sicilian Grapevine Cultivars in Response to Potassium Availability and Drought Stress

Oddo, E., L. Abbate, S. Inzerillo, F. Carimi, A. Motisi, M. Sajeva, and A. Nardini. 2020. Plant Physiology and Biochemistry 148:282-290. DOI: https://doi.org/10.1016/j.plaphy.2020.01.025.

Abstract: We investigated the response of two Sicilian grapevine cultivars, Catarratto and Nero d'Avola, to potassium deficiency and drought stress. Two-year-old plants grafted on 1103 Paulsen were grown in agriperlite, with or without potassium in the fertigation solution for six weeks, and subjected to moderate drought stress by suspending irrigation for one week. Potassium content of leaves, roots and xylem sap were measured with an ion-selective electrode. Changes in stomatal conductance, stem and leaf water potential and hydraulic conductance were compared between genotypes and treatments. Potassium deficiency led to significant decreases in leaf potassium content in both cultivars and under both well-watered and drought stress conditions. Potassium content in xylem sap showed no significant differences between cultivars and was correlated with stem hydraulic conductance, particularly in the drought stress treatments. Under drought stress conditions, potassium availability led to an increase in stomatal conductance, particularly in Nero d'Avola. Both cultivars showed

a rather isohydric behavior under these experimental conditions, and the level of isohydry varied with potassium availability. These results can be useful for the development of optimal fertigation practices and the selection of drought tolerant varieties.

Nitrogen Uptake, Growth and Yield Response of Orange-Fleshed Sweet Potato (*Ipomoea Batatas* L.) to Potassium Supply

Shunyi Wang, Huan Li, Qing Liu, Shuwen Hu, and Yanxi Shi. 2020. Communications in Soil Science and Plant Analysis 51(2):175-185. DOI: 10.1080/00103624.2019.1695821.

Abstract: The excessive absorption of nitrogen (N) is easy to cause shoot overgrowth and reduce the root yield of sweet potato. The purpose of this study was to investigate the effects of potassium (K) application on N uptake, growth, and yield of sweet potato. A field experiment with four potassium application treatments (added at rates of 0, 75, 150, and 225 kg ha^{-1}, expressed separately by K_0, K_{75}, K_{150}, K_{225}) was conducted on the fecund soil at Jiaozhou peninsula of China from 2014 to 2015. The results showed that total N accumulation and dry matter increases with increasing K fertilizer application. K supply reduced leaf and shoot N/K ratio, and increased the N transport rate from 9.8% to 20.1% and root N distribution rate from 50.3% to 59.3% at 150 DAP, and then increased the root dry matter distribution rate, and subsequently increased the yield by 15.3-39.0% of sweet potato. While, K supply improved the efficiency of N absorption and utilization. To enhance the sweet potato yield, K application rate of 150-225 kg ha^{-1} was identified as optimal.

Long-Term Effects of Controlled-Release Potassium Chloride on Soil Available Potassium, Nutrient Absorption and Yield of Maize Plants

Zeli Li, Zhiguang Liu, Min Zhang, Chengliang Li, Yuncong C. Li, Yongshan Wan, Cliff G. Martin. 2020. Soil and Tillage Research 196:104438. DOI: https://doi.org/10.1016/j.still.2019.104438.

Abstract: Controlled-release potassium chloride (CRK) has been shown to improve potassium (K) use efficiency (KUE) and crop yields. However, its widespread use has limited by its high manufacturing costs. To help address this problem and to find the best techniques for using CRK, we mixed it with traditional potassium chloride (KCl) in 1:1 ratios in a five-year field test to find the resulting KUE, bleeding sap, yields, and economic returns of maize (*Zea mays* L.). There were six treatments subjected to varying K fertilization: full-dose, traditional KCl; full-dose, CRK; reduced-dose, CRK; full-dose, mixed CRK and traditional KCl; reduced-dose, mixed CRK and traditional KCl; and the control, which had no added K fertilizer. Applying high dose, mixed CRK and traditional KCl and high dose, CRK to maize significantly increased grain yields 14.0% and 7.2%, respectively, compared with the traditional KCl treatment during 2014-2018. When the K was provided at the low rate (reduced by one-third), the low dose, mixed CRK and traditional KCl and low dose, CRK treatments led to the same yields as the traditional KCl treatment. However, crude starch contents of the mixed CRK and traditional KCl and CRK treatments each were significantly increased compared with the traditional KCl treatment in 2018. Mean KUE increased 30.5%–56.5% for mixed CRK and traditional KCl treatments, compared with traditional KCl during 2016-2018. Mean net profits from the high dose, mixed CRK and traditional KCl treatment significantly increased 18.9%, when K was provided by the lower rate of mixed CRK and traditional KCl led to the same net profit, compared with traditional KCl treatment from the 2016-2018 years. During the milky maturity stage of maize plants, bleeding sap in the high dose, mixed CRK and traditional KCl treatment were 47.5% and 23.4% lower than from the traditional KCl and high dose, CRK treatments, respectively. Meanwhile, the high dose, mixed CRK and traditional KCl and high dose, CRK treatments significantly increased soil available K levels compared with the traditional KCl treatment, hence, meeting the nutrient demands of maize plants during their later growth stages. The exchangeable Ca^{2+} levels within the soil near the surface was also maximized by the long-term application of mixed CRK and traditional KCl treatments. Hence, applying mixed CRK and traditional KCl fertilizers were recommended for maintaining continued nutrient absorption soil fertility, sustainable increases in crops yields and for maximizing net profits.

Potassium Requirements for Pinot Noir Grapevines

Schreiner, R.P., and J. Osborne. 2019. Am. J. Enol. Vitic. 71:33-43. DOI: 10.5344/ajev.2019.19043.

Abstract: The potassium (K) requirements of Pinot noir grapevines were studied in a microplot vineyard, where four levels of fertilizer K supply were carefully controlled. Vine nutrient status, productivity, and must chemistry were studied over four years, and fermentation dynamics were evaluated over three years. Vine productivity, based on leaf area, pruning weights, and yield, was reduced by K supply only after four years in vines receiving no K fertilizer. K deficiency symptoms were apparent on leaves and fruit in vines receiving no K the year before productivity was altered, and after must pH was already reduced. Must pH was reduced below the level of control (100% K) vines in year 2, and thereafter in vines receiving no K, and also in years 3 and 4 in vines receiving 20% K. Late bunch stem necrosis occurred on some fruit clusters in year 3 in vines receiving no K and 20% K; this increased dramatically in year 4 in the no-K vines. Low must pH values of ~3.0 and must K concentrations as low as 600 mg K/L did not influence the rate of alcoholic fermentation. These findings indicate that monitoring must pH in addition to leaf

blade or petiole K concentrations would be helpful in managing vine K status. A leaf blade K level of 6.0 g K/kg dry weight (DW) at veraison is proposed as the critical concentration for Pinot noir vines cropped at levels typical for the region. Growers should monitor vine K status closely and must pH when leaf blade K at veraison approaches 7.0 g K/kg DW in western Oregon Pinot noir vineyards to account for sampling and laboratory error.

Zinc and Potassium Fertilizer Recommendation for Cotton Seedlings under Salinity Stress Based on Gas Exchange and Chlorophyll Fluorescence Responses

Zahra Hatam, Mohammad Sadegh Sabet, Mohammad Jafar Malakouti, Ali Mokhtassi-Bidgoli, Mehdi Homaee. 2020. South African Journal of Botany 130:155-164. DOI: https://doi.org/10.1016/j.sajb.2019.11.032.

Abstract: Cotton is typically grown in warm regions in which salinity and nutrient deficiency stresses are ubiquitous and often simultaneously influence plant growth. Under saline conditions, fertilizer recommendation is highly challenging, since nutrient application may increase or decrease plant salt tolerance, which may complicate prediction of crop yield. So far, no investigations have been conducted in salt-affected soils to determine optimum concentrations of potassium (K) and zinc (Zn) fertilizers based on chlorophyll fluorescence (ChlF) and gas exchange (GEx) responses in upland cotton (*Gossypium hirsutum* L.). Accordingly, in this study, a factorial experiment was conducted in a complete block design with six replicates under controlled conditions. Treatments included various K_2SO_4 (0, 50, 100, and 150 kg ha^{-1}), and ZnSO4 (0, 50, and 100 kg ha^{-1}) concentrations applied to soil before planting. Cottonseeds were sown in non-saline soils and soils formerly salinized with natural saline water diluted to 15 dS m^{-1}. One month after sowing, results showed that salinity significantly decreased dry weight, chlorophyll content index, photosynthesis rate (A), leaf to air vapor pressure, transpiration rate (E), stomatal conductance, and minimum fluorescence of dark-adapted leaf, but increased root to shoot ratio (R/Sh). Under salinity, combined application of K and Zn boosted physiological properties including yield of photosystem II photochemistry (*ΦPSII*), A, and E without improving biomass. Combined application of K and Zn at highest concentrations decreased R/Sh by 93% compared to the control. Rate of increase was higher in E than that of A leading to reduction in water use efficiency. High Zn concentration in saline soils increased non-photochemical quenching and energy loss in form of heat. Under non-saline condition, Zn application significantly decreased A probably due to inhibitory effect on electron transfer within photosystem II. K significantly increased stomatal conductance and accordingly E. GEx parameters were more sensitive to used treatments than ChlF parameters. Based on GEx and ChlF responses, the most salt-tolerant cotton seedlings were obtained under combined application of 50 kg K_2SO_4 ha^{-1} and 50 kg $ZnSO_4$ ha^{-1}, thus these concentrations are recommended for optimal establishment of cotton seedlings under salinity stress.

Sunflower (*Helianthus annuus* L.) Biochemical Properties and Seed Components Affected by Potassium Fertilization under Drought Conditions

Saeid Zamani, Mohammad Reza Naderi, Ali Soleymani, Bahram Majd Nasiri, and Mohammad Miransari. 2020. Ecotoxicology and Environmental Safety 190:110017. DOI: https://doi.org/10.1016/j.ecoenv.2019.110017.

Abstract: The seed yield and healthy oil in sunflower (*Helianthus annuus* L.), as an important industrial crop, decrease under stress. There is not much investigation, to our knowledge, on the use of potassium fertilization, a regulator of plant water potential, affecting the biochemical properties and seed components of sunflower under drought stress. Accordingly, such parameters were investigated in a split-split plot field experiment, conducted in two different field sites (Natanz (Nt) and Eghlid (Eg), Iran), using potassium fertilization (subplots, 0, 150 and 300 kg/ha) and six drought levels (main plots) in four replicates. Although stress significantly affected sunflower biochemical properties and seed components in the two fields, the effects of stress were more pronounced in the Eg site (significant interaction of field and drought). The plant alleviated the stress by increasing the proline, oleic and linoleic acid concentrations, however, potassium fertilization also increased plant tolerance further under stress by enhancing such components compared with control. Interestingly, the Eg site was more responsive to the potassium fertilization (significant interaction of field and fertilization), as the fertilizer resulted in a higher rate of plant biochemical properties and seed components. The use of potassium fertilization at 300 kg/ha (K3) was the most effective treatment in the alleviation of stress. Interestingly, under drought stress, potassium contributed to the enhanced quantity and quality of sunflower by increasing seed components, and enhancing the biochemical properties of the plant, which can also improve crop physiological mechanisms. The results can further increase our understanding related to the effects of potassium fertilization on the yield and physiology of sunflower under drought stress. Such results are of economic, environmental and health significance.

Read on

What Can Potassium Fertilization Do For You?

King, M. 6 August 2019. Hay & Forage Grower.

Giving Potassium Some Respect

Henning, J. 7 January 2020. The News-Enterprise.

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OPEN FOR PHOTO ENTRIES: The 2020 IPI Photo Contest "Capturing Nutrient Deficiencies in Crops"

See a crop suffering from a nutrient deficiency? Then photograph it. You could be a winner!

At the International Potash Institute (IPI), we are pleased to open the 2020 IPI Photo Contest "Capturing Nutrient Deficiencies in Crops" (see https://photo.ipipotash.org/). The contest is held in memory of our dear colleague Ricardo Melgar who strongly believed in the power of people to promote crop stories.

Capturing crops deficient in nutrients

The 2020 IPI Photo Contest is open to images of any nutrient deficiency in crops: nitrogen (N), phosphorus (P), and potassium (K), sulfur (S), calcium (Ca) and magnesium (Mg); and micronutrients including boron (B), copper (Cu), chloride (Cl), iron (Fe), manganese (Mn), molybdenum (Mo), nickel (Ni), and zinc (Zn).

So, find your crop nutrient deficiency and capture it in a great photo.

You can submit up to 10 photos, simply send each one with your name, email address, a photo caption or description, and where the photograph was taken. You can submit your photos up until 30 November 2020 at https://photo.ipipotash.org/.

Photo example. Typical magnesium (Mg) deficiency symptoms on the leaves of tea plants grown in Hangzhou, Zhejiang, China, 2017.

The prize-winners will be announced during December 2020.

We look forward to seeing this year's entries.

Team IPI

We are pleased to announce a new Coordinator

IPI Coordinator for Europe: Dr. Francisco J. Morell

Dr. Francisco Morell has over 15 years' experience working in agronomy research, agriculture extension, and providing agronomic expertise to private companies. He has international experience in France, Portugal, Spain, UK and the US in field crops including barley, wheat, maize, and sunflower. He also has extensive experience with citrus cropping and irrigated field-crop farming systems in southern Europe.

Dr. Morell trained as a biologist from the University of Valencia, and an agricultural engineer from the Polytechnic University of Valencia. He completed his PhD at the Department of Crop and Forest Sciences, at the University of Lleida, Spain. His PhD thesis was supervised by Prof. C. Cantero-Martínez and was entitled "Soil organic carbon dynamics and carbon sequestration in a semi-arid Mediterranean agroecosystem: effects of conservation tillage and nitrogen fertilization".

During his postdoctoral experiences at the Department of Agronomy, at the University of Nebraska, and the National Institute for Agricultural Research (INRA) in France, Dr. Morell gained additional competencies in crop modelling, GIS and remote sensing.

Dr. Francisco Morell started as the Coordinator for IPI activities in Europe in January 2020, and is based in the Netherlands. His expertise is invaluable in the coordination of IPI's projects.

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Impressum *e-ifc*

ISSN 1662-2499 (Online); ISSN 1662-6656 (Print)

Publisher: International Potash Institute (IPI)

Editors: Amnon Bustan, Israel; WRENmedia, UK; Patrick Harvey, Green-Shoots, UK; Patricia Imas, IPI; Hillel Magen, IPI

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