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Optimizing Crop Nutrition

Editorial

Dear readers,

The United Nations has declared 2020 as the International Year of Plant Health (IYPH). The year is a once-in-a-lifetime opportunity to raise global awareness of how protecting plant health can help end hunger, reduce poverty, protect the environment, and boost economic development.

IPI is joining in this celebration. Why? Because potassium and balanced crop nutrition contributes hugely to plant health. Potassium not only increases yield and quality of agricultural produce, but also enhances the ability of plants to resist diseases; insect attacks; cold and drought stress; and other adverse conditions.

Potassium enhances plant growth, ensuring a healthy crop, free from stresses and much more resistant to attack from pests and diseases. Potassium promotes vigorous growth to help plants outgrow or escape damage, and also hastens early maturity, reducing the opportunity for disease establishment.

The role of K in crop resistance to diseases was extensively examined in an IPI review of 2,450 literature references. The results showed that adequate amounts of K decreased the incidence of fungal diseases by 70%; of bacterial diseases by 69%; of insect and mite damage by 63%; and of viruses by 41%.

In the current edition of the *e-ifc*, we explore different aspects of polyhalite: its salt index and solubility pattern in the field. We have a report from a field trial in Indonesia revealing the positive response of rice to polyhalite application. We share the progress of the first year of an important USAID funded project in Tanzania. Finally, two reports on IPI events in India (IPI-FAI Roundtable) and in China (IPI-CAU-ISSAS Symposium) are also included.

I wish you an enjoyable read and a very happy and fertile 2020!

Dr. Patricia Imas
IPI Scientific and Communications Coordinator

Photo cover page: Pomegranate experiment in Israel. Photo by N. Cohen Kadosh.

Research Findings

Polyhalite solubility field experiment. Photo by the authors.

Solubility of Granular Polyhalite under Laboratory and Field Conditions

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Abstract

The potential of polyhalite, a natural mineral consisting of K_2O, SO_3, MgO, and CaO at 14%, 48%, 6%, and 17%, respectively, to become a slow-release multi-nutrient fertilizer was the focus of the present study. Fertilizer solubility, and hence the potential availability of its various constituent minerals, was investigated in both a laboratory test and a field experiment. In the laboratory test, the potassium (K) and magnesium (Mg) salts were completely dissolved, while the calcium (Ca) salts displayed significantly limited solubility. In the field experiment, under repeated cycles of wetting that simulate successive rainfall events, all polyhalite constituents were between 75-100% dissolved following 300 mm of accumulating water application, in the order of K>Mg>S>Ca. Significant differences in solubility occurred with the rising amounts of water application up to 800 mm. While K and Mg displayed no or negligible residues, S dissolution was very gradual, and Ca residues remained constant. Supported by previous studies, the present study demonstrates that polyhalite dissolution in water takes longer and requires larger water volumes compared to other soluble fertilizers. This advantage reduces possible risks

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of damage due to over-fertilization and enables the application of polyhalite as a slow-release substance.

Keywords: Calcium; fertilizer; magnesium; polyhalite; potassium; sulfur.

Introduction

Polyhalite gained strong interest during the early 1930's as a potassium (K) fertilizer or a source of sulfate of potash (SOP) (Mansfield and Lang, 1929; Fraps, 1932). However, the interest vanished after the discovery of muriate of potash (MOP) in vast quantities, making the industry move completely to MOP (Lazenby, 2012). Since then, polyhalite has not been commercially available as a fertilizer, and consequently there is little recent published information about its performance as a fertilizer for crop production. In recent years, there have been three major reasons why the potassium fertilizer industry is shifting back, while polyhalite is emerging as a potential fertilizer source. First, the dramatic price increase of MOP has resulted in significant economic incentives for alternative K fertilizers. The second reason is the emerging need for sulfur (S) fertilization to optimize crop yield and quality (Khan *et al.*, 2005; Haneklaus *et al.*, 2008), a consequence of the prompt decline in atmospheric S concentration due to changing regulations to reduce industrial pollution (Kovar and Grant, 2011). The recent development of significant minable deposits of high quality polyhalite in the United Kingdom is the third. ICL Fertilizers currently mines polyhalite from a portion of the Zechstein deposits in the UK and is marketing polyhalite fertilizer under the product name Polysulphate® with a published analysis of 14% K_2O, 48% SO_3, 6% MgO, and 17% CaO (Imas, 2017).

Solubility is an important fertilizer property, and it varies considerably between fertilizers. Solubility affects nutrient release rates and therefore nutrient availability to plants, potential for losses due to leaching, runoff, and volatilization, and their use in liquid fertilizers. The solubility threshold of MOP, 344 g L^{-1}, is approximately three times greater than for SOP (120 g L^{-1}) (IPNI, 2010a, b). Barbarick (1991) stated that polyhalite was less water soluble than more conventional fertilizer sources. That study suggests that the behavior of nutrients after polyhalite was applied to soil may be different from its behaviour in water, although polyhalite nutrient release rates in soil are relatively unknown. Barbier *et al.* (2017) characterized a polyhalite fertilizer (POLY4, Sirius) in terms of total elemental content, solubility in water, salt index, and mobility in soil compared with other potassium based fertilizers.

Practical examinations of polyhalite in recent years have demonstrated significant advantages for a broad number of crops (PVFCCo, 2016a, b; Satisha and Ganeshamurthy, 2016; Tam *et al.*, 2016; Vale and Sério, 2017; Bernardi *et al.*, 2018; Melgar *et al.*, 2018; Tien *et al.*, 2018; Eryuce *et al.*, 2019). Nevertheless, there have been field observations that granules remain visible in the field for some time after application, raising doubts regarding nutrient availability following application of this fertilizer. The objective of the present study was therefore to characterize solubility under laboratory as well as field conditions, focusing on the different nutrients comprising this fertilizer.

Materials and methods

The work was divided into two stages: a laboratory observation and a field experiment.

Laboratory observation

Amounts of 9, 18 and 27 g of polyhalite were dissolved in beakers containing 1 liter of tap water, and stirred with a magnetic stirrer for 24 hours. Tap water, and not distilled water, was used as the field experiment also used tap water with similar qualities. The concentrations of Ca, Mg and K were measured in the solution.

Field experiment

In a field at the western Negev in Israel (sandy soil), 0.5 x 0.5 m agryl sheets were placed and fixed to the soil with hooks (Fig. 1). The sheets were covered with a layer (1-2 cm) of dry, sieved soil (<2 mm). A wooden 0.3 x 0.3 m frame was placed at the center of each sheet. Granular polyhalite was broadcast over the soil, within the outline of the wooden frame, at 9, 18 and 27 g sheet^{-1} (equivalent to 1,000, 2,000 and 3,000 kg ha^{-1}), respectively (Fig. 2). The wooden frame was removed after application.

Two soil samples (<2 mm) were taken for analysis, to assess soil Ca, Mg, K and S contribution, without polyhalite application.

A pre-installed sprinkler irrigation system applied water every five days at rates of 10 mm h^{-1}, 35 mm per application, including rainfall events. This irrigation scheme was adopted in order to avoid runoff. Rainfall was monitored in a nearby (200 m) standard

Fig. 1. Agryl sheet installation, and soil application, in the field experiment. *Source:* Authors.

Fig. 2. Polyhalite application onto the agryl sheet, within the wooden frame (A); polyhalite application rates of 9 (B), 18 (C), and 27 (D) g per frame, equivalent to 1,000, 2,000, and 3,000 kg ha^{-1}, respectively. *Source:* Authors.

meteorological station. Weed control was carried out regularly using herbicides.

Following about 300 mm of accumulated water application, one set (three polyhalite application levels in four replicates) of agryl sheets were collected. The soil + residual polyhalite from each sheet was dried, weighed and homogenized using a soil grinder. A 25 g sample of soil homogenate was mixed with 500 ml distilled water (soil:water ratio 1:20) and shaken for 24 hours. The suspension was filtered and the concentrations of Ca, Mg, K, and S were determined, followed by calculation of their residual amounts and, subsequently, percentage of the initial application. This procedure was repeated following each interval of 100 mm water application, up to 800 mm (six sampling events).

The reference soil samples were analyzed using the same methodology. The residual amounts of each element for each treatment were calculated, after subtracting the soil's contribution.

Statistical analysis

The field experiment was carried out in a randomized block design with four replicates. Each block comprised six replicates of three polyhalite application rates for the six accumulated water application rates. One-way ANOVA was practiced using JMP 13.0.

Results and discussion

Laboratory observations

The results of the laboratory observation are presented in Fig. 3, where the measured solubility values of Mg, Ca, and K were scattered against the assumed 100% hypothetic solubility of each element in polyhalite.

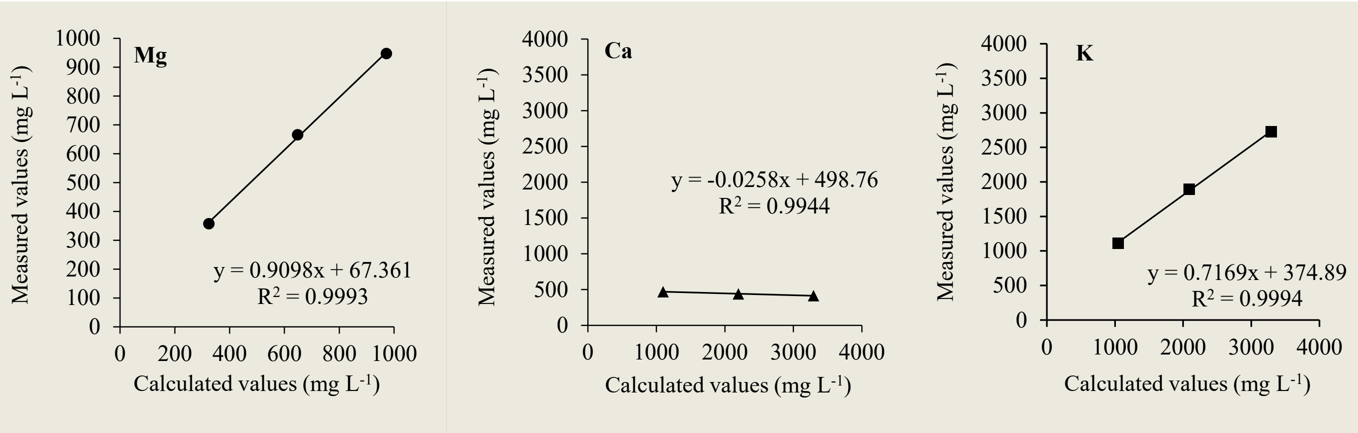

Fig. 3. Polyhalite's measured vs. expected (calculated) dissolution rates of Mg, Ca, and K in a laboratory observation. For a detailed description, please see the 'Materials and methods' section.

In agreement with earlier work (Barbarick, 1989), preliminary studies carried out within the framework of the CFPN in 2016 revealed a differential dissolution of polyhalite constituents. This differential dissolution was confirmed in the present laboratory test (Fig. 3). The Mg fraction of the fertilizer dissolved completely, even at the highest polyhalite concentration tested, 27 g L^{-1}. The K dissolved completely at the lowest fertilizer concentration (9 g L^{-1}), however the dissolution rate decreased with the rising concentration of polyhalite in the solution. Yet, most of the K in the fertilizer, about 72%, dissolved well. On the other hand, very little Ca dissolved at the lowest fertilizer application rate, and this decreased further from 470 to 415 mg L^{-1} with the rising polyhalite concentration (Fig. 3). The Ca in polyhalite is in fact comprised mostly of gypsum (22.6%), a low-solubility salt with a saturation threshold of 1.5 g L^{-1}. Mixing 9 g of polyhalite in one liter of water yields 2.03 g L^{-1} of $CaSO_4$ (gypsum), already above the maximum solubility threshold. Thus, adding more polyhalite to the solution will cause no further increase in Ca concentration, as it would immediately precipitate.

These results should be interpreted according to the methodology of the solubility test. In solubility tests where the draining water constantly removes the dissolved Ca, more Ca is dissolved from the polyhalite crystals. Still, the $CaSO_4$ dissolution rate is much slower than K_2SO_4 and $MgSO_4$, the saturation thresholds of which are two orders of magnitude higher at 351 and 120 g L^{-1}, respectively.

In accordance with our results, Barbier *et al.* (2017) found that solubility of natural polyhalite, when determined using the "simple solubility" method, showed a solubility range at 25°C of 11.9-17.3 g L^{-1} and a slightly higher solubility for calcined polyhalite, with a range of 18.3-21.8 g L^{-1}. It is worth mentioning that significant differences might emerge from differing methodologies. Nevertheless, all measurements show that the solubility of polyhalite is much lower than reported values for other K source fertilizers such as MOP and SOP (IPNI, 2010a, b).

Barbier *et al.* (2017) also concluded that while polyhalite has a lower solubility limit in water than other K source fertilizers, when it is applied at rates below its solubility limit, it should provide more than enough Ca, Mg, K and S for plant growth.

Field experiment

Mineral concentrations decreased with the increasing amounts of applied water (Fig. 4). For all polyhalite constituents, most of the dissolution occurred during the initial 300 mm of water application. For Ca, a residual value of about 20-25% was measured after the initial 300 mm application, followed by a much slower decline during the 300-800 mm water application. At the two lower polyhalite application levels (1,000 and 2,000 kg ha^{-1}), the percentage of residual Ca remained more or less constant at about 20%, regardless of the amount of water applied, whereas it decreased a bit further at the highest polyhalite dose (3,000 kg ha^{-1}) (Fig. 4). A significantly large portion of the Mg in the applied polyhalite, 94.5%, dissolved during the first 300 mm application of water. The residual Mg percentage remained more or less constant afterwards, regardless of the amount of applied water (Fig. 4).

The residual K was very close to zero after the application of 300 mm water at both upper polyhalite application rates, 2,000 and 3,000 kg ha^{-1}, and decreased slowly but consistently to the negative range as accumulated water increased (Fig. 4). At the lowest polyhalite rate (1,000 kg ha^{-1}), negative residual values were obtained even earlier, at 300 mm of applied water. Negative values provide a strong indication that the soil contributed K to the samples, elevating the recovery above the applied amount. Percentage of residual S reached 20-26% after application of 300 mm water, and decreased steadily

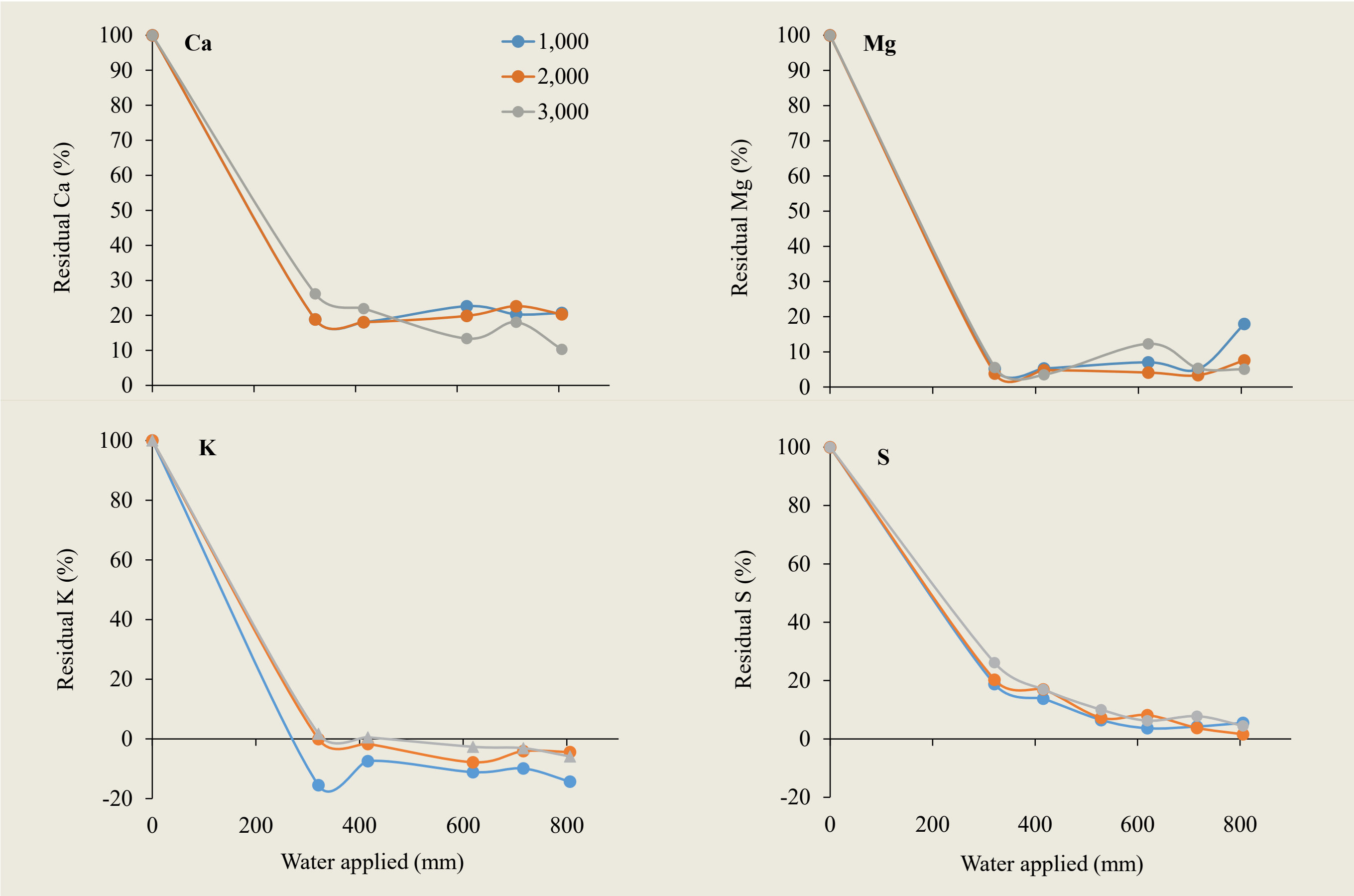

Fig. 4. Residual percentage of the polyhalite elements Ca, Mg, K, and S from the field experiment. Polyhalite was applied at rates equivalent to 1,000, 2,000, and 3,000 kg ha^{-1}. Measurements took place at accumulated water applications between 300 and 800 mm.

in all polyhalite treatments, reaching a value of 1.5-5.5% once 800 mm had been applied (Fig. 4).

The results of the field experiment are in agreement with the results of the laboratory observation, where most of the Ca, Mg, K, and S were released after 300 mm of accumulated water application, and the dissolution rate of Ca in polyhalite was slowest. The disintegration pattern of the polyhalite granule and its partial dissolution in the field trial are demonstrated in Fig. 5.

Nevertheless, due to the complex composition of polyhalite, there are plenty of potential chemical interactions with the solid and liquid soil phases, as well as with their interphase. Under field conditions, what occurs to the polyhalite constituents is determined by these interactions, not just by the solubility thresholds. A simplified qualitative demonstration of the complexity of the field experiment is shown in Table 1, with respect to each element in polyhalite.

It appears that the best indicator of polyhalite dissolution would be S. Sulfur concentration in the irrigation water is negligible, it is not adsorbed to the solid soil phase, and its soluble amount in the soil solution is very low, hence the major contribution of S is from polyhalite. As mentioned above, the low solubility of gypsum ($CaSO_4$), an integral component of polyhalite, might explain the relatively high S residue following water application of 300 mm (Fig. 4). Calcium, in contrast, interacts strongly with calcareous soils, in addition to adhesion to soil particles. Thus, Ca adhesion to the thin soil layer might explain the relatively high and constant Ca residues found, in spite of considerably high precipitation rates on the agryl sheets. In a similar way, but to a considerably lesser extent, the weaker Mg interactions would explain its significantly smaller but constant residue under the field conditions in the present study (Fig. 4).

Potassium, however, is the most important nutrient in polyhalite, and the most soluble one as well. On the other hand, K^+ cations interact with the soil's solid-liquid interphase, with significant dependence on soil texture (particle size) and pH. Furthermore, soluble K might be incorporated into certain clay particles on

Fig. 5. Polyhalite disintegration under field conditions at an application rate of 1,000 kg ha^{-1} following accumulated water application of 530 mm (left); and at 3,000 kg ha^{-1} following 400 mm of water (right). *Source:* Authors.

Table 1. Qualitative demonstration of the potential interactions between the soil and polyhalite constituents.

	Source				
Element	Irrigation water	$CaCO_3$	Adsorbed	Soluble	Polyhalite
Ca	+	++++	++	++	+++
Mg	-	++	++	++	+
K	-	-	+++	++	+++
S	-	-	-	+	++++

Note: - no interaction; + very weak interaction; ++ weak interaction; +++ medium interaction; ++++ strong interaction.

K-poor soils, and vice versa; it might emerge from soil particles to the liquid soil phase (Zörb *et al.*, 2014). In the present study, K residues from the agryl sheets diminished after accumulating only 300 mm of water (Fig. 4). This may indicate that the K fraction in polyhalite is dissolved quite easily and rapidly. However, in terms of rain or irrigation in semiarid regions, 300 mm of water when applied gradually (as done here), can suffice an entire cropping season. Therefore, the starting point and resolution of sampling in the present field experiment did not allow for adequate discernment of the polyhalite K performance.

The interactions of the various constituent minerals in polyhalite with the local soil determine the ratio between leaching and retention, and hence, beyond solubility, define nutrient availability to the crop (Barbier *et al.*, 2017).

Conclusions

An optimal fertilizer should display a solubility level that would accurately match nutrient availability with current crop requirements and, at the same time, retain sufficient nutrient residues for as many subsequent opportunities as possible (rainfall events or scheduled irrigations). Supported by previous studies (Barbarick, 1989; Barbier *et al.*, 2017), the present study demonstrated that polyhalite dissolution in water takes longer and requires larger volumes of water compared to other soluble fertilizers. This advantage reduces possible risks of damage due to over-fertilization and enables the application of polyhalite as a slow-release substance. Nevertheless, the slow-release impact would be largely dependent on interactions with the local soil properties and on soil wetting regimes.

Acknowledgements

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The paper "Solubility of Granular Polyhalite under Laboratory and Field Conditions" also appears on the IPI website.

Trial Focus

Photo 1. Bountiful tomato harvest, Tanzania. Photo by the authors.

Balanced Fertilization: A Boon for Tanzania's Vegetable Farmers

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Background

Fertilizer use is below recommended rates in most of sub-Saharan Africa, contributing to poor crop yields and poverty. Farmers in Tanzania have low levels of fertilizer use, hence low productivity. Tanzanian farmers apply only 10 kilograms of fertilizer per hectare, in contrast with Brazilian and Indian farmers, who apply 175 and 165 kilograms per hectare, respectively. In addition to the low fertilizer use, Tanzanian farmers mostly apply only N and P nutrients, while other essential nutrients like K, S, Ca, Mg and micronutrients are neglected. In this light, adoption of a balanced fertilizer approach can increase yields, profits, and improve living standards among farmers in Tanzania.

The Project

The first year of the USAID-funded project, Mboga Na Matunda ("fruits and vegetables"), which started in February of 2018, successfully came to an end in March 2019. The purpose of the work was to strengthen the fertilizer input supply system and increase the yields of smallholder horticulture farmers in the farming regions of Iringa and Mbeya in Tanzania. The

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objectives were to increase agro-dealers' knowledge of fertilizer products and smallholder farmers' access to affordable and quality fertilizer products; facilitate training on balanced fertilization and available fertilizer products; and enable the adoption of appropriate fertilization practices by farmers (especially women and youth). The target of the project was to reach 3,000 farmers by setting up 30 demonstration plots and to connect the farmers to a distribution network through local agro-dealers.

Demonstration plots

In order to achieve the project aims, lead farmers were identified in the target regions to establish demonstration plots of at least ¾ acre in size. Farmers with greenhouses were sought in particular to demonstrate how to incorporate fertilizer within their irrigation systems. A total of 30 demonstration plots (15 in Mbeya, 15 in Iringa) were established (see Fig. 1), producing tomatoes (17 plots), potatoes (5 plots) or onions (8 plots). Soil analyses were conducted at each demonstration site to guide the fertilizer regimens (products and quantities) used at the demonstration plots.

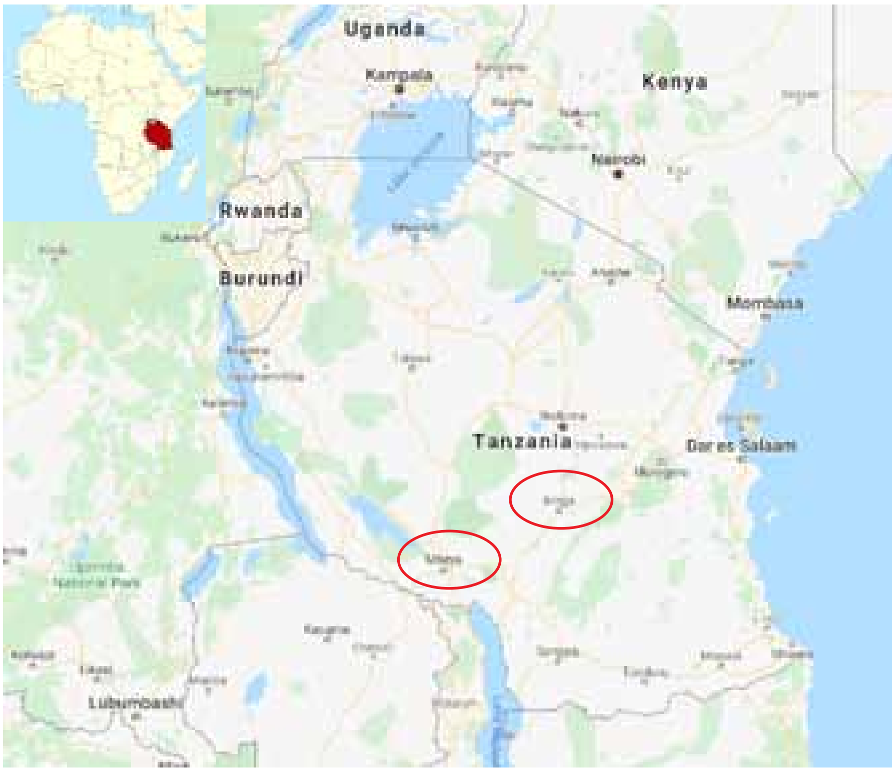

Fig. 1. Location of the 30 demonstration plots: 15 in Mbeya and 15 in Iringa regions in Tanzania. *Source:* Google maps.

Plots were divided into two sections, each 0.15 hectares in size. On one side, the farmers applied their normal fertilization regime (farmers' practice, FP), while on the other, ICL[1] fertilizers were applied based on an improved fertilization regime (improved fertilizer practice, IFP) as shown in Table 1. The fertilizer used in the IFP is a blend of controlled nitrogen which allows for farmers to apply all the basal fertilizer at planting with no topdressing needed. In comparison, the farmers practice includes one top-dressing fertilizer application for onions and potatoes and three top-dressings for tomatoes. For onions and potato, FP treatment included only N and P nutrients while IFP treatment included five nutrients (N, P, K, S and Mg). For tomato crop, FP treatment included N, P, Ca and B while IFP treatment included seven nutrients (N, P, K, S, Mg, Ca, B and Zn) (Table 2).

Table 1. Fertilizers applied to the demonstration plots (kg ha^{-1}) in the two treatments: Farmers' practice (FP) and improved fertilizer practice (IFP).

Treatment	DAP	CAN	Urea	Calcium nitrate + boron	Agromaster[1]	Polysulphate[2]
Application	Basal at planting	1st top dressing	2nd top dressing	3rd top dressing	Basal at planting	Basal at planting
	kg ha^{-1}					
	Onions and potatoes					
FP	125	125	0	0	0	0
IFP	0	0	0	0	275	0
	Tomatoes					
FP	125	125	60	60	0	0
IFP	0	0	0	0	275	60

[1]Agromaster is a compound fertilizer which combines controlled release nitrogen with other nutrients. In these plots, Agromaster 16:10:22 was used.
[2]Polysulphate: Natural multi-nutrient fertilizer containing 48% SO_3, 14% K_2O, 6% MgO and 17% CaO.

[1]ICL Fertilizers is one of the world's largest fertilizer companies. ICL provides farmers, growers and manufacturers with a range of plant nutrition solutions: potash, Polysulphate, phosphoric fertilizers, phosphoric acid, specialty fertilizers, phosphate rock and tailor-made compound fertilizers.

Table 2. Nutrients applied to the demonstration plots (kg ha^{-1}) in the two treatments: Farmers' practice (FP) and improved fertilizer practice (IFP).

Treatment	Nutrient application							
	N	P_2O_5	K_2O	MgO	SO_3	CaO	B	Zn
	kg ha^{-1}							
	Onions and potatoes							
FP	53.9	56.3	0	0	0	0	0	0
IFP	39.2	24.5	53.9	7.35	31.8	0	0	0
	Tomatoes							
FP	61.2	56.3	0	0	0	15.3	0.18	0
IFP	39.2	24.5	53.9	7.35	31.8	10.4	0.49	0.49

All other practices, such as weeding, crop protection and irrigation were standard across the two sections. All required inputs were provided by ICL for the full (0.30 hectares) plot and to ensure robustness of the experiment, the company monitored the activities on each plot closely from the onset (land preparation) to the conclusion (harvesting).

Results

From the results of the demonstration plots, the following observations were made:

a) The yields of the IFP treated plots for all three crops (onions, potatoes and tomatoes) were higher across all plots than those of the FP treatment (Figs. 2, 3 and 4). Increases in onion yield varied at the different farms from 29% up to 73%, for potato from 40% up to 88% and for tomato from 30% up to 82%.

b) Average yields of IFP treated plots were significantly higher than FP treatment for all three crops. The average increase in yields was 46% for tomatoes, 47% for onions and 57% for potatoes (Fig. 5).

c) The cost of inputs in the IFP treatment was higher than in the FP treatment, however, the return on investment (ROI) was higher at IFP as shown in Table 3. A calculation on the value:cost ratio (VCR) based on every extra US$1 spent on fertilizer showed that the farmer was getting US$6 more for onions and potatoes and US$11 more for tomatoes.

Training

Seven training sessions were provided at the inception of the project in order to sensitize farmers and create awareness about fertilizer products. Additionally, at least three training were held at each demonstration plot, which aimed to teach farmers basic crop nutrition methods and showcase the difference between an improved fertilization regime and more traditional practices by demonstrating the difference in crop growth and production level. The training were conducted during crop establishment and crop growth, and field days were held in each plot at the crop harvesting stage. A total of 3,375 farmers were trained.

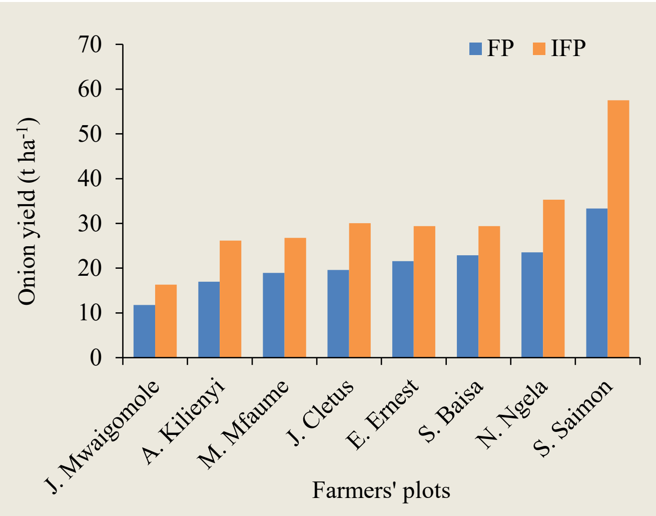

Fig. 2. Effect of the two treatments (farmers' practice (FP) and improved fertilizer practice (IFP)) on onion yield (t ha^{-1}) at eight demonstration plots.

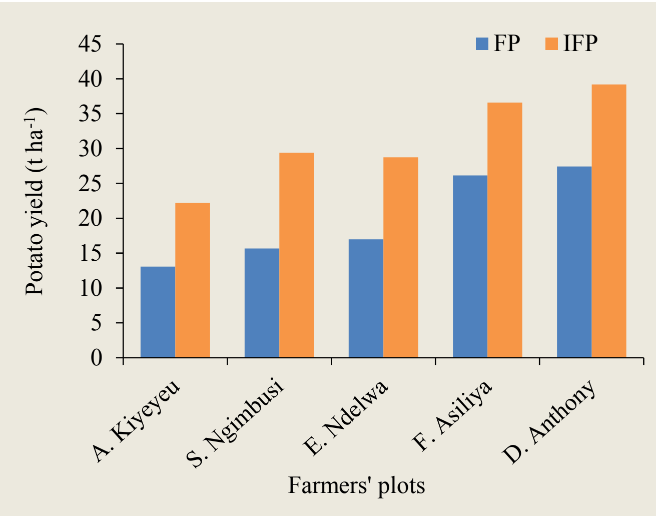

Fig. 3. Effect of the two treatments (farmers' practice (FP) and improved fertilizer practice (IFP)) on potato yield (t ha^{-1}) at five demonstration plots.

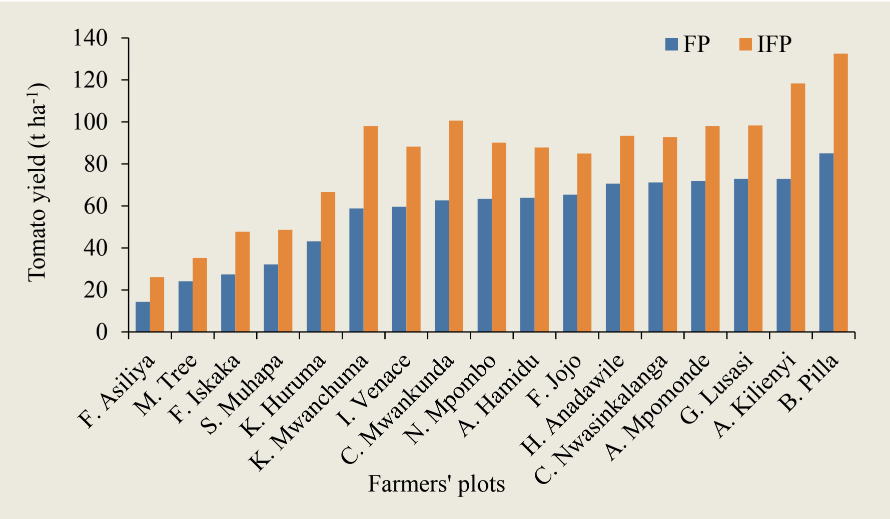

Fig. 4. Effect of the two treatments (farmers' practice (FP) and improved fertilizer practice (IFP)) on tomato yield (t ha^{-1}) at 17 demonstration plots.

Distribution channels

Under the project, 45 agro-dealers were identified and trained on the use of fertilizer products and fertilization techniques to increase their ability to recommend specific techniques and products for farmers. These training were conducted at the individual level for all identified agro-dealers and staff at their outlets and culminated in two joint training – one in Iringa and another one in Mbeya. These agro-dealers were linked with Tanzania Crop Care Ltd, a large fertilizer distributor, and a system was established by which these agro-dealers would receive products to promote in their respective areas.

Conclusions

The targets of the USAID-funded project were successfully met and farmers greatly benefited from the introduction and penetration of a balanced fertilization approach in Iringa and Mbeya, with significant increases in yields and profits.

Given the success of the project, USAID has decided to extend the funding for one more year – from July 2019 to August 2020.

Table 3. Economic calculations for three crops under each of the two treatments: Farmers' practice (FP) and improved fertilizer practice (IFP).

Crop	Fertilizer cost		Income		ROI		% ROI	VCR
	FP	IFP	FP	IFP	FP	IFP		
	USD ha^{-1}							
Onions	182	331	1,878	2,784	1,696	2,454	45	6
Potatoes	199	337	1,485	2,354	1,286	2,017	56	6
Tomatoes	206	387	4,506	6,582	4,301	6,194	44	11

Photo 2. Farmer examining his crop; Tanzania. Photo by the authors.

Photo 3. Farmers' training; Tanzania. Photo by the authors.

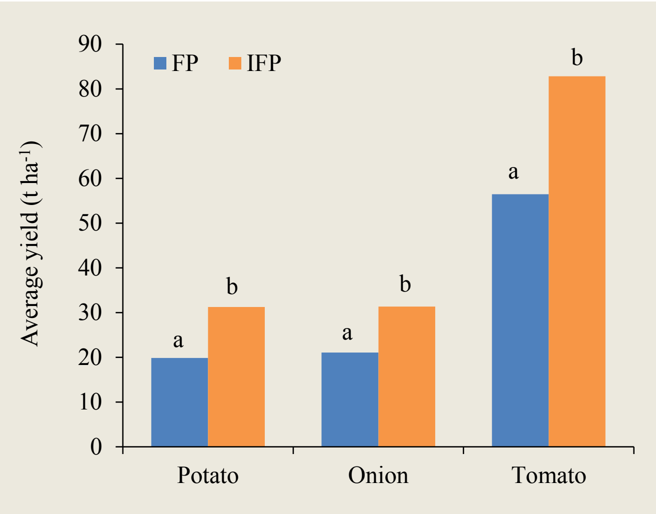

Fig. 5. Average yields of the three crops under the two treatments: Farmers' practice (FP) and improved fertilizer practice (IFP). Different letters above bars indicate significant differences among treatments ($p<0.05$).

Photo 4. Happy farmers after harvest; Tanzania. Photo by the authors.

Acknowledgement

The activities of this project were made possible through an award granted to ICL Fertilizers under Fintrac's contract with the US Agency for International Development (USAID) in Tanzania (#AID-621-C-17-00001), Feed the Future Tanzania – Mboga na Matunda.

The report "Balanced Fertilization: A Boon for Tanzania's Vegetable Farmers" also appears on the IPI website.

Trial Focus

Photo 1. Control plot on the left and polyhalite-treated plot on the right, showing the plant height difference; Karawang, Indonesia. Photo by L.P. Yeo.

Optimizing Rice Fertilization with Polyhalite in Karawang, Indonesia

Yeo, L.P.[(1)*], and P. Imas[(2)]

Introduction

Indonesia's 2019 rice production is forecast to reach 37.4 million tonnes, which would represent 8% of rice production globally and make Indonesia the third largest rice producer in the world (USDA, 2019). Rice is important as both an export crop and, as a staple food in Indonesia, a critical crop for food security (Panuju *et al.*, 2013). Milled rice consumption in Indonesia is around 127 kg per person per year. The Global Rice Science Partnership (GRiSP) forecasts that in 20 years' time Indonesia will require 38% more rice than today. To manage that, rice yields will need to significantly increase (GRiSP, 2013).

On a global scale, rice production and yields are increasing. One of the most important factors of this is optimized fertilizer use. Rice production accounted for 14.3% of the total applied fertilizers in agriculture during 2010-2011. In order to obtain high rice yields, fertilizer use must meet the nutrient requirements of the plant (Singh, 2017). In an effort to help Indonesia increase its rice yields through enhanced fertilization practices, this study

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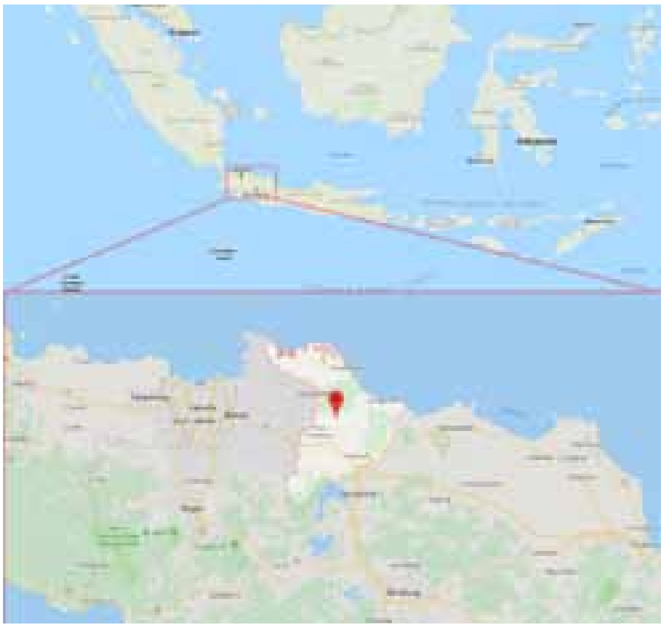

Fig. 1. Location of the polyhalite fertilizer study. The plot is marked with a red marker, and Karawang Regency in West Java province is outlined in red. *Source:* Google maps.

was conducted with the objective of evaluating the effects of polyhalite on paddy rice.

Materials and methods

The study was conducted in Karawang Regency, West Java province (Jawa Barat) in January 2018 (Fig. 1). Two varieties of paddy, Sertani and Kabir, were studied under polyhalite fertilizer treatment. Polyhalite is a natural mineral fertilizer containing four important plant nutrients: sulfur, magnesium, potassium and calcium (Tam Yermiahu *et al.*, 2017).

An unreplicated field trial was carried out on a 0.8 ha plot, with a control plot of the same size where the farmer's previous fertilizer regime was used. In the control plot, the farmer added 250 kg urea at transplanting and 500 kg NPK (15/15/15) at 10 and 30 days after transplanting. In the polyhalite-treated plots, 250 kg of urea was applied at transplanting and 150 kg of polyhalite was applied at 20 and 35 days after transplanting.

Results

Under the polyhalite treatment, the rice yield was 20% higher than for the control. Net weight (adjusted for the moisture content and thrashing) was 0.75 kg in the control and 0.90 kg in the polyhalite-treated plot. This translates to 7.5 and 9.0 t ha^{-1} for the control and polyhalite-treated plots, respectively.

Average rice yields of the Karawang area are 7.0-8.0 t ha^{-1}, so the yield results of both treatments are representative of the area. However, the polyhalite-treated paddy had bigger and stronger panicles compared to the control (Fig. 2). The grains were also rounder with a more uniform shape and better filling. Based on three samples containing 100 grains, the average weight of the grains was 9% higher in the plot treated with polyhalite (Fig. 3). In regards to the plant height, the polyhalite-treated rice was, on average, 8-10 cm higher than the control and appeared less affected by diseases (Photo 1, p. 15).

Fig. 2. Better grains filling and stronger panicle in polyhalite treated panicle compared to the control. Photo by L.P. Yeo.

Fig. 3. Weight of 100 grains in control and polyhalite treated rice. Note 9% higher grain weight in the polyhalite treated rice compared to the control. Photos by L.P. Yeo.

It was observed that plants in the polyhalite-treated plot were more resistant to lodging or damage caused by wind. Further, the farmer reported less blast disease (*Pyricularia oryzae*) and smut compared to the control plot. There was no identifiable difference between the two rice varieties Kabir and Sertani.

Discussion

The results from this field trial clearly demonstrate the effect of polyhalite and show that a combination of urea and polyhalite is more suitable than a combination of urea and NPK for paddy rice production. Polyhalite fertilization leads to a substantial yield increase, improved grain characteristics, and taller and healthier plants, indicating that it is a suitable fertilizer, containing essential rice nutrients.

But while this study shows a strong increase in yield and health of rice plants, it is not possible to evaluate the variability of the benefits obtained from polyhalite. The study was performed on a small scale with only three samples measured, making statistical analysis of the results unfeasible. More research on a larger scale needs to be carried out to further evaluate the reliability of this response, and to specifically test for additional benefits of polyhalite, such as increased disease resistance.

Conclusions

We conclude that a substantial 16% yield increase can be achieved by replacing NPK fertilizer with polyhalite in rice. Besides yield benefits, plants in the polyhalite-treated plot were taller, and appeared to be more resistance to disease, lodging and wind. Further research is needed to characterize the benefits and provide more detailed recommendations.

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Photo 2. Paddy producer (center) with the distributor (right) and an agronomist (left). Photo by L.P. Yeo.

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The report "Optimizing Rice Fertilization with Polyhalite in Karawang, Indonesia" also appears on the IPI website.

Trial Focus

Photo by N. Cohen Kadosh.

Salt Index (SI) of Polyhalite

Fried, R.[(1)*], E. Tsoglin[(1)], and P. Imas[(2)]

Abstract

Fertilizers applied pre-sowing or pre-planting at a full-season dose might cause salinity hazards to a young developing crop. The fertilizer salt index (SI) concept provides several methods to evaluate the risk of a given fertilizer to increase soil salinity and consequently cause osmotic stress. Polyhalite is a natural, organic, new emerging complementary fertilizer which contributes potassium (K), calcium (Ca), magnesium (Mg), and sulfur (S). Polyhalite is marketed under the trade name Polysulphate® (ICL, Israel). In the present study, we determined the SI of polyhalite, using two methods, to compare it with other commercial fertilizers (MOP, SOP, and SOPM) that donate some of the above listed nutrients. Although considerable differences occurred between the methods, polyhalite consistently obtained lower SI values, suggesting it is a safer product compared to MOP and SOP. The results are discussed and compared to previously published equivalent data.

Keywords: Gypsum; salt stress; solubility; plant nutrition.

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Introduction

Fertilizer application is a pre-requisite for productive sustainable farming. When properly practiced, fertilization should support a crop's nutrition demands and replenish the soil's mineral status with minimum influence on the environment. Virtually all fertilizer materials are salts; they dissolve in water, which conveys the nutrients through the soil matrix, and is the medium where they are accessible to plant roots. However, increasing salt concentrations above certain thresholds in the growth medium might cause serious adverse effects to the crop, generally addressed as salt stress. In order to avoid fertilizer-induced salinity problems, it is essential, therefore, to perceive the chemical nature of fertilizers in use not only as nutrient suppliers but also as salts, and to set rules and limits for reasonable application methods.

Salinity has two major impacts on plants: toxic and osmotic stresses (Munns and Tester, 2008). Toxic effects occur when the concentration of sodium (Na) or chloride (Cl) ions in the cytosol in leaf cells increases above a certain threshold, usually 150-200 µmol, damaging sensitive photosynthetic enzymes and structures. Various plant species activate compartmentation mechanisms, storing salt ions in vacuoles and organs, trying to avoid their poisonous influence. However, as these abilities differ greatly between crop species, a toxicity test seems useless to evaluate and compare a fertilizers' salinity effect. Furthermore, most fertilizers do not contain Na, while Cl-free fertilizers are gaining increasing appreciation.

In contrast, the osmotic component of salt stress has similar effects on all plant species. As concentrations of ions or soluble compounds in the liquid soil phase rise, the availability of water to plant roots declines. This phenomenon is expressed by the osmotic potential of the soil extract, the strength of which also depends on the chemical properties of the soluble compounds. Consequently, chemical fertilizers may significantly differ in their effect on soil's osmotic potential. Thus, in order to evaluate the osmotic effect of a particular fertilizer and to compare between various fertilizers, a salt index (SI) parameter was established as early as the 1940's (Rader *et al.*, 1943). SI expresses the proportion of the increase in osmotic pressure of the salt solution produced by a particular fertilizer to the osmotic pressure of the same weight of sodium nitrate ($NaNO_3$), which was selected as the standard to measure salt index (SI = 100) because it is completely water-soluble.

Nevertheless, the Rader method often appeared impractical and, furthermore, their SI tables could not include many fertilizers developed later. Jackson (1958) later published a much simpler laboratory method, where salt index of a fertilizer was measured by electrical conductance relative to sodium nitrate. Several laboratories have used this method to evaluate new materials. More recently, many references, such as the Crop Protection Handbook (CPH) and Western Fertilizer Handbook (WFH), have adopted and published SI tables based on calculations that make use of values from both methods (Mortvedt, 2001; A&L Great Lakes Labs, 2002). In a comparison between four methods, Murray and Clapp (2004) showed that SI values obtained for different potassium (K) fertilizers might differ significantly (Table 1) and hence, in evaluations of fertilizer SI, more than one approach should be considered. Barbier *et al.* (2017) also found considerable differences between laboratories determining SI values for the same fertilizer.

Table 1. Salt index (SI) values of K sources using the Rader and Jackson methods, and calculated according the Mortvedt method and reported in CPH and WFH.

K source	Method			
	Rader	Jackson	CPH	WFH
Potassium chloride (MOP) (KCl)	116.3	149.6	116.2	116.3
Sulphate of potash (SOP) (K_2SO_4)	46.1	111.2	42.6	46.1
Potassium nitrate (KNO_3)	73.6	97.6	69.5	73.6
Potassium-magnesium sulphate ($K_2SO_4 \cdot MgSO_4$)	43.2	64.8	43.4	43.4
Potassium thiosulphate ($K_2S_2O_3$)	-	63.2	68.0	64.0

Adopted from: Murray and Clapp, 2004.

Polyhalite is an emerging new fertilizer available under the tradename Polysulphate® (ICL). It comes from a sedimentary rock layer over 1,000 m below the North Sea off the North Yorkshire coast in the UK. Deposited 260 million years ago, it lies 150-170 m below the potash seam at the Cleveland Potash Boulby Mine. Polyhalite is available in its natural state; since no chemical processes are involved, it is a fully organic, sustainable fertilizer with a low environmental footprint. Polyhalite is comprised of 14% potassium oxide (K_2O) from sulphate of potash (K_2SO_4, SOP), 6% magnesium oxide (MgO) from magnesium sulphate ($MgSO_4$), 17% calcium oxide (CaO) from calcium sulphate ($CaSO_4$), and 48% as sulphate (SO_3).

As a complementary multi-nutrient fertilizer, polyhalite is applied before sowing or planting at a full-season dose. Therefore, the assessment of polyhalite SI is of great significance to potential utilizers. The objective of the present study was to determine and compare Polysulphate SI using two approaches: the direct Jackson and the CPH methods, thus providing the necessary information to farmers and stakeholders in agriculture.

Materials and methods

Analyses and measurements took place at IMI TAMI Institute for Research & Development at Haifa, Israel. Several fertilizers, donors of K, S, Mg or Ca, were selected and analyzed in order to compare their SI with that of standard and granular Polysulphate, as follows: MOP (KCl); gypsum ($CaSO_4$); SOP (K_2SO_4); magnesium sulphate ($MgSO_4$); Kieserite® ($MgSO_4 \cdot H_2O$); K-Mag® ($K_2SO_4 \cdot MgSO_4$); Patentkali® ($K_2SO_4 \cdot MgSO_4$); and potassium nitrate (KNO_3). Two different methods were employed to determine each fertilizer's SI – Jackson (1958), and CPH.

For the Jackson method, 1 g of the tested fertilizer was dissolved in 400 ml deionized water at 20°C contained in a 500 ml volumetric flask by stirring vigorously for 15 minutes until complete dissolution. The electrical conductivity (EC) of the solution was measured using an Accumet AR60 multi-parameter meter (Thermo Fisher Scientific, Waltham, MA). Sodium nitrate (reagent grade $NaNO_3$) served as the standard. The salt index (SI) was calculated using the equation:

$$SI = (\text{EC of fertilizer solution} / \text{EC of } NaNO_3) \times 100$$

Additional data on salt index for polyhalite and other potassium fertilizers were obtained from other sources, as cited by Barbier *et al.* (2017). In all cases the Jackson method was used to determine the salt index, although there was likely some variation in the method among laboratories.

The SI of a mixed fertilizer (NPKS) is the sum of the SI of each component per unit of plant nutrient multiplied by the number of units in that component. SI calculation using this method, which was adopted by CPH and WFH, is described in detail in Mortvedt (2001), and demonstrated here in Table 2 for polyhalite, using data extracted from A&L Great Lakes Laboratories (2002).

Results

The theoretic calculation of polyhalite SI yielded the value 32.3 (Table 2), significantly lower than the standard 100 of $NaNO_3$. Interestingly, the smaller polyhalite component, $MgSO_4$, had the highest partial contribution to the total SI, while $CaSO_4$ (actually, gypsum), gave rise to the lowest contribution (Table 2).

Nevertheless, there were huge differences between the theoretic calculation and the Jackson method, the latter being consistently far higher (Table 3). The differences between fertilizers within each method, however, were consistent. Among the K-donor fertilizers, SI values decreased in the order of:

MOP>SOP>Patentkali>potassium nitrate
>Polysulphate (standard)>Polysulphate (granular)>K-Mag.

Among the Mg-donor fertilizers, SI varied considerably. Patentkali and K-Mag, both comprised of $K_2SO_4 \cdot MgSO_4$ in different formulations, were at the higher and lower end of the SI scale, respectively, while Kieserite obtained the lowest SI value (Table 3). Within the same group, Polysulphate (standard), together with magnesium sulphate ($MgSO_4$), had intermediate SI values while granular Polysulphate displayed a lower SI (Table 3).

Gypsum showed the lowest SI value among the small group of Ca-donor fertilizers in the study, whereas Polysulphate had higher SI values in both forms. The SI values for S-donor fertilizers decreased as follows:

SOP>PatentKali>$MgSO_4$>Polysulphate (standard)
>Polysulphate (granular)>gypsum>K-Mag>Keiserite
(Table 3).

Overall, MOP displayed the highest SI values, SOP was the second highest, and Polysulphate obtained intermediate SI values, with the granular grade exhibiting a considerably lower SI according to the Jackson method (Table 3).

Discussion

In a world where human populations continue to grow and food demand consistently increases, it is important to farm as efficiently and sustainably as possible. The efficiency of crop production is measured as the ratio between the output (yield) and inputs (land, water, fertilizer, etc.). The sustainability of crop production systems is measured through their long-term ability to maintain stable soil fertility with minimal environmental side effects. Fertilizer application management can be a powerful tool to achieve both goals. Ideally, nutrient availability in the rhizosphere should match the dynamic crop requirements during

Table 2. Calculation of polyhalite SI according to the Mortvedt method (2001) adopted by CPH (using data extracted from A&L Great Lakes Laboratories (2002)).

Polyhalite component	Typical analysis	Partial salt index	Per tonne	N	P_2O_5	K_2O	CaO	MgO	SO_3	Salt index
			-----*kg*-----				-%			
K_2SO_4	K_2O-50%, SO_3-45%	0.852	280	-	-	14.0	-	-	12.6	11.93
$MgSO_4$	MgO-32%, SO_3-65%	2.687	187.5	-	-	-	-	6.0	12.2	16.12
$CaSO_4$	CaO-32%, SO_3-42.5%	0.247	531.25	-	-	-	17.1	-	22.6	4.23
Residues			1.25							
Total	Calculated formula		1,000	0	0	14.0	17.1	6.0	47.4	32.28

the growing season, along with the replenishment of soil nutrients, while avoiding surplus fertilizer application and soil pollution.

Nevertheless, crop production systems are extremely complex, which significantly challenges any attempts to achieve this ideal situation. Controlled fertigation is the approach that apparently performs closest to that optimum range; however, this technology is highly sophisticated and expensive, and hence beyond the reach of most of the world's farming systems. In fact, the opposite approach, delivering the complete seasons dose of fertilizer before the crop is sown or planted, is the dominant method worldwide. This way, the chemical characteristics of a given fertilizer, and particularly its interactions with the solid and liquid soil phases and with the crop species, largely determine its performance.

Fertilizer solubility in water is crucial; very low solubility might restrict nutrient availability to the developing crop, with consequent poor yields. On the other hand, a too rapid dissolution rate might convey the complete seasons fertilizer dose into the liquid soil phase too early. On well-drained soils, most of the nutrient dose is prone to diminish, leached below and away from the rhizosphere, leaving a very narrow opportunity for nutrient uptake by the crop. On slow-draining soils, excessive ion concentrations in the liquid soil phase adjacent to the plant roots might cause severe salinity problems, especially at the relatively sensitive stage of plant emergence.

Polyhalite is a new multi-nutrient organic fertilizer, which complements regular NPK fertilizers, enriching the soil with Ca, Mg, and S, and with additional K. Practically, polyhalite is applied in considerable doses pre-planting or pre-sowing. Consequently, estimations of any risks of salt stress or damage were required, and hence, the SI of polyhalite was calculated, as well as directly measured, in the present study. Several methods have been developed since SI was established 80 years ago (Rader *et al.*, 1943). Although the principal idea of SI is common and shared among all methods, technical motives have led to significantly different results. Murray and Clapp (2004), and more recently, Barbier *et al.*, (2017), as well as in the present study (Table 3), demonstrated these differences very clearly. A major lesson is, therefore, to ensure use of a single method when comparing the SI values of different fertilizers.

The Mortvedt (2001) method seems very useful for sorting the components of complex fertilizers in order to identify those with significant contribution to the fertilizer's SI. In polyhalite, $MgSO_4$ theoretically furthers the fertilizer's SI, being responsible for about 50% of the total SI, much beyond its relative fraction on a weight basis (18.7%). Conversely gypsum ($CaSO_4$), 53% of polyhalite's mass, contributes only 12.5% of its SI (Table 2). Nevertheless, the CPH calculation method for SI relates a fertilizer as a mixture of salts, with no chemical interactions among them. In contrast, polyhalite represents a crystalline structure rather than a simple salt mixture, and hence, the SI calculation method is less suitable for this fertilizer.

The Jackson (1958) method directly measures SI through the electrical conductivity (EC) of the solution after a complete visible dissolution of the fertilizer has been reached under standard conditions. This method is easily accessible for most users and, therefore, has become very popular, despite the high SI values it produces when compared to other methods (Table 1). It appears, however, that the Jackson method is very sensitive to slight differences in the formulation between apparently similar fertilizers. For example, two $K_2SO_4{\cdot}MgSO_4$ fertilizers gave rise to substantially differing SI values (Table 3). Similarly, a large difference in SI was observed between $MgSO_4$ and $MgSO_4{\cdot}H_2O$ (Table 3). These results, as well as differences between standard and granular Polysulphate, suggest that fertilizers' solubility might be significantly affected by particle size distribution, coating materials and thickness, and other factors influencing the kinetics of the process. This may provide an explanation for the relatively low SI value of gypsum, which possesses naturally low solubility rates but may support supersaturated solutions under certain conditions (Lebedev and Kosorukov, 2015).

Polysulphate displayed intermediate SI values (Table 3) that can be attributed to the dominant portion of gypsum in the fertilizer. This is a significant advantage of Polysulphate over common starter K-donor fertilizers such as MOP, SOP, and even KNO_3, lessening risks of salinity during the sensitive initial stage of many crops (Havlin *et al.*, 1999). Some of the fertilizers tested had similar or much lower SI values than Polysulphate; nevertheless, they also supply fewer nutrients than Polysulphate. Gypsum

Table 3. Salt indices for different fertilizers (K, Mg, Ca or S donors), as determined by calculation (Mortvedt, 2001) and the Jackson (1958) methods at IMI TAMI R&D Institute, Haifa, Israel.

Fertilizer	SI method	
	CPH	Jackson
Polysulphate® (standard)	32.3	73
Polysulphate® (granular)	32.3	52
Potassium chloride (MOP) (KCl)	116.2	138
Gypsum ($CaSO_4$)	8.1	42
Sulphate of potash (SOP) (K_2SO_4)	42.6	100
Magnesium sulphate ($MgSO_4$)	44.0	76
Kieserite® (granular) ($MgSO_4{\cdot}H_2O$)	-	24.2
K-Mag® (granular) ($K_2SO_4{\cdot}MgSO_4$)	-	26.6
Patentkali® (granular) ($K_2SO_4{\cdot}MgSO_4$)	-	91.5
Potassium nitrate (KNO_3)	69.5	85

Table 4. Salt index (SI) values for four fertilizers: MOP (KCl), SOP (K_2SO_4), SOPM ($K_2SO_4{\cdot}MgSO_4$), and polyhalite in standard and granular forms. Comparing present study's SI values for Polysulphate with SI values determined by several laboratories using the Jackson (1958) method and published by Barbier *et al.* (2017).

Laboratory	Fertilizer				
	MOP	SOP	SOPM	Polyhalite	
				Standard (<200 µm)	Granular
Thornton Labs., Tampa, FL, USA	115	96	85	70	58
Spectrum Analytic Inc., Ohio, MI, USA	110	42	67	62	62
Southern Environmental Testing, Florence, AL, USA	141	109	104	96	96
Midwest Labs. Inc., Omaha, NE, USA	132	114	-	73	77
Shandong Agricultural University, Tai'an, China	136	100	97	92	-
Pavinato Labs., Piracicaba, Brazil	137	-	-	-	63
Barbier *et al.*, 2017	128	103	49	69	-
IMI TAMI R&D Institute Ltd, Haifa, Israel	138	100	92	73	52
Mean	130	95	82	76	68
± SD	11	24	21	13	16

donates Ca and S but not K or Mg; others provide Mg and S, and some also K but not Ca (Table 3).

The rising interest in polyhalite has promoted several commercial laboratories and research institutes worldwide to carry out comparative examinations of this fertilizer against MOP, SOP, and SOPM ($K_2SO_4{\cdot}MgSO_4$); their results are brought together by Barbier *et al.* (2017). In Table 4, we expand this comparison and include results regarding POLY4 (Barbier *et al.*, 2017) and Polysulphate (present study). Table 4 confirms our findings from Table 3; among the tested fertilizers, polyhalite clearly obtained the lowest SI values. As expected, MOP consistently displayed the highest SI, followed by SOP. Here also, there was a considerable variability among SOPM SI, indicating inconsistent methodologies, or a significant influence of the fertilizers' formulation (e.g., particle size distribution and solubilization kinetics). Furthermore, SI of granular polyhalite tended to be lower than that of standard polyhalite. These results strengthen the indication that the chemical composition is not the sole factor determining SI, as may have been postulated by the calculation methods. The packaging of the fertilizer, namely, particle size and shape, has considerable influences on its SI value, possibly by affecting solubility.

In conclusion, polyhalite exhibits low SI values compared to most common and equivalent starter fertilizers. Thus, polyhalite provides a broad number of complementary nutrients with a relatively safer application. It should be emphasized, however, that the SI value covers only the osmotic vector of the salinity effects on plants, while the toxic component is, as yet, difficult to evaluate (Murray and Clapp, 2004). Being almost chloride-free, and thus avoiding risks of chloride accumulation and hazardous impacts on young developing crops, polyhalite shows a clear additional advantage.

Acknowledgements

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The report "Salt Index (SI) of Polyhalite" also appears on the IPI website.

Events

July 2019

Photo 1. Dr. S.K. Malhotra (3rd from left), chief guest, addressing the delegates at the inaugural function. Photo by FAI.

FAI-IPI Roundtable
Potassium in Balanced Fertilization - Emerging Issues

The Fertiliser Association of India (FAI) and the International Potash Institute (IPI) jointly organized a roundtable discussion, Potassium in Balanced Fertilization – Emerging Issues, on 10 July 2019 at the FAI House, New Delhi. Dr. S.K. Malhotra, Agriculture Commissioner of the Department of Agriculture Cooperation & Farmers Welfare (MOA&FW), was the chief guest at the inaugural ceremony, presided over by Mr. Hillel Magen, Director of IPI in Switzerland. Forty delegates representing ICAR, IARI, PRII, MOA&FW, IPI and FAI participated in the roundtable.

In his welcome address, Dr. S. Nand, Deputy Director General of FAI, mentioned that the crop uptake of potassium (K) far exceeded its replenishment. According to FAI estimates, there exists an annual negative balance of 8.6 million tonnes between K uptake by crops and its addition through fertilizers. The problem is compounded further by India's total dependence on imports to meet K demands.

Dr. Nand stated that the selective implementation of the nutrient-based subsidy (NBS) scheme in 2010 caused a major distortion in prices of phosphorus (P) and K, vis-à-vis urea. The MRP of MOP, which was roughly equal to urea before the NBS scheme, is now 3.5 times higher than urea. This increase has affected its consumption and distorted the NPK use ratio. He informed guests that the government has taken steps, such as a switch over to neem-coated urea in 45 kg bags as opposed to 50 kg to rationalize the use of urea. However, this has not increased K use as price is the overriding factor in consumption.

Dr. Nand emphasized the importance of subsidies to promote the balanced use of fertilizers. He said that a diversification of crops is needed to improve soil health and farmers' income, but that local economics do not support this. He added that increased extension efforts are needed to improve farmers' awareness on fertilizer best management practices.

Excerpt from Indian Journal of Fertilisers 15(8):908-911 with permission from FAI, India
Contact: Dr. Adi Perelman, IPI Coordinator for India; adi.perelman@icl-group.com.

Photo 2. At the inaugural session, seen in the picture (L-R) are Mr. Hillel Magen, Dr. S. Nand, Dr. S.K. Malhotra and Dr. R.K. Tewatia. Photo by FAI.

Mr. Magen also gave an address in which he explained that this roundtable was the 7th of its series. He went on to describe the main objective of the roundtable in bringing together key stakeholders to exchange views and look for solutions related to K use. He pointed out that environmental issues have added a new dimension to discussions, as food security and environmental stewardship should always go together.

According to Mr. Magen, nitrogen (N) use efficiency is the biggest management end product. There is also a need to re-examine other minerals including polyhalite and other new products as K sources. Expressing optimism at the polymer coating technology, Mr. Magen stated that it reduces leaching of N and K. Mr. Magen expected that the roundtable would discuss best use of this technology and other new innovations to get the best economic returns.

Dr. Malhotra, in his inaugural address, mentioned that a target of 291 million tonnes of food grain production has been set for the year 2019-20, which is a 6 million tonnes increase on that attained in the previous year. In regards to the country's agriculture situation, Dr. Malhotra stated that India is comfortable on the food production front, but is lagging behind in oilseeds, importing 14.5 million tonnes of edible oil last year. He informed delegates that special efforts are being made to increase oilseed production under the National Mission on Edible Oils.

Dr. Malhotra stated that without fertilizers, it is not possible to harvest the full potential of other inputs. The balanced use of nutrients including K can break the yield barriers. K deficiency in Indian soils has been on the rise due to K removal far-exceeding its addition. He stressed that correcting K deficiency and enhancing use efficiency should constitute core topics of the discussions, and emphasized the need to look for region-based solutions, considering wide variations in soils, crops and K use patterns.

The roundtable discussion had three technical sessions; the first was chaired by Mr. Magen. Four papers were presented in this session. The second technical session was chaired by Dr. A.K. Patra, Director, ICAR-Indian Institute of Soil Science, Bhopal. Three papers were presented in the session. In technical session three, a panel discussion was held on bridging research, extension and policy gaps to promote use of K, chaired by Dr. P.S. Gahlaut, Managing Director, Indian Potash Ltd., New Delhi. Brief presentations were made by the four panelists.

In summing up the panel discussion, Dr. Gahlaut explained that field trials conducted in India and abroad have established that crop response to K is better under split application compared to basal application. He expressed that awareness among farmers about balanced plant nutrition is poor, largely due to a lack of coordination among scientists, state departments of agriculture and farmers.

Mr. Satish Chander, Director General, FAI, mentioned that the extension machinery of state governments has not been fulfilling its task. Extension efforts by the private sector are also not meeting demand. He underlined the need to re-build extension mechanisms for the rapid transfer of improved farm technologies to farmers.

In his concluding address, Dr. Gahlaut explained that fertilizer-based food security has led to an excess production of wheat. Similarly, the country is facing a glut of sugar due to excess production of sugarcane. Neither has improved farmers' income due to suppressed prices. The solution lies in agri-exports but agri-exports are not competitive. He informed delegates that Brazil produces sugar and exports it at Rs. 22 per kg. It also produces the cheapest corn and soybean.

Dr. Gahlaut highlighted a genuine need to subsidize agri-inputs and exports, but recognized that reducing the cost of crop production continues to be a major challenge. He mentioned the important role of potash in improving N use efficiency, and the need to promote K as an eco-friendly nutrient in combating water stress and reducing the incidences of pest and diseases. He added that the fertilizer industry should come forward to fund research in these areas.

Other important conclusions and recommendations that emerged from the discussions are:

Conclusions

1. K is the third most limiting nutrient. Sixty-two percent of Indian soils are deficient in available K. K soil deficiencies have been on the rise as its removal by crops far-exceeds its addition through fertilizers and other sources.
2. Irrespective of soil mineralogy, continuous cropping with K omission has invariably led to a decline in soil K pools. The release of K from non-exchangeable sources increases the K fixing capacity of soil, eventually requiring astronomically high doses of K application.
3. Indian soils are currently operating at an annual net negative balance of 8.6 million tonnes of K. Apparent K balances are mostly negative across all soil types and cropping systems.
4. A decreasing trend in K application has been witnessed in the current decade due largely to the selective implementation of the NBS scheme for P&K fertilizers w.e.f. 1.4.2010.
5. Current K consumption at 14.3 kg ha^{-1} $year^{-1}$ is very low. There exist wide zone-wise, state-wise and crop-wise variations. The adoption of soil test-based K recommendations at farmers' fields is virtually non-existent.
6. Farmers tend to overlook the benefits of K application as its effect is visible only in the later stages of growth or around maturity of the crop – in the form of improved produce quality.
7. Availability/price distortion and limited promotion of potash-carrying complexes, particularly in North India, have adversely affected growth in K consumption.
8. Research on water soluble fertilizers is being done by precision farming development centers at various universities but it is still inadequate.
9. Farmers have either limited or no access to scientific information for making micro-irrigation (drip) and fertigation decisions. Weather conditions like clouds and rainfall have a major influence on the duration of drip system operations, and hence nutrient supply to the crops.
10. Organic recycling through the application of crop residues, byproducts or manures and compost application may substantially supplement crop K needs.

Recommendations

1. The fertilizer pricing policy needs to be amended to bring parity to the costs of primary nutrients to help ensure balanced fertilization.
2. There is a need to highlight the role of K in improving N use efficiency and its promotion as an eco-friendly nutrient, essential for combating biotic and abiotic stresses and improving quality of economic produce.
3. Development and/or standardization of soil test methods like NaTPB capable of extracting interlayer K through short and medium-term field experiments, constitutes a priority area of research.
4. There is a need to revisit and revise the critical limits of K in vertisols and acid alfisols. Soil test-based K recommendations should be refined for pre-determined specific yield targets.
5. There is a need to re-define/re-work the optimum NPK use ratio for the all the 126 NARP zones.
6. The fertilizer product resource base should be expanded by exploring and promoting other K minerals like polyhalite, gluconite, etc. The use of non-conventional sources of K such as organic manures of plant, animal and agro industrial origin; bagasse ash; incinerated spent wash ash; fly ash; schoenite, etc., should be encouraged to supplement demand and reduce soil mining of potash.
7. The development and use of K nano-fertilizer by farmers should be encouraged for effective and precise nutrient management.
8. Better coordination among all key stakeholders is needed to promote K use in Indian agriculture. Scientists and fertilizer companies should make joint research and development efforts to reduce K deficiency and enhance use efficiency of applied K.

Photo 3. At the concluding session, seen in the picture (L-R) are Mr. Hillel Magen, Mr. Satish Chander, Dr. P.S. Gahlaut, and Dr. R.K. Tewatia. Photo by FAI.

The report "FAI-IPI Roundtable - Potassium in Balanced Fertilization - Emerging Issues" also appears on the IPI website.

Events

November 2019

Photo 1. Opening Session of the Symposium. Photo by IPI.

Symposium Review: 13th IPI-CAU-ISSAS International Symposium in Kunming, China 6-8 November 2019

Background

Fertilizer use and uptake by crops can, in many instances, be improved. There is growing international concern about the cost – economic and environmental – of less-than-balanced and imprecise fertilizer strategies. But what scientific evidence is there to use to emphasize and explain the benefits of balanced fertilizer strategies? This was the context and question for the recent major fertilizer scientific conference in China that brought together agri-professionals from around the world to hear and discuss optimized fertilizer strategies for sustainable farming.

The theme "Potash and Polyhalite: Potassium, Sulfur, Magnesium and Calcium for Efficient Balanced Plant Nutrition" was chosen for the 13th International Symposium, organized by the International Potash Institute (IPI) together with Chinese Agricultural University (CAU) and the Institute of Soil Science of Chinese Academy of Sciences (ISSAS). The National Agro-Tech Extension and Service Center (NATESC), China Inorganic Salts Industry Association (CISIA) and Yunnan Agricultural University were co-organizers of the three-day event in Kunming, China, 6-8 November 2019.

More than 300 professionals – including researchers, students, farmer advisors and fertilizer retailers, from China and many other parts of the world – gathered for three days to learn, discuss and share fertilizer best practice.

Connecting to core secondary nutrient evidence

Speakers from around the world stressed the same message: sulfur (S), magnesium (Mg) and calcium (Ca) nutrient deficiencies are increasingly becoming an important limiting factor in intensive crop production systems. The depletion of these key nutrients in soils was flagged up as a growing concern.

Evidence was presented from research into the benefits of balanced plant nutrition with secondary nutrients in China and other countries including Brazil, India, USA, Switzerland, Israel and UK. The conference participants agreed that evidence, from painstaking research and observations, is essential for inspiring

Excerpt from Fertilizer Focus 37(1):68-71 Jan-Feb 2020, published with permission
Contact: Dr. Patricia Imas, IPI Scientific and Communications Coordinator;
patricia.imas@icl-group.com

Photo 2. Mr. Hillel Magen, IPI Director, giving his opening remarks at the symposium. Photo by IPI.

Photo 3. More than 300 professionals invested three days to learn, discuss and share in the symposium. Photo by IPI.

and developing better fertilizer strategies in China and beyond.

Philip White (The James Hutton Institute, UK) presented the role of Ca in plant nutrition, while Jiwan Palta (University of Wisconsin, USA) went deeper in illustrating the role of Ca for potato and its importance in skin quality. The crucial functions of sulfur were presented by Surinder K. Bansal (Potash Research Institute of India, India). Magnesium's role was explained by Chunjian Li (China Agricultural University).

Matching crop needs

An efficient solution to the need for S, Mg and Ca in agriculture was presented at the Symposium: polyhalite, the new multi-nutrient and natural fertilizer from the first and only polyhalite mine in the world (marketed as Polysulphate®).

Farmer and fertilizer manufacturer demand globally for polyhalite continues to increase. In the month of the Symposium the ICL Boulby mine, in the UK, hoisted and processed a record-breaking 75,000 t of polyhalite for delivery to farmers on four continents. Production is reported to be on track to reach the target output of 1 Mt in 2020 and 3 Mt y^{-1} by 2030 to supply multi-nutrient polyhalite.

Polyhalite has a gradual nutrient release pattern that steadily delivers S, Mg, K, and Ca, reducing the risk of leaching. Different experimental results presented during the symposium showed the positive effect of polyhalite on crop growth, yield and quality worldwide.

A world of experience brought together

Listening to the symposium speakers was a globe-trotting experience. Kang Ni (Tea Research Institute, China) presented their work on improved tea quality following polyhalite application. Michael Castellano (Iowa State University, USA) summarized polyhalite trials with corn and soybean in USA. Polyhalite fertilizer management was explained for potatoes in Inner Mongolia by Mingshou Fan (Inner Mongolia Agricultural University, Hohhot, China); for pastures in Brazil by Alberto Bernardi (Embrapa); for greenhouse tomatoes by Mollie Sacks (Israel Ministry of Agriculture, Extension Service), and for soybean in Brazil by Fabio Vale (IPI Coordinator for Latin America). Patricia Imas (IPI Scientific and Communications Coordinator) presented polyhalite in the context of potash fertilizers: a new K fertilizer with additional three nutrients.

From Vietnam, an update on research with polyhalite in a range of crops including pasture, coffee and groundnut was presented by Toan Tran Duc (Soils and Fertilizers Research Institute, Vietnam). However, according to Mr. Duc, presenting was not preventing learning from others too. "I have learned a lot from presentations about the effect of polyhalite on crops.", he said at the end of the session. "Vietnam, as a country, is still poor, but we really desire to have a progression on agricultural technologies, to not only increase crop yields but also product quality. Using polyhalite is one of the promising solutions".

Strength in numbers: multinational evidence of benefits of polyhalite

The conference heard examples from four continents of the benefits of polyhalite:

- **From Brazil** – IPI experiment in Tocantins state presented a 12.7% yield increase in soybean yield due to polyhalite application as compared to potassium chloride. Another experiment in alfalfa showed the positive effect of polyhalite on nutritive value for livestock: polyhalite decreased lignin by 11%, while increasing protein by 4%.

- **From China** – an IPI experiment on potato showed 21% increase in yield with polyhalite as compared with potassium sulfate in Inner Mongolia. In Guandong province, 16% more yield was obtained with polyhalite application to wax gourd as compared with the farmers' practice. Polyhalite was also shown to be an effective source of magnesium for pepper, showing a 19% increase in yield as compared with no Mg application.
- **From India** – polyhalite enhanced lycopene and ascorbic acid contents in tomato by 31% and 21% respectively, as compared with farmers' practice. In onion, polyhalite application increased yield by 38% while also increasing the quality as measured by enhanced protein content and higher TSS.
- **From USA** – corn trials showed that compared to other sulfate-based fertilizers, lab and field results suggest polyhalite redresses sulfur deficiency in the first year and has a residual effect.

Pointing out the need for precision with potash

It is always good to be reminded how much potassium requirements vary. Fast-growing fruits and vegetables have different needs to cereals or oil seeds. Several presentations at the symposium profiled potassium's role in crop production and the importance of using potash in order to achieve optimum crop productivity and sustainability.

Importantly though, the symposium also featured different dimensions to the potassium story. Sessions covered topics from basic breeding and genetics for K-efficient rice, through to K issues in plant physiology, and the role of K in increasing plant resistance to diseases. Sharing new knowledge and ideas is helping evolve new strategies for promoting balanced fertilization.

Field visits

There was plenty of inspiration outside of the conference plenary hall. The poster session – with over twenty scientific posters on display – provided a wide variety of stimulating snapshots of research underway.

The sight and fragrance of flowers, on one of the field visits, was another opportunity to measure the benefits of balanced fertilizer use. The host farmers welcoming Symposium visitors in one village showed how they grow sweet-scented and beautiful Hoary Stocks for the regional cut flower market.

In their polytunnels, farmers demonstrated their novel portable spinner to apply polyhalite and explained that with polyhalite the flowers are more colorful and the plants stronger and higher.

Photo 4. Demonstrating polyhalite application with a manual device during the field trip to vegetables and flowers tunnels. Photo by IPI.

In other protected cropping areas, growing leafy vegetables, the study group was shown that polyhalite application results in better root development.

Ahead of the sustainability curve

The final Symposium session focused on the call for high quality 'green' agriculture. This presented the chance for speakers and audience to show and discuss the role of fertilizers – polyhalite and potash – for each of the following key steps to achieve that goal:

1. To transform from production-oriented to quality-oriented agriculture – balanced fertilization supplying 4 quality-enhancing nutrients is evidently beneficial.
2. To achieve high nitrogen use efficiency and less environmental damage – by applying K, S, Mg and Ca, farmers ensure better uptake of N, improved utilization of precious irrigation water, more robust growth and yield, and increased profits.
3. To increase sustainability – efficient and balanced nutrient management is closely related with the 17 Sustainable Development Goals (SDG's) set by the United Nations.
4. To benefit the whole food supply chain – balanced use of fertilizers is key to serve food companies, supermarkets and consumers with nutritional and quality food.
5. To use precision to feed the world – evidence and data, big data and metadata analysis will lead to fertilizer optimization and site-specific fertilization recommendations to help farmers maximize crop yields in the most efficient and cost-effective way.

Photo 5. Participants at the symposium. Photo by IPI.

Amir Gerber, FertilizerpluS Marketing Manager with ICL Fertilizers, was very impressed by the enthusiasm in China for achieving better and sustainable crop nutrition. "Polysulphate development in the Chinese market is really inspiring.", he commented after the special side event for fertilizer retailers. "What impressed me most was when one of our biggest customers from Yunnan province described how 'it feels better in the heart' to promote this natural and environmentally-friendly fertilizer."

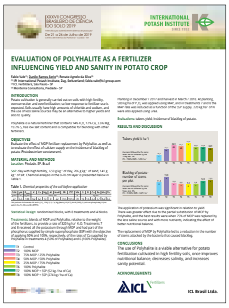
Take home messages

Inspiration from the Symposium is already driving developments in China and beyond. According to Dr. Lilian Wanjiru Mbuthia, IPI Coordinator for East Africa, the IPI conference was refreshing and informative. "There was lots of both scientific and practical information on potassium, calcium, sulfur and magnesium", she reflected. "There is a lot that we can learn [in China] and use in East Africa."

Dr. Francisco Morell, IPI Coordinator for Europe, was equally inspired. "The 2019 IPI conference, celebrated in Kunming (China), was an inspiring event. It has brought together experiences from worldwide, highlighting the importance of balanced nutrient supply, for long-term management and enhancement of soil fertility, for increased yields and environmental sustainability."

The presentations from the event are available on the IPI website at the Presentations from the 13th IPI-CAU-ISSAS International Symposium page at www.ipipotash.org/13th-potash-and-polyhalite-symposium.

Publications



Evaluation of Polyhalite as a Fertilizer Influencing Yield and Sanity in Potato Crop

Poster by Vale, F., D.R. Sério, and R. Agnelo da Silva. 2019.

This poster was presented at the

"XXXVII CONGRESSO BRASILEIRO DE CIÊNCIA DO SOLO 2019"

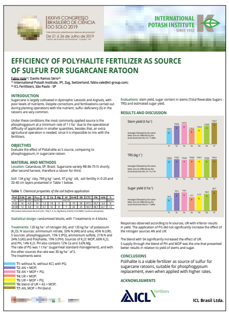
"Intencificação sustentável em sistemas de produção", 21-26 July 2019

The poster summarizes research on potato crops to evaluate polyhalite as a replacement for MOP fertilizer, and to evaluate the effect of calcium supply on the incidence of blackleg of potato (*Pectobacterium carotovorum*).

Potato cultivation is generally carried out on soils with high fertility, overcorrection and overfertilization; so low response to fertilizer use is expected. Soils usually have high amounts of chloride and sodium, and the use of less saline sources may be an alternative for higher yields and also to imrove quality.

Polyhalite is a natural fertilizer that contains 14% K_2O, 12% Ca, 3.6% Mg, 19.2% S, has low salt content and is compatible for blending with other fertilizers, and is examined in this poster.

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



Efficiency of Polyhalite Fertilizer as Source of Sulfur for Sugarcane Ratoon

Poster by Vale, F., and D.R. Sério. 2019.

This poster was presented at the

"XXXVII CONGRESSO BRASILEIRO DE CIÊNCIA DO SOLO 2019"

"Intencificação sustentável em sistemas de produção", 21-26 July 2019

This poster summarizes research to evaluate the effect of polyhalite as a sulfur (S) source, compared to phosphogypsum, in sugarcane ratoon.

Sugarcane is largely cultivated in dystrophic latosols and argisols, with poor levels of nutrients. Despite corrections and fertilizations carried out during planting operations with the nutrient, sulfur deficiency in the ratoons is very common. Under these conditions the most commonly applied source is the phosphogypsum at a minimum rate of 1 t ha^{-1} due to the operational difficulty of application in smaller quantities, besides that, an extra agricultural operation is needed, since it is impossible to mix with the fertilizers.

The poster highlights that polyhalite is a viable fertilizer source of sulfur for sugarcane ratoons, suitable for phosphogypsum replacement, even when applied at higher rates.

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

Maize and Grass Integrated System Fertilized with Polyhalite and KCl

Poster by Bernardi, A.C.C., G.B. Souza, and F. Vale.

This poster was presented at the

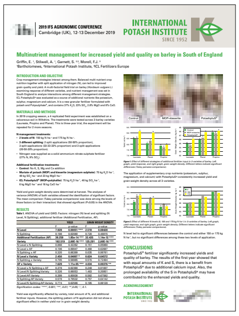
2019 ASA-CSSA-SSSA International Annual Meeting, San Antonio, Texas, 10-13 November 2019

Providing an adequate supply of nutrients is important for high yields and is essential to maintain high quality and profitable yields in integrated systems. Potassium chloride is the most used potash fertilizer in Brazil. However, there are other minerals composed of sulfates that may be considered. Polyhalite is a natural occurrence multi-nutrient mineral (11.7%-K, 19%-S, 3.6%-Mg, and 12.1%-Ca), whose potential to be a fertilizer for high yield and quality forage and crop needs to be investigated. The objective of this research was to evaluate the effect of K source fertilizers on maize Piatã grass yield and nutritional status in crop-livestock integrated systems (CLIS).

The field experiment was carried out in São Carlos, SP, Brazil in a Typic Hapludox, during the two growing seasons. The CLIS is sown with maize (*Zea mays* cv. AG 8690-Pro3) together with Piatã grass (*Urochloa brizantha*). Treatments comprised two K sources: polyhalite and KCl (60% K_2O) and five ratios of polyhalite:KCl. The treatments were: i) Control (no K, S, Mg or Ca); ii) KCl 100%; iii) KCl 87,5% + Polyhalite 12,5%; iv) KCl 50% + Polyhalite 50%; v) KCl 12,5% + Polyhalite 87,5%; vi) Polyhalite 100%. The treatments were applied in the sowing and topdressing fertilization. Piatã grass utilized the residual fertilization of K for growth. Maize and grass yield obtained with the polyhalite and KCl mixture was significantly higher ($p < 0.05$) than the control.

The best results of dry matter yield of maize and Piatã grass were obtained with the treatments with the highest ratios of polyhalite. These values were 20% to 36% higher than the best yield obtained in control. The treatments were also efficient in increasing S in soil and exportation of K, Mg, and by maize. This study demonstrated that polyhalite is an alternative source of K, Ca, Mg, and S.

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



Multinutrient Management for Increased Yield and Quality on Barley in South of England

Poster by Griffin, E., A. Stilwell, S. Garnett, and J.F. Morell. 2019.

This poster was presented at the

2019 IFS Agronomic Conference, Cambridge, UK, 12-13 December 2019

Balanced multi-nutrient crop nutrition, together with split application of nitrogen (N), can lead to improved grain quality and yield. A multi-factorial field trial on barley (*Hordeum vulgare* L.) examining the response of different varieties, and nutrient management practices was run in UK to analyze interactions among different management strategies. This poster summarizes the trial and the results.

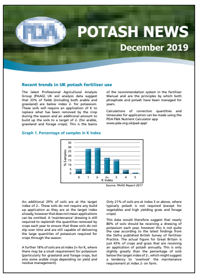
The poster is available for download at the IPI website. For more information contact Mr. Scott Garnett, IPI Coordinator for UK and Ireland.

Publications by the PDA

Potash Implications of Baling Straw

POTASH News, September 2019

Last harvest there were quite a lot of last-minute decisions to bale as a result of anticipated straw shortages and higher prices. Baling and removing straw, where there is no specific requirement for other enterprises on the farm, can often be a sensible agronomic and economic decision. These include high level of residue on the surface which may reduce the establishment of the following crop, or straw prices that are sufficient to cover the costs of baling and replacement of nutrients and organic matter. This last calculation is often not considered in enough detail and will depend on the price of phosphate and potash required to replace what is removed, and being able to allocate a cost to organic matter. Read more on the PDA website.



Recent Trends in UK Potash Fertiliser Use

POTASH News, December 2019

The latest Professional Agricultural Analysis Group (PAAG) UK soil analysis data suggest that 33% of fields (including both arable and grassland) are below index 2- for potassium. These soils will require an application of K to replace what has been removed by the crop during the season and an additional amount to build up the soils to a target of 2- (for arable, grassland and forage crops). This is the basics of the recommendation system in the Fertiliser Manual and are the principles by which both phosphate and potash have been managed for years. Calculations of correction quantities and timescales for application can be made using the PDA P&K Nutrient Calculator app www.pda.org.uk/pda-app/. 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

Response of Crops to Applied Potassium and Estimation of Critical Limits in Vertisols

Muneshwar Singh, R.H. Wanjari, B.L. Lakaria, Abhay Shirale, Uttam Kumar and Shweta Jamra. Indian J. Fert. 15(7):748-753.

Abstract: Field experiments were conducted to study the response of crops to applied potassium (K) and estimate the critical limit of available K for Vertisols with different cropping systems, namely, soybean-wheat and rice-wheat at Bhopal, rice-wheat at Raipur, rice-rice at Jagtial, and soybean-wheat at Jabalpur with graded doses of K. Nitrogen (N) and phosphorus (P) were supplied as per the requirement of crops. Results revealed that rice responded to applied K in the farmers' fields at different centers. Increase in yield was significant up to 40 kg ha^{-1} at Raipur and *rabi* rice of Jagtial; however, in case of Bhopal all the crops and *kharif* rice at Jagtial responded up to 80 kg ha^{-1} of applied K. In *rabi* season, wheat responded up to 40 kg K ha^{-1} at Jabalpur, whereas at Bhopal response was noted at 80 kg K ha^{-1}. Crop response to applied K during *kharif* was larger than during *rabi* season on the same field. Decline in available status of K occurring due to wetting is probably the reason for larger response of crop during wet season (*kharif*). Critical level of K deficiency in Vertisols computed using Cate and Nelson's graphical procedure for 1N neutral ammonium acetate (1N NH_4OAc, pH 7.0) was 335 kg K ha^{-1} which

was closer to 337 kg K ha^{-1} using statistical procedure of the same authors. Higher critical level *vis-à-vis* the current value of 280 kg K ha^{-1} suggests for a reworking of 4Rs of K fertilization as current inadequate K could pose a threat to sustainability of the cropping systems in Vertisols.

Potash Management in Black Gram-Sorghum Sequence on Dryland Soils of Maharashtra

Vijay Amrutsagar, Nilkanth More, Archana Pawar, Surinder Kumar Bansal, and Patricia Imas. 2019. Indian J. Fert. 15(7):758-764.

Abstract: Field experiments were conducted on dryland soils of AICRPDLA, Solapur for three years (2015-2016 to 2017-2018) to evaluate the influence of different levels of potassium on kharif black gram-rabi sorghum cropping sequence in the randomized block design (RBD) for kharif black gram and split plot design for rabi sorghum. Grown in a sequence, kharif black gram and rabi sorghum responded significantly to the application of 20 and 50 kg K_2O ha^{-1}, respectively. Potassium application to both the crops sustained optimum levels of water soluble, exchangeable and non-exchangeable K in the soil which enhanced the K uptake and improved the moisture use efficiency over the farmers' practice which exclude the application of K. Inclusion of K in fertilization schedule gave 38 and 9.5% higher yield in kharif black gram and rabi sorghum crops, respectively. Higher monitory returns and B:C ratio over the farmers' practice were associated with application of potassic fertilizers.

Effect of Potassium Application on Yield, Nutrient Uptake and Quality of Sugarcane and Soil Health

Ashok Kumar, Lokesh Babar, Narendra Mohan, and Surinder Kumar Bansal. 2019. Indian J. Fert. 15(7):782-786.

Abstract: Potassium (K), being an essential major nutrient, is critical for sustenance of crop yields. Removal of K by crops is either equal to or more than that of nitrogen (N). Balanced nutrition, comprising of application of N, phosphorus (P) and K in optimum proportions holds key to the maximization of crop productivity. Scant or non-application of K fertilizer has exhausted soils of their native K and is coming in the way of realizing the potential yields. Sugarcane crop, because of its high K requirements, must be fertilized with K to produce an optimum yield of the millable canes and also get the quality cane juice. Field experiments with sugarcane variety Co 0238 were conducted on the alluvial soil of National Sugar Institute, Kanpur during 2015-2016 and 2016-2017 using N and K fertilizers in different combinations. Data emanating from these experiments on several physico-chemical and nutritional parameters of sugarcane such as length, diameter, number of leaves, weight, millable canes, yield, available N, P & K, brix, pol per cent cane, purity and benefit: cost ratio showed that the treatment comprising of 240 kg N + 120 kg K_2O ha^{-1} maximized the economic yields and produced the best quality cane. Results indicate that the application of K in the range of 120 or 180 kg K_2O ha^{-1} along with N can provide higher cane yield and improve further the cane quality attributing characteristics and benefit: cost ratio and sustain the soil health.

Impact of Potassium Nutrition on Fruit Yield and Physico-Chemical Characteristics of Apple Cultivar Red Delicious

G.H. Rather, Surinder Kumar Bansal, Owais Bashir, and Umar Waida. 2019. Indian J. Fert. 15(7):790-797.

Abstract: Field experiments were conducted in a randomized complete block design (RCBD) with four doses of potassium (K) {2.5, 3.0, 3.5 and 4.0 kg muriate of potash (MOP) $tree^{-1}$} applied in two, three and four equal splits to access the effect of K on fruit quality of apple cultivar Red Delicious during 2015-2016 and 2016-2017. Results revealed that the K application @ 2.5 to 3.0 kg MOP $tree^{-1}$ was optimum in producing quality fruits. Potassium applied in four equal splits improved the K use and had a significant benficial impact on the physico-chemical characters of the apple fruits.

High Nitrogen Availability Limits Photosynthesis and Compromises Carbohydrate Allocation to Storage in Roots of *Manihot esculenta* Crantz

John Okoth Omondi, Naftali Lazarovitch, Shimon Rachmilevitch, Uri Yermiyahu, and Or Sperling. 2019. Front. Plant Sci. DOI: https://doi.org/10.3389/fpls.2019.01041.

Abstract: Cassava (*M. esculenta* Crantz), feeding countless people and attracting markets worldwide, is a model for traditional crops that need physiology-based fertigation (fertilization through irrigation) standards in intensive cultivation. Hence, we studied the effects of 10 to 200 mg L^{-1} nitrogen (N) fertigation on growth and yields of cassava and targeted alterations in their photosynthetic, transpiration, and carbohydrate management. We found that increasing irrigation N from 10 to 70 mg L^{-1} increased cassava's photosynthesis and transpiration but supported only the canopy's growth. At 100 mg N L^{-1} cassava reached a threshold of sugar in leaves (~47 mg g^{-1}), began to accumulate starch and supported higher yields. Yet, at 200 mg N L^{-1}, the canopy became too demanding and plants had to restrain transpiration, reduce photosynthesis, decrease carbohydrates, and finally lower yields. We concluded that the phases of cassava response to nitrogen are: 1) growth that does not support yields at low N, 2) productive N application, and 3) excessive use of N. Yet traditional leaf mineral analyses fail to exhibit these responses, and therefore we propose a simple and inexpensive carbohydrate measurement to guide a precise use of N.

Phosphorus Affects Storage Root Yield of Cassava through Root Numbers

John Okoth Omondi, Naftali Lazarovitch, Shimon Rachmilevitch, and Uri Yermiyahu. 2019. J. Plant Nutr. 42(17):2070-2079. DOI: 10.1080/01904167.2019.1655033.

Abstract: The objective of this study was to determine the effect of phosphorus applied through fertigation on growth and root yield of cassava. This was achieved through a greenhouse pot-experiment consisting of 1, 4, 7, 10, 20 and 30 mg P L^{-1}. Increasing P from 1 to 30 mg P L^{-1} realized a 57.1 and 150.0% increase in leaf blade P in 2014 and 2015, respectively. Similarly, chlorophyll content and shoot growth increased as P concentration in solution increased. However, leaf stomatal conductance and net photosynthesis reached a maximum in 7 and 20 mg P L^{-1} in 2014 and 2015, respectively. This trend of stomatal conductance and net photosynthesis was consistent with that of dry root yield and storage roots numbers. Regressing dry root yield against storage root numbers showed that R^2 = 0.80. Phosphorus encourages formation of storage roots and the duration of cassava's growth affects the amount of P required for maximum root yield.

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Mineral NPK and Manure Fertilisation Affecting the Yield Stability of Winter Wheat: Results from a Long-Term Field Experiment

Macholdt, J., H.-P. Piepho, and B. Honermeier. 2019. European Journal of Agronomy 102:14-22. DOI: https://doi.org/10.1016/j.eja.2018.10.007.

Abstract: It is well known that a balanced nutrient supply ensures high crop yields and stable cropping systems. In comparison, little is known about the influence of different fertilisation regimes on the yield stability of crops. Therefore, the objective of this study was to identify the impact of mineral and organic fertilisation supplied in different combinations (P + K/N + P/N + K/N + P + K) and levels (50%/100%/100% + manure) on the stability of the winter wheat grain yield. A long-term fertilisation field experiment at Giessen University (Germany, temperate climate, silty clay), established in 1956 with a multifactorial set up, was used. For an accurate stability analysis that matches the experimental design, we subjected the data to a mixed model analysis based on the restricted maximum likelihood (REML) method calculating Shukla's stability variance and Finlay-Wilkinson regression and performing Eskridge's risk analysis. It was found that without any nutrient supply, the wheat yields exhibited high annual variability and only modest stability. A similar pattern was identified for the fertiliser combination of the minerals P + K. The combinations containing mineral N showed a significant improvement in yield stability in which N + P and N + K are almost identical. In all fertilisation variants, the additional supply of manure stabilised the wheat yields. The mineral supply of N + P + K with additional manure provided the best yield stability and lowest agronomic risk for yield failure.

Mineral Nutrient Management for Onion Bulb Crops – A Review

Khalid Mahmud Khokhar. 2019. Journal of Horticultural Science and Biotechnology 94(6):703-717. DOI: 10.1080/14620316.2019.1613935.

Abstract: The mineral nutrient requirements of onion (*Allium cepa* L.) largely depend on several factors, such as cultivar, plant density, crop environment, soil fertility, fertilisation methods and managing the distributed quantity of fertiliser by using proper system of water irrigation. Production of bulbs as much as 60 tonnes ha^{-1} removes108 kg ha^{-1} of nitrogen (N), 21 kg ha^{-1} of phosphorus (P) and 120 kg ha^{-1} of potassium (K) from the field by crop harvest. Taking into account the stock of plant available mineral nutrients in the top 60 cm soil layer (onions also may effectively acquire mineral nutrients from up to 60 cm soil depth) a total supply of 120 to 140 kg N, 22-26 kg P and 150 kg K is recommended for onion production. Peak N, P, K and sulphur (S) uptake occurs during 15 to 60 days after transplanting (DAT) and fertilisers should be applied before 60 DAT for increasing bulb yield and nutrient use efficiency. Drip irrigation systems keep the nutrient solution around roots for a longer period than other systems, so it is more adapted for shallow rooted plants like onion. Adequate plant nutrition strategies involving mineral and organic fertilisers or their combinations are critical for increasing the yield of onion bulbs.

Predicting Rice Yield Under Salinity Stress Using K/Na Ratio Variable in Plant Tissue

Valère Cesse Mel, Vincent Boubié Bado, Saliou Ndiaye, Koffi Djaman, Delphine Aissata Bama Nati, Baboucarr Manneh, and Koichi Futakuchi. 2019. Communications in Soil Science and Plant Analysis 50(11):1321-1329. DOI: 10.1080/00103624.2019.1614605.

Abstract: Estimation of yield reduction in crop caused by the salinity stress is mostly based on variations of soil electrical conductivity and the severity of water stress. Crop response curves to salinity were developed without considering ion toxicity and

nutritional imbalance in the plant. The objective of this study was to explore the possibility of using the ratio of the concentration of potassium by sodium in rice leaf (leaf-K/Na) to predict yield under the salinity stress. The rice (*Oryza sativa* L.) yield under fresh and saline condition and the leaf-K/Na related database was created. Data were collected from consecutive three seasons of a field experiment in the Africa Rice Center experimental farm in Senegal (16° 11'N, 16° 15'W). We studied the relationship between the relative yield (Y_r), a ratio of yield under the salinity stress to the potential yield and the leaf-K/Na (x). Furthermore, we did regression analyses and F-test to determine the best fitting function. Results indicate that the exponential function [i.e. Y_r = 100 exp (-b x)] was the best fitting model with the lowest root mean square error (9.683) and the highest R^2 value (0.90). Example applications on independent data from published papers showed relatively good predictions, suggesting that the model can be used to predict rice yield in saline soils.

Improving the Productivity and Sugar Recovery of Cane by Potash Nutrition under Different Planting Methods

Muhammad Waqas Aslam Cheema, Riaz Ahmad, Abdul Khaliq, and Rashid Ahmad. 2018. Pak. J. Agri. Sci. 55(3):557-566. DOI: 10.21162/PAKJAS/19.7552.

Abstract: Potassium-nutrition is a subject of great consideration, as research has revealed its importance in increasing sugar recovery in sugarcane. While it cannot achieve its genetic expression of yield without proper planting technology. Therefore, the present study was conducted to optimize the planting method and K level to improve the yield and sugar recovery of sugarcane at University of Agriculture Faisalabad in 2014-2016. Treatments comprised of four planting methods viz. i) 90 cm spaced pits with a diameter of 90 cm, ii) 90 cm spaced pits with a diameter of 90 cm in diagonal fashion, iii) 90 cm spaced double row strips and iv) 120 cm spaced trench planting in combination with four K nutrition levels i.e., 0, 100, 200 and 300 kg/ha K_2O. Results revealed that K application improved the growth, cane yield and sugar recovery irrespective of planting method. However, maximum number of tillers were recorded in sugarcane sown in diagonal pit planting at 90 cm with 100 kg/ha K_2O. Likewise, Leaf area index and net assimilation rate were substantially improved with K application in all planting methods. More cane weight (15%) was obtained at sugarcane sown in 120 cm spaced trenches with 200 kg/ha K_2O during both the years. Stripped cane yield was maximum in diagonal pit planting at 90 cm with 100 kg/ha K_2O (113.7 t/ha) during the plant crop year and diagonal pit plantation + 200 kg/ha K_2O (98.22 t/ha) during the ratoon crop year. Likewise, maximum potassium use efficiency (KUE) i.e. 99.5 and 88.2 kg/kg were recorded in planting of sugarcane in diagonal pits at 90 cm with 100 kg/ha K_2O during plant crop year and 120 cm trenches +100 kg/ha K_2O during the ratoon crop year, respectively. Sugar recovery was also enhanced by all the K nutrition levels over control. The cultivation of sugarcane in 90 cm spaced pits with the supplementation of potash at 100 kg/ha gave the maximum sugar yield of 15.8 t/ha in plant crop year and 13.2 t/ha in the ratoon crop year. The combined economic analysis over two years (plant + ratoon year) revealed that sugarcane planting was more beneficial at 120 cm spaced trenches, with 100 kg potash/ha (3678$); which was followed by 90 cm diagonal pit plantation +100 kg/ha K_2O which gave the combined benefits of 3611$. Sugar cane may be planted in 90 cm diagonal pits and 120 cm spaced trenches with 100 kg/ha potash to improve the cane yield and sugar recovery.

Increased Rate of Potassium Fertilizer at the Time of Heading Enhances the Quality of Direct Seeded Rice

Anjana J. Atapattu, B.D. Rohitha Prasantha, K.S.P. Amaratunga, and Buddhi Marambe. 2018. Chem. Biol. Technol. Agric. 5(22). DOI: https://doi.org/10.1186/s40538-018-0136-x.

Abstract: *Background:* Potassium (K) is not easily assimilated into organic matter but helps to improve rice quality. Paddy yield and its quality depend on the correct time of fertilization and harvesting (days after flowering) in the field.
Methods: Changes in the grain quality of (*Oryza sativa* L.) were studied in a field experiment over two dry seasons using three rates of muriate of potash (MOP; 60% K_2O) as 12.5, 25 and 37.5 kg/ha applied at the time of heading (7 weeks after planting-WAP). Paddy samples were harvested during 25, 30 (control), 35 and 40 days after 50% flowering (DAFF). Grain yield and physico-chemical characteristics of grain were studied after harvesting.
Results: The impact of seasons and treatments' interactions was not statistically significant ($P > 0.05$) and, hence, data were averaged over two seasons. Length, breadth, true density and bulk density of rice grains were the highest with 37.5 kg MOP/ha applied at heading and harvested at 30-35 DAFF. Crude protein (6.24%) and crude fat (2.61%) contents in grains were the highest when harvested at 40 DAFF and 35-40 DAFF, respectively. Amylose content decreased with increased MOP rates at the time of heading and delayed paddy harvest. The highest average paddy yield (APY; 6.85 t/ha), head rice yield (HRY; 65%) and total rice milling yield (TMY; 67%) were recorded with 37.5 kg MOP/ha applied at heading of rice plant and paddy harvested at 35 DAFF. The APY, HRY and TMY were also 13.8, 7.7 and 5.9% higher, respectively, compared to the control. Applying K fertilizer at a rate 50% more (18.75 kg K/ha) than the recommended rate at the time of heading (7 WAP) and harvesting paddy at optimum maturity (35 DAFF), which is 5 days later than the recommendation, increase the yield and grain quality of direct seeded rice. Harvesting later than 35 DAFF resulted in a 10.5% loss of HRY ($P < 0.05$).
Conclusions: The present study showed that K fertilizer applied at

the rate of 37.5 kg MOP/ha at the time of heading 50% higher than the recommended rate is the best among K fertilizer treatments to obtain the highest HRY.

Importance of Potassium Ions for Ribosome Structure and Function Revealed by Long-Wavelength X-ray Diffraction

Rozov, A., I. Khusainov, K. El Omari, R. Duman, V. Mykhaylyk, M. Yusupov, E. Westhof, A. Wagner, and G. Yusupova. 2019. Nat. Commun. 10(2519). DOI: https://doi.org/10.1038/s41467-019-10409-4.

Abstract: The ribosome, the largest RNA-containing macromolecular machinery in cells, requires metal ions not only to maintain its three-dimensional fold but also to perform protein synthesis. Despite the vast biochemical data regarding the importance of metal ions for efficient protein synthesis and the increasing number of ribosome structures solved by X-ray crystallography or cryo-electron microscopy, the assignment of metal ions within the ribosome remains elusive due to methodological limitations. Here we present extensive experimental data on the potassium composition and environment in two structures of functional ribosome complexes obtained by measurement of the potassium anomalous signal at the K-edge, derived from long-wavelength X-ray diffraction data. We elucidate the role of potassium ions in protein synthesis at the three-dimensional level, most notably, in the environment of the ribosome functional decoding and peptidyl transferase centers. Our data expand the fundamental knowledge of the mechanism of ribosome function and structural integrity.

Contrasting Effects of Phosphorus and Potassium Deficiencies on Leaf Area Development in Maize

Usandivaras, L.M.A., F.H. Gutiérrez-Boem, and F. Salvagiotti. 2018. Crop Sci. 58(5):2099-2109. DOI: 10.2135/cropsci2018.02.0092.

Abstract: Management of P and K in agricultural systems is similar, since both move mainly by diffusion in soil. In maize (*Zea mays* L.), radiation capture is a consequence primarily of leaf area formation and senescence, but little is known about P and K interaction in determining both variables. The objective of this study was to assess the effects of P, K, and P × K interaction on (i) leaf appearance rate and final leaf number, (ii) individual leaf area, (iii) leaf senescence rate, and (iv) leaf area development in maize. Two field experiments were performed in the 2011-2012 and 2012-2013 growing seasons, under no water and N limitations. Treatments consisted of different levels of P and K fertilization. Differential effects of both nutrients occurred for leaf area formation and senescence. Phosphorus deficiencies decreased average leaf appearance rate by 10% and individual leaf area by 18%, whereas K deficiency reduction of individual leaf area was 14%. Final leaf number did not change under both P and K deficiency. Phosphorus deficiencies decreased leaf senescence rate by 2%, whereas K deficiencies accelerated this process by 12%. As the result of the counteracting processes of expansion and senescence, P deficiency effects on green leaf area index were larger at the beginning of the crop cycle and tended to attenuate after, whereas K deficiencies were more important in later stages. These results may help in modeling the effects of P and K shortage in maize.

Influence of Stalk Residue Retention and Fertilization on the Rhizospheric Effect with Drip-Irrigated Cotton

Zhang, G., W. Zhang, X. Pu, P. Zhang, and Y. Ou. 2019. Agron. J. 111(3):1028-1038. DOI: 10.2134/agronj2018.07.0447.

Abstract: By using less chemical fertilizer to produce cotton (*Gossypium hirsutum* L.), farmers could reduce input costs, increase efficiency, and protect the environment. The objective of this study was to determine the effects of stalk residue management and fertilizer application on the rhizospheric and bulk soil properties. The split-plot design included two main plot treatments (stalk residue removal and stalk residue retention) and four subplot fertilizer treatments (no fertilizer; N, P, and K fertilizer; poultry manure; and NPK plus poultry manure). Results showed that stalk residue retention increased soil pH, whereas fertilization reduced it. Stalk residue retention and fertilizer application both increased organic C, total N, and microbial biomass C. The NPK plus poultry manure treatment had the highest nitrate (NO_3^--N) and available N contents. Stalk residue retention had negative rhizospheric effect on soil pH, total N, and ammonium (NH_4^+-N) but positive rhizospheric effect on soil organic C, microbial biomass C, and NO_3^--N. The NPK plus poultry manure treatment had positive rhizospheric effect on soil pH, organic C, and NO_3^--N but negative rhizospheric effect on total soil N, microbial biomass C and NH_4^+-N. Overall, stalk residue retention plus fertilization had positive rhizospheric effect on soil organic C and NO_3^--N, negative rhizospheric effect on total N and NH_4^+-N, and no net rhizospheric effect on soil pH and microbial biomass C. Stalk residue retention improved soil quality and increased soil organic C and available N. Stalk residue retention plus NPK fertilizer and poultry manure can significantly increase soil organic C and active C components, thus ensuring high productivity.

Placement of Ion-Exchange Membranes for Monitoring Nutrient Release from Flooded Soils

Bremer, E., J.J. Miller, and T. Curtis. 2018. Canadian Journal of Soil Science 98:709-715. DOI: https://doi.org/10.1139/cjss-2018-0082.

Abstract: Placement of Plant Root Simulator (PRS®) probes (ion-exchange membranes in a plastic support) may strongly influence nutrient supply measurements and their relationship to nutrient loss to overlying water due to gradients in ion activity and redox potential with depth. A laboratory study was conducted with two soils contrasting in potential nutrient loss (manured vs. unamended control) to determine the impact of probe placement (vertical, horizontal, and flat on the soil surface) on nutrient supply rate. The supply rates of the redox-sensitive nutrients Mn and Fe were generally 1-2 orders of magnitude lower for PRS probes placed on the soil surface than buried vertically. In contrast, the supply rate of P and K varied by 1-2 orders of magnitude between soils, but placement impacts were modest or absent. The ratio between manured and control soils in water P concentration was identical to that of soil P supply rate determined with PRS probes placed flat on the soil surface. All placements were effective in demonstrating the increased potential for loss of P and K from the manured soil, but only measurements from PRS probes placed on the soil surface were closely related to loss of the redox-sensitive nutrients Mn and Fe.

Dry Matter Production, Nutrient Accumulation, and Nutrient Partitioning of Barley

Rogers, C.W., B. Dari, G. Hu, and R. Mikkelsen. 2019. J. Plant Nutr. Soil Sci. 182(3):367-373. DOI: https://doi.org/10.1002/jpln.201800336

Abstract: Total dry matter (TDM) and nutrient accumulation, nutrient partitioning, and cumulative growing degree days at the time of maximum nutrient accumulation for two-row spring barley (*Hordeum vulgare* L.) are not well quantified under high-yielding irrigated conditions common in the semi-arid western United States. Thus, five cultivars of barley were grown under irrigated conditions on a loam soil in the 2015 and 2016 growth seasons to determine these factors. Total nutrient accumulation was greatest at either the soft dough or maturity stage where specific nutrients were greater at one stage as compared to the other. Mean N accumulation was greatest at the soft dough stage (256 kg ha^{-1}) where the regression model accounted for 80% of the variation in the data. Additionally, spike N increased from 91 to 105 kg ha^{-1} from soft dough to maturity. Specific nutrients (e.g., K) had significantly greater plant (i.e., culms *plus* leaves) accumulation between soft dough and maturity, 253 and 172 kg ha^{-1}, respectively, where the spike at the same growth stages had an accumulation of 37 and 42 kg ha^{-1}, respectively. In contrast, other nutrients (e.g., P) were remobilized to the spike as noted by the increase from 14 kg ha^{-1} at soft dough to 26 kg ha^{-1} at maturity. In addition to nutrient partitioning, linear regressions resulted in well-correlated models between TDM and total nutrient accumulation (R^2 = 0.35-0.88) for measured nutrients. Results from the current study provide critical data on nutrient accumulation as well as regression models for two-row barley under high-yielding conditions. This information can be used to improve harvest decisions as well as more accurately predict nutrient cycling in barley cropping systems.

Soil Fertility Requirements of Root Chicory (*Cichorium intybus* var. *sativum*): A Review

Gordon, D.H., J.C. Hughes, and A.D. Manson. 2018. J. Plant Nutr. 41(20):2644-2659. DOI: 10.1080/01904167.2018.1482918.

Abstract: Root chicory is mainly grown in Belgium and the Netherlands with production also elsewhere in Europe, India, and South Africa. The world's crop is worth an estimated US$56.04 million. India and South Africa focus on supplying root chicory to the blend coffee industry. Only limited and variable information is available on the fertilizer requirements of root chicory. Most studies on nitrogen (N) report that chicory in cooler, temperate regions requires 40-75 kg N/ha compared to 200 kg N/ha in warmer areas. Recommended rates for phosphorus (P) range from 0 to 69 kg P/ha. Poor responses to potassium (K) are reported with recommended rates from 0 to 190 kg K/ha. Application rates for sulfur (S) of 10-30 kg S/ha have been suggested. Suitable micronutrient requirements and soil acid saturation and pH values for root chicory have not been published. To establish crop norms a concerted effort is needed to quantify the fertilizer use of root chicory.

Response of Soil Aggregate-Associated Potassium to Long-Term Fertilization in Red Soil

Kailou Liu, Tianfu Han, Jing Huang, Qinghai Huang, Daming Li, Zhihua Hu, Xichu Yu, Qaswar Muhammad, Waqas Ahmed, Huiwen Hu, and Huimin Zhang. Geoderma 352:160-170. DOI: https://doi.org/10.1016/j.geoderma.2019.06.007.

Abstract: Potassium (K) deficiency is commonly observed during crops grown in the red soil (which is a typical Plinthosol based on the IUSS guidelines) of China, but few studies have examined soil aggregate-associated K. In a long-term field experiment (initiated in 1986), the following treatments were applied: no fertilizer (CK), nitrogen and phosphorus fertilizers (NP), NP and K fertilizers (NPK) and a combination of manure and NPK (NPKM). After 30 years of fertilization, the nonexchangeable K (Nonex-K), and exchangeable K (Ex-K) contents or stocks in most aggregates varied among different treatments. Compared with NP treatment, the Nonex-K contents in the aggregate fractions of >2-, 1–2-, 0.5–1-, 0.25–0.5- and 0.053–0.25-mm under NPKM treatment were increased by 40.57%, 40.78%, 42.71%, 40.82% and 55.43%, respectively. The Nonex-K contents in 0.5–1-, 0.25–0.5-, 0.053–0.25- and <0.053-mm aggregates of the NPK treatment were 29.17%, 31.63%, 43.48% and 35.42% higher

than those of the NP treatment, respectively. The Ex-K contents in all aggregates of the NPKM treatment were significantly ($p < 0.05$) higher than those of the other treatments (CK, NP and NPK). Compared with the NP treatment, the Ex-K contents in 1–2-, 0.5–1-, 0.25–0.5- and 0.053–0.25-mm aggregates of NPKM treatment were significantly increased by 30.30%, 32.65%, 33.67% and 33.33%, respectively. Moreover, the Ex-K stocks in the >2-,1–2-, 0.5–1- and 0.053–0.25-mm aggregates of NPKM treatment were significantly increased by 74.36%, 123.63%, 44.88% and 37.47%, respectively, compared with those of the NPK treatment. Furthermore, a random forest model showed that K stocks in the >2-, 1–2- and 0.5–1-mm aggregates were the main factors affecting the uptake of K by maize. The relationships between the uptake of K by maize and K stocks in the >2-, 1–2- and 0.5–1-mm aggregates could be fitted by linear equations. Therefore, the long-term combination of chemical fertilizers with manure improved K contents and stocks for most aggregate sizes in red soil, especially Ex-K. We found that the turnover rate of K in the >2-mm aggregates was faster than in the other aggregates (1–2- and 0.5–1-mm) through slopes of linear regressions, allowing the soil to meet the requirements for crop K uptake.

Effect of Irrigation Regimes and Soil Texture on the Potassium Utilization Efficiency of Rice

Yousef Alhaj Hamoud, Zhenchang Wang, Xiangping Guo, Hiba Shaghaleh, Mohamed Sheteiwy, Sheng Chen, Rangjian Qiu, and Mohammed M.A. Elbashier. 2019. Agronomy 9(2):100. DOI: https://doi.org/10.3390/agronomy9020100.

Abstract: Understanding the effects of irrigation regime and soil texture on potassium-use efficiency (KUE) of rice (*Oryza sativa* L.) is essential for improving rice productivity. In this regard, experiments were conducted from July to October in 2016 and 2017 by using a randomized complete block design in a factorial arrangement with four replications. The rice plants were grown in three soils, with clay contents of 40%, 50%, and 60%, which were marked as $S_{(40\%)}$, $S_{(50\%)}$, and $S_{(60\%)}$, respectively. For each soil type, irrigation regimes, namely, $R_{(F, S100\%)}$, $R_{(F, S90\%)}$, and $R_{(F, S70\%)}$, were established by setting the lower limit of irrigation to 100%, 90%, and 70% of saturated soil water content, respectively, and the upper limit of irrigation with 30 mm of flooding water above the soil surface for all irrigation regimes. Results showed that the responses of the roots and shoots and the potassium accumulation (KA) and KUE of rice were significantly affected by the water regime and soil texture. In the same irrigation regime, increasing the soil clay content improved the K utilization of rice. Under the same soil type, $R_{(F, S100\%)}$ was the optimal water management practice for growing rice. The $R_{(F, S100\%)}$ $S_{(60\%)}$ treatment presented the highest KUE, which was 56.4% in 2016 and 68.1% in 2017. The $R_{(F, S70\%)}$ $S_{(40\%)}$ treatment showed the lowest KUE, which was 13.8% in 2016 and 14.9% in 2017. These results enrich knowledge regarding the relationship among soil, water, and rice, and provide valuable insights on the effect of irrigation regime and soil texture on the KA and KUE of rice.

The Effect of Potassium on Photosynthetic Acclimation in Cucumber During CO_2 Enrichment

Dabu, X., S. Li, Z. Cai, T. Ge, and M. Hai. 2019. Photosynthetica 57(2):640-645. DOI: 10.32615/ps.2019.073.

Abstract: Long-term CO_2 enrichment (1,000 μmol mol^{-1}) leads to photosynthetic acclimation in cucumber. Here, through hydroponic experiments in an open-top climate chamber system, we investigated key photosynthetic parameters of cucumbers using potassium stimulation (120 or 240 mg L^{-1}). Short-term CO_2 enrichment (less than 25 days) significantly increased the net photosynthetic rate in cucumber. However, long-term CO_2 enrichment (43 d) led to photosynthetic acclimation and decrease in stomatal conductance. The increase in potassium alleviated the decrease in photosynthetic rate and stomatal conductance, which reduced photosynthetic acclimation. In addition, 13C isotope tracing showed that under CO_2 enrichment, plants with higher potassium concentrations showed higher sink/source and flow/source ratios of photosynthetic assimilative C ($\delta^{13}C$) abundance. Moreover, the abnormal accumulation of soluble carbohydrates and starch resulted in photosynthetic acclimation in cucumber. Increasing potassium significantly reduced the accumulation of soluble carbohydrates and promoted the transport of soluble carbohydrates to the sink, which alleviated photosynthetic acclimation.

Leaf Photosynthetic Characteristics and Photosystem II Photochemistry of Rice (*Oryza sativa* L.) under Potassium-Solubilizing Bacteria Inoculation

Yaghoubi Khanghahi, M., H. Pirdashti, H. Rahimian, G.H. Nematzadeh, M. Ghajar Sepanlou, E. Salvatorei, and C. Crecchio. 2019. Photosynthetica 57(2):500-511. DOI: 10.32615/ps.2019.065.

Abstract: The current research was performed to investigate the effects of three potassium-solubilizing bacteria (KSB) strains (*Pantoea agglomerans, Rahnella aquatilis,* and *Pseudomonas orientalis*) on leaf photosynthetic characteristics in rice (*Oryza sativa* L. cv. Pajohesh). A pot and a field experiment were conducted in a paddy field. The results indicated that the KSB inoculums significantly enhanced chlorophyll (Chl) *a*, Chl *a+b*, SPAD value, and stomatal conductance as compared to the control in both experiments, especially when applied along with half the recommended dose of the potassium chemical fertilizer. KSB inoculations, alone or combined with K fertilizer, significantly increased the value of photochemical quenching, photosynthetic

electron transport rate, and the effective quantum efficiency as compared to the control. In conclusion, these native KSB strains could be used as inoculants to reduce consumption of K chemical fertilizer and improve the efficiency of photosynthesis for rice production under the flooding irrigation conditions.

Validation of Soil-Test-Based Phosphorus and Potassium Fertilizer Recommendations for Irrigated Soybean.

Fryer, M.S., N.A. Slaton, T.L. Roberts, and W.J. Ross. 2019. Soil Sci. Soc. Am. J. 83(3):825-837. DOI: 10.2136/sssaj2019.02.0032.

Abstract: Soil testing is the best available technology for making crop fertilizer recommendations, and precision agriculture has increased the demand for soil-testing. Our primary research objectives were to validate the accuracy of soil-test P (STP) and K (STK) availability (Mehlich-3) and trifoliolate leaflet-P and leaflet-K concentration interpretations for predicting irrigated-soybean [*Glycine max* (L.) Merr.] yield response to P and K fertilization at 22 site-years. Each trial contained six treatments involving two P rates and four K rates including a no fertilizer-P or -K control and the soil-test recommendation. Yield and tissue nutrient concentration responses were assessed at three significance levels ($p \leq 0.05$, $p \leq 0.10$, or $p \leq 0.25$) and identified as correct or incorrect according to the response predicted by soil-test recommendations. The accuracy of soil and tissue analyses to predict the correct plant response to fertilization increased as the significance level moved from conservative ($p \leq 0.05$) to liberal ($p \leq 0.25$). Mehlich-3 STP accurately identified soils that did not respond to fertilizer P and had an overall accuracy of 40 ($p \leq 0.05$) to 48% ($p \leq 0.25$) in predicting yield response to fertilization. Existing STK interpretations were 72 ($p \leq 0.05$) to 82% ($p \leq 0.25$) accurate. Critical leaflet-K concentrations accurately identified soybean response to K fertilization at 46 ($p \leq 0.05$) to 60% ($p \leq 0.25$) of the sites. Interpretation errors were most common in the very low and low STP levels, low and medium STK levels, and the low tissue-K level. The accuracy of the soil and tissue testing and their interpretation process were reasonably accurate for K but substantial improvements are needed for P.

Potassium Uptake Efficiency of Two Pear Cultivars and Leaf Concentration at Deficiency Symptoms Appears

Soumaya Dbara, Amira Melaouhi, Messaoud Mars, and Mehdi Ben Mimoun. 2019. J. Plant Nutrition 42(14):1660-1667. DOI: 10.1080/01904167.2019.1628977.

Abstract: Two pear cultivars (Meski Ahrech and Alexandrine) grown in pot culture under normal daylight conditions in a greenhouse were submitted to potassium deficiency treatments. The potassium-free treatment decreased leaf K concentration, relative water content, SPAD, and gas exchange comparatively to the control. "Alexandrine" appeared more sensitive to potassium deficiency due to the main decrease in stomatal conductance (gs), photosynthesis (A) and transpiration (E) compared to "Meski Ahrech" that reduced only carbon assimilation (A). After 42 days of treatments, leaf K concentration in "Alexandrine" was 0.75% DM compared to 1.15% DM in "Meski Ahrech", which appeared to be more efficient in potassium uptake.

Long-Term Influence of Different Production Systems on Potassium Buffering Capacity of *Typic Ustochrept* Soil

Debashis Dutta, N. Ravisankar, R.P. Mishra, N.K. Jat, Amit Kumar, P.C. Ghasal, A.L. Meena, R.B. Tewari, Vaibhav Kumar, Kautilya Chaudhary, Shweta Singh, and A.S. Panwar. 2019. J. Plant Nutr. 42(13):1472-1482. DOI: 10.1080/01904167.2019.1628976.

Abstract: Imbalanced application of nutrients in the intensively cropped areas results in deterioration of soil fertility. Application of recommended dose of potassium (K) is essential for improving the use efficiency of other nutrients. To assess the buffering capacity of soil, three composite soil samples were collected from the surface soil (0-30 cm) during 2015 from 3 production systems *viz*., organic, inorganic and integrated which was maintained from 2004 with basmati rice-wheat-*Sesbania* system under Network Project on Organic Farming at ICAR-Indian Institute of Farming Systems Research, Modipuram. Fractionation of potassium (K) was achieved by sequential extraction of soil samples with distilled water, ammonium acetate and nitric acid in the same order. The relationship between the adsorbed and equilibrium potassium concentration, quantity was determined by plotting Freundlich adsorption isotherms. This was used to determine the buffering capacity and the concentration levels of potassium adsorbed on un-specific sites in the soil. The suitability of the adsorption equation was determined by applying the least square regression analysis. The results revealed that available potassium in the soils ranged from 119.51 to 135.01 mg/kg with 126.02 ± 5.24 mg/kg as mean (ammonium acetate method) while water soluble and nitric acid extracted potassium ranged from 28.51 to 29.05 mg/kg and 2594.49 ± 19.33 mg/kg (mean) in various production systems. The mean free energy of replacement was found to be −1998.01 ± 28.38 cal/mol indicating that soils have comparatively higher potassium supply under organic system. The potassium buffering capacity of the soils was found to be 0.7462 ± 0.16 mg/kg, 0.6295 ± 0.20 mg/kg and 0.6774 ± 0.09 mg/kg in organic, integrated and inorganic systems, respectively. The amount of potassium adsorbed on un-specific sites of the organic, integrated and inorganic systems was found to be 7.4730 ± 1.81, 15.11 ± 2.40 and 11.6 89 ± 3.58 mg/kg, respectively. It can be concluded that long-term organic production system improves K^+ buffering capacity of *Typic Ustochrept* soil as compare to the integrated as well as inorganic production systems.

Rice OsHAK16 Functions in Potassium Uptake and Translocation in Shoot, Maintaining Potassium Homeostasis and Salt Tolerance

Feng, H., Q. Tang, J. Cai, B. Xu, G. Xu, and L. Yu. 2019. Planta 250(2):549. DOI: https://doi.org/10.1007/s00425-019-03194-3

Abstract: The HAK/KUP/KT transporters have been widely associated with potassium (K) transport across membranes in both microbes and plants. Here, we report the physiological function of OsHAK16, a member belonging to the HAK/KUP/KT family in rice (*Oryza sativa* L.). Transcriptional expression of *OsHAK16* was up-regulated by K deficiency or salt stress. OsHAK16 is localized at the plasma membrane. *OsHAK16* knockout (KO) dramatically reduced root K net uptake rate and growth at both 0.1 mM and 1 mM K supplies, while *OsHAK16* overexpression (OX) increased total K uptake and growth only at 0.1 mM K level. *OsHAK16*-KO decreased the rate of rubidium (Rb) uptake and translocation compared to WT at both 0.2 mM and 1 mM Rb levels. *OsHAK16* disruption decreased while its overexpression increased K concentration in root slightly but in shoot remarkably. The relative distribution of total K between shoot and root decreased by 30% in *OsHAK16*-KO lines and increased by 30% in its OX lines compared to WT. *OsHAK16*-KO diminished K uptake and K/Na ratio, while *OsHAK16*-OX improved K uptake and translocation from root to shoot, resulting in increased sensitivity and tolerance to salt stress, respectively. Expression of *OsHAK16* enhanced the growth of high salt-sensitive yeast mutant by increasing its K but no Na content. Taking all these together, we conclude that OsHAK16 plays crucial roles in maintaining K homeostasis and salt tolerance in rice shoot.

Long-Term Impact of Potassium Fertilization on Soil and Productivity in Intensive Olive Cultivation

Haberman, A., A. Dag, N. Shtern, I. Zipori, R. Erel, A. Ben-Gal, and U. Yermiyahu. 2019. Agronomy 9(9):525. DOI: 10.3390/agronomy9090525.

Abstract: The olive growing sector is transitioning from traditional to intensive irrigated cultivation, dictating a need to reconsider orchard management practices including fertilization. Potassium (K) is an essential nutrient, typically found in high concentrations in plants. Orchard K fertilization requirements are commonly derived from the disparity between assumed tree requirements and extractable soil K. The long-term impact of insufficient fertilization on K available in the soil, growth, and yield of irrigated field-grown olive trees was evaluated over six consecutive seasons. Withholding of K fertilization led to lower exchangeable and soluble K concentrations in the soil and significantly impaired yield. The reduction in yield was attributed to reduced flowering and fruit set, resulting in a lower fruit number. Tree vegetative growth and flowering quality traits were not affected. In addition, trees not receiving K appeared to be more susceptible to alternate bearing. Following two seasons of omitting K fertilization, leaf K concentration did not decrease below the conventionally accepted sufficiency threshold for olive (0.8%). In spite of this, the trees produced significantly lower yields. Our results suggest that long-term insufficient K fertilization results in reduced soil available K and consequently impairs tree productivity. The results imply that the sufficiency threshold for K in diagnostic leaves should be reconsidered for intensive orchards. Moreover, the current method for K deficiency detection using leaf K concentration may be inadequate for intensive orchards. Integration of other parameters, such as fruit K content, leaf Na, and changes in soil exchangeable K content or sorption energy, may promote a more reliable analysis of orchard K nutritional status.

A Review on Soil Potassium Scenario in Vertisols of India

Gurav, P.P., S.K. Ray, P.L. Choudhari, A.K. Biswas, and A.O. Shirale. 2018. J. Sci. 2(1):89-90. DOI: 10.15406/oajs.2018.02.0005.

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

Effect of Supplemental Potassium Application on Growth and Yield of Potato Cultivars

Mohammad Wasiullah Khan, Saqib Farooq, Gohar Ayub, Murad Ali, Ahmad Naeem, Rabia Riaz, Muhammad Afzaal, Ali Shah, Imtiaz Khan, Rafi Ullah, Kamran Rauf, and Syed Qaiser. 2019. Pure and Applied Biology (PAB) 8(2):1554-1563. DOI: http://dx.doi.org/10.19045/bspab.2019.80096.

Abstract: A trail was carried out to evaluate the effect of supplemental potassium application on growth and yield of potato cultivars at Horticulture Farm, The University of Agriculture Peshawar during winter season, 2014. The experiment was laid out on Randomized Complete Block Design, with split plot arrangement, using three replications. Potassium was kept in main plot while potato cultivars were kept in subplot. Four levels of supplemental potassium (0, 50, 75, 100 kg ha^{-1}) were allotted to main plots, whereas sub plot factor consisted of potato cultivars

(Rocko, Kuroda and Asterix). The supplemental potassium levels significantly influenced the growth and yield of potato cultivars. The maximum values for growth variables; plant height (45.82 cm) and survival percentage (89.56 %) and yield variables; number of small tubers plant^{-1} (4.56), number of medium tubers plant^{-1} (4.11), number of large tubers plant^{-1} (4.56), tuber weight plant^{-1} (463.67), yield (21.65 tons ha^{-1}) were found in plot treated with supplemental potassium applied @ 75 kg ha^{-1}. Among cultivars, the maximum values for growth variables; plant height (45.33 cm) and survival percentage (85.30%) and yield variables; number of small tubers plant^{-1} (3.92), number of medium tubers plant^{-1} (3.33), number of large tubers plant^{-1} (3.83), tuber weight plant^{-1} (451.17), yield (21.15 tons ha^{-1}) were found in cultivar Kuroda. Interaction between supplemental potassium levels and potato cultivars was found non-significant. Supplemental potassium should be applied @ of 75 kg ha^{-1} to potato crop. Among tested cultivars, the cultivar Kuroda showed better growth and yield under the agro-climatic region of Peshawar.

Effect of Potassium Fertilization on Growth Indices, Yield Attributes and Economics of Dry Direct Seeded Basmati Rice (*Oryza sativa* L.)

Vijayakumar, S., Dinesh Kumar, Y.S. Shivay, Anjali Anand, P. Saravanane, S. Poornima, Dinesh Jinger, and Nain Singh. 2019. Oryza 56(2):214-220. DOI: 10.35709/ory.2019.56.2.6.

Abstract: Two-year field experiment was conducted during rainy (*kharif*) seasons of 2015 and 2016 at ICAR-Indian Agricultural Research Institute, New Delhi to evaluate the effect of potassium (K) fertilization on growth indices, yield attributes and economics of the dry direct seeded basmati rice. Application of recommended dose of K (60 kg ha^{-1}) half at basal and remaining half at panicle initiation increased the grain yield (5.4 t ha^{-1}), net returns (Rs. 85,000 ha^{-1}) and B:C (1.8) ratio by 10, 16 and 20% respectively, over applying the entire amount of K as basal. Significant positive correlation was observed between yield attributes [total tillers (r^2 = 0.74), effective tillers m^{-2} (r^2 = 0.79)] and grain yield of dry direct seeded basmati rice. The two foliar sprays (1st spray at active tillering, 2nd spray at panicle initiation) of 2.5% potassium nitrate (T_6) increased fertile tillers % (93.8%), fertility % (83.5%) and grain yield (4.3 t ha^{-1}) by 5%, 6% and 8% respectively, over T_1 (control). In case, K is not available for top dressing then two foliar sprays of 2.5% KNO_3 at active tillering and panicle initiation stage is found optimum to obtaining higher net returns (Rs. 85200 ha^{-1}) and return from investment on K (Rs. 19.9 rupee^{-1}). Insufficient supply of K during active tillering and panicle initiation stage, decreased the production of tillers m^{-2} and conversion of tillers into fertile tillers respectively. Hence, active tillering and panicle initiation stage are most critical for K supply in dry direct seeded basmati rice.

Phosphorus and Potassium Fertilizer Rate Verification for a Corn-Wheat-Soybean Rotation System in Tennessee.

Singh, S., H.J. Savoy, X. Yin, L. Schneider, and S. Jagadamma. 2019. Agron. J. 111(4):2060-2068. DOI: 10.2134/agronj2018.12.0749.

Abstract: Soil test-based fertilizer recommendations are necessary for profitable farming without adversely affecting the environment. The University of Tennessee (UT) stopped recommending P and K fertilizers in 2008 for soils with high Mehlich-1 P and K levels because they were unprofitable. However, commercial laboratories tend to recommend higher fertilizer rates than UT, despite equivalent soil test results. To address this discrepancy, field trials were conducted from 2009 to 2015 for a corn (*Zea mays* L.)-wheat (*Triticum aestivum* L.)-soybean [*Glycine max* (L.) Merr.] rotation on low- to medium-testing soils at UT's Research and Education Centers at Milan and Springfield. Our specific objectives were to (i) evaluate yield responses to P and K rates; (ii) determine critical fertilizer rates, critical soil test P (STP), and soil test K (STK) levels, and critical grain P and K removals for maximum productivity; and (iii) examine the response of STP and STK levels to fertilizer P and K rates. We evaluated five rates of P (0-118 kg ha^{-1}) and K (0-186 kg ha^{-1}) fertilizers. Since 2013, significant yield responses to P and K fertilization were frequent, except no response to K was seen at Milan during the entire study period. Application of >59 kg ha^{-1} P resulted in high soil P levels over time at both locations but the highest K rate (186 kg ha^{-1}) brought soils from a low to only a medium level. Critical fertilizer rates and soil test levels corroborated UT's current recommendations for maximum yield.

Investigating the Effect of Biochar on the Potential of Increasing Cotton Yield, Potassium Efficiency and Soil Environment

Xiuwen Wu, Dian Wang, Muhammad Riaz, Lin Zhang, and Cuncang Jiang. 2019. Ecotoxicology and Environmental Safety 182(109451). DOI: https://doi.org/10.1016/j.ecoenv.2019.109451.

Abstract: Potassium (K) is an essential macronutrient for plant growth and development. However, in China, available K is relatively low in the soil, and with the extensive use of chemical fertilizer, K use efficiency is constantly reducing, and consequently increasing the potential risk of environmental pollution and economic loss. Therefore, it is essential to reduce the negative impact of over-fertilization on the environment to obtain optimal crop yield. Biochar as a soil amendment has been applied to improve soil fertility and increase crop yield. However, the effects of successive biochar application on cotton yield, agronomy efficiencies and potash fertilizer reduction are not well documented. Our results of a pot experiment showed that the application of 1% biochar to soil under different K levels

significantly improved dry mass accumulation and K content of different plant parts, and increased the number of buds, bolls and effective branches of cotton. Particularly, plants treated with 150 mg/kg K_2O and 1% biochar had the highest growth parameters. The most important characteristics including the harvest index, K fertilizer contribution index, partial factor productivity, agronomic efficiency and apparent recovery efficiency of K under C1 (1% biochar) were generally greater than those under C0 (without biochar). The 75 mg/kg K_2O application was optimal to produce the highest yield with 1% biochar, demonstrating that biochar can increase cotton yield and therefore, reduces chemical K fertilizer application and alleviates agricultural environment risks of chemical fertilizer.

Alfalfa and Potassium Fertilization: What You Need to Know

Sheaffer, C. 2019. No-Till Farmer.

Forage crops such as alfalfa remove large quantities of potassium (K) on an annual basis. When manure application is not an option, fertilizer must be purchased to supply K to alfalfa. Potassium can impact plant health, potentially affecting the ability of alfalfa to overwinter. Under-application of K can result in less tons produced per acre. While K fertilizer has historically been cheap compared to the other major macronutrients, supplying removal rates of K to alfalfa annually can result in a significant expense to alfalfa producers.

Soybean Production under Continuous Potassium Fertilization in a Long-Term No-Till Oxisol

Antonangelo, J.A., R.F. Firmano, L.R.F. Alleoni, A. Oliveira, and H. Zhang. 2019. Agron. J. 111(5):2462-2471. DOI: 10.2134/agronj2019.02.0084.

Abstract: Potassium (K) is essential for soybean production but over use of K fertilizer negatively impact the environment and farming profit. Therefore, the optimum K recommendation needs to be verified, especially in pedo-environmental contrasting regions and long-term cultivated areas. We evaluated the effects of continuous annual K fertilization on plant-available K by Mehlich-1 (K_{M-1}) and ion exchange resin (K_{resin}), plant uptake (K_{tissue}) and the yields of two soybean cultivars (*Glycine max* L.) grown in an Oxisol under long-term no-till (NT). The treatments included four K rates (0, 40, 75, and 110 kg ha^{-1}) with four replications. K_{resin} was highly correlated with K_{M-1} (R^2 = 0.94, $p < 0.0001$). Plant-available K was linearly correlated with K_{tissue} (trifoliate leaflets) with r of 0.76 and 0.82 ($p < 0.0001$) for K_{M-1} and K_{resin}, respectively. Maximum K_{M-1} and K_{resin} that expressed the highest K_{tissue} concentrations were in the ranges of 1.72 ± 0.26 to 2.36 ± 0.35 and 2.58 ± 0.22 to 3.11 ± 0.33 $mmol_c$ K dm^{-3}, respectively. The Ca+Mg/K ratios in tissues decreased by increasing K application. Soybean yields increased from 1,823 to 2,611 kg ha^{-1} as the rates of annual-K application increased from 0 to 40 kg ha^{-1}. Additional K application did not further improve yields. For yields, the maximum responsive soil test K was 2.16 ± 0.58 mmolc K dm^{-3} for K_{M-1} and 3.42 ± 0.91 $mmol_c$ K dm^{-3} for K_{resin}; while the maximum responsive K_{tissue} at R2 stage was 14.5 ± 0.98 to 18.1 ± 2.2 g K kg^{-1}. Our results confirm that soil test for plant-available K and plant tissue test are important to guide K fertilizer recommendations.

Potassium Fertilisation Reduced Late Embryogenesis Abundant (*LEA*) Gene Expression in Malaysian Rice (MR220) under Water Stress Condition

Nurul Amalina Mohd Zain, Mohd Razi Ismail, Norazrin Ariffin, Wan Abd Al Qadr Imad Wan-Mohtar, and Fairuz Fatini Mohd Yusof. 2019. AIMS Agriculture and Food 4(2):376-385. DOI: 10.3934/agrfood.2019.2.376.

Abstract: The application of potassium fertiliser might mitigate water stress effects in developing rice, thus influencing *Late Embryogenesis Abundant (LEA)* gene expression and growth in the plant tissue. This study was conducted to examine *LEA* gene expression in its drought tolerance mechanisms and the growth of Malaysian Rice (MR220) when exposed to water stress and potassium fertilisation. Three treatments were developed, namely the control (CF; Continuously flooding + 80 kg K_2O/ha), water stress under standard potassium fertilisation (WS; Water Stress 25 days + 80 kg K_2O/ha) and water stress under high potassium fertilisation (WSK; Water Stress 25 days + 120 kg K_2O/ha). The plant growth and yield components were measured for each treatment with randomly tagged plant by 3 replicates. The result showed that *LEA* gene expression on WSK was 36% less than on WS, thus indicating that the application of additional potassium fertilisation on MR220 rice might mitigate the water stress effect imposed on this plant. The study showed that high *LEA* gene expression in WS was accompanied by a reduction in plant growth and yield performance, such as plant tillers, height, number of leaves and grain yield compared to the control and WSK.

Validation of Soil-Test-Based Phosphorus and Potassium Fertilizer Recommendations for Flood-Irrigated Rice

Fryer, M.S., N.A. Slaton, T.L. Roberts, J.T. Hardke, and R.J. Norman. 2019. Agron. J. 111(5):2523-2535. DOI: 10.2134/agronj2019.03.0159.

Abstract: Soil testing is a widely accepted practice for evaluating soil-P and soil-K availability but can be inconsistent for making accurate fertilizer-P and fertilizer-K recommendations. Our research objectives were to assess the accuracy of established soil- and tissue-P and -K concentration interpretations for predicting flood-irrigated rice (*Oryza sativa* L.) yield response to fertilization at three levels of significance ($p \leq 0.05$, 0.10, and 0.25). Six treatments combining two fertilizer-P rates (0 or 32 kg P ha^{-1}) and four fertilizer-K rates (0, 56, 84, 112 kg K ha^{-1}) were applied at 24 sites. Soil-test P (STP) interpretations were 40% accurate, regardless of the significance level, and whole-plant-P concentrations at the V6-V7 stage were 50% accurate. Soil-test K (STK) interpretations were 40 ($p \leq 0.05$ and 0.10) and 36% ($p \leq 0.25$) accurate, and whole-plant-K concentrations at the R2-R3 stage were 61% ($p \leq 0.25$) or 62% ($p \leq 0.05$ and 0.10) accurate in predicting the yield response to K fertilization. Nearly all of the error in both soil-test- and whole-plant-P and -K concentration interpretations occurred in the suboptimal categories. The accuracy ($p \leq 0.05$) of yield response predictions for levels where no fertilizer was recommended was 100% for STP and 86% for STK and 82 to 100% for whole-plant-P and -K concentrations. The false-positive error was the most common soil-test recommendation inaccuracy and suggests that fertilizer recommendations are skewed to reduce the risk of yield loss from insufficient fertilization.

Interactive Effects of Nitrogen and Potassium on: Grain Yield, Nitrogen Uptake and Nitrogen Use Efficiency of Rice in Low Potassium Fertility Soil in China

Wenfeng Hou, Xinxin Xue, Xiaokun Li, Muhammad Rizwan Khan, Jinyao Yan, Tao Ren, Rihuan Cong, and Jianwei Lu. 2019. Field Crops Research 236:14-23. DOI: https://doi.org/10.1016/j.fcr.2019.03.006.

Abstracts: Elucidating the mechanism underlying the interactive effects between nitrogen (N) and potassium (K) on rice yield is requisite to further study soil K deficiency in paddy ecosystems in Southeast Asia. Field studies with combined application of four N rates (0, 90, 180, and 270 kg N ha^{-1}) and four K rates (0, 60, 120, and 180 kg K_2O ha^{-1}) in 2013, 2014 and 2016 and a hydroponic experiment in 2017 were conducted to investigate their effects on rice yield as well as N use efficiencies (NRE). Co-application of N and K significantly promoted the growth and development of root and leaf, grain yield and NRE of rice. The application of N combined with zero-K increased the grain yield by 10.6-22.0%, 24.0-37.4% and 12.7-21.9% in 2013, 2014 and 2016 respectively. Similarly, leaf area index (LAI) increased by 5.9-17.9%, 8.1-19.7% and 27.9-62.7% across the three years. An increase of grain yield by 15.5-32.5%, 26.6-46.1% and 11.5-23.0% and LAI by 22.6-31.5%, 34.2-42.8% and 26.7-79.1% across the three years was recorded due to combined application of N and K. Application of higher doses of K resulted in relatively higher N uptake and N NRE. Application of K improved the N uptake and NRE by 5.6-10.0%, 7.4-16.2%, 10.9-26.4% and 12.0-22.3%, 16.9-36.4%, 20.6-43.3 % respectively across the three years. To deduct the effect of soil N and K background value, we also did a hydroponic experiment to do some physical test. In the hydroponic experiment, the leaf and root glutamine synthetase (GS), glutamate synthetase (GOGAT) and glutamate dehydrogenase (GDH) activities were significantly improved with the improvement of N and K. The leaf and root GS, GOGAT and GDH activity of the treatment with sufficient N and K (+N+K) was significantly increased by 402.3%, 332.5%, 265.2% and 200.0%, 410.4%, 239.0% respectively compared with that of the treatment with deficient N and K (-N-K). These results indicated that the combined use of N and K could further improve the grain yield as well as NRE in rice production.

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, and Cliff G. Martin. 2019. 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 Affects Alfalfa Yield, Quality, and Root Traits

Adapted from Jungers, J.M., D.E. Kaiser, J.F. Lamb, J.A. Lamb, R. Noland, D.A. Samac, M.S. Wells, and C.C. Sheaffer. 2019. Potassium Fertilization Affects Alfalfa Forage Yield, Nutritive Value, Root Traits, and Persistence. Agron. J. CSA News 64(10):12. DOI: 10.2134/csa2019.64.S043.

Abstract: Potassium fertilization of alfalfa is important for maintaining yields but can have negative consequences on forage quality: a tradeoff that could vary depending on cultivar and growing environment. Moreover, reports of potassium fertilization on stand persistence have been inconsistent largely as a result of poor understanding of how potassium influences root biomass and architecture, pathogen resistance, winter survival, and other drivers of stand persistence.

New research in *Agronomy Journal* reports on the effects of potassium fertilization on forage yield and quality responses and belowground traits that relate to stand persistence. The potassium responses of eight modern alfalfa cultivars grown at three locations varying in soil type were studied.

Among all cultivars, potassium fertilization increased alfalfa forage yield but decreased forage quality. The concentration of potassium increased in both fo rage and root tissues when fertilized at rates beyond those needed to maximize forage yield, which suggests that alfalfa exhibits "luxury consumption" of potassium. Therefore, over-fertilization is not just an economic detriment to growers, but it can also reduce forage quality enough to put lactating dairy cows at risk of milk fever. Although potassium fertilization did increase root biomass, it did not result in any differences in the root disease crown rot and had inconsistent effects on stand persistence.

Can Potassium Silicate Mineral Products Replace Conventional Potassium Fertilizers in Rice-Wheat Rotation?

Zhao, X., S. Gao, D. Lu, H. Wang, X. Chen, J. Zhou, and L. Zhang. 2019. Agron. J. 111(4):2075-2083. DOI: 10.2134/agronj2019.01.0020.

Abstract: Potassium (K) silicate minerals are important insoluble K resources and exploring their potential as alternatives to conventional K fertilizers would be helpful to deal with the widespread K deficiency in the world. Thus on-farm experiments with potassium silicate mineral products (KSMPs), e.g., Fubang (FB), Zhongke (ZK), Ziguang (ZG) – manufactured from natural K-bearing rocks – were conducted to investigate their effects on crop yield, soil K fertility and pH in rice-wheat (*Oryza sativa* L.–*Triticum aestivum* L.) rotation at Guangde County and Jiangdu County, China. The experiments lasted 2 yr at two sites and six treatments about K fertilizers were tested: no K fertilization (CK); 100% K chloride (KCl); 100% ZG; 50% KCl +50% ZG; 50% KCl +50% FB; 50% KCl +50% ZK. Results showed that both wheat and rice grain yields for CK were markedly decreased compared with that for the other treatments, regardless of K fertilizer types. Similar to KCl, the KSMPs could maintain crop yields and soil potassium fertility. Besides, the KSMPs significantly improved soil pH by average 0.47 and 0.38 at Guangde and Jiangdu, respectively, compared with that for KCl, after its application for 2 yr. However, the apparent K balances for most treatments at two sites were negative. In terms of economic aspect, the value cost ratio averaged by sites of ZG was 2.59 which was significantly higher than that for FB and ZK. In conclusion, the KSMPs can sustain crop yields and soil K fertility and thus can partly substitute conventional K fertilizers in rice-wheat rotation on the Aquic Haplanthrepts soils.

Assessment of Soil Nutrient Status under Different Cropping Systems in Khotang, Nepal

Devkota, P., D. Aryal, and B. Khanal. 2019. International Journal of Applied Sciences and Biotechnology 7(3):341-346. DOI: https://doi.org/10.3126/ijasbt.v7i3.25697.

Abstract: Availability of plant nutrients in rhizosphere is directly influenced by types of crop grown and land use pattern. The experiment was conducted in Diktel Rupakot Majhuwagadhi Municipality, Khotang, Nepal to assess the soil nutrients dynamics as influenced by different cropping system. Five different cropping systems (Rice-Wheat, Maize-Millet, Maize-Vegetables, Ginger and Cardamom) were selected as treatments and all treatments were replicated for five times for blocking in Randomized Complete Block Design. Soil samples from 0-15 cm depth were collected from each site and evaluated for soil pH, soil organic carbon (SOC), total nitrogen (N), available phosphorus (P), and available potassium (K). All the tested parameters except N were found to be significantly affected by cropping system. Soil in all five cropping systems were found acidic (pH<6.5) in nature with pH ranging from 5.180-6.640. The SOC was recorded highest (3.102%) from Cardamom based system and lowest amount of SOC was observed in Ginger based system. The highest amount of P (32.14 mg/kg) was reported in Maize-Vegetables cropping system and lowest P content (5.72 mg/kg) was recorded from Cardamom

based system. P content in Ginger based system (31.51 mg/kg) was statistically at par with that of Rice – Wheat system. The highest K content (306.50 mg/kg) was recorded from Maize-Vegetable cropping system and lowest K content (34.80 mg/kg) was observed in Cardamom based system which is statistically similar to Rice-Wheat (35.70 mg/kg) and Maize-Millet systems (77.20 mg/kg). The result indicated that cropping systems have huge impact on plant nutrient dynamics in soil.

Potassium Fertilization for Fresh Market Potato Production in Tropical Soils

Job, A. L.G., R. P. Soratto, A. M. Fernandes, N. S. Assunção, F. M. Fernandes, and R. Yagi. 2019. Agron. J. 111(6):3351-3362. DOI: 10.2134/agronj2019.05.0336.

Abstract: Potassium (K) is the most taken up and removed nutrient by potato (*Solanum tuberosum* L.), and has a great influence on tuber yield and quality. This study was performed to evaluate the effects of three rates (100, 200, and 400 kg K_2O ha^{-1}) and two timings of application of K (single application at planting furrow and split application of 50% at planting furrow plus 50% at hilling), as potassium chloride, as well as a control (without K application) on the plant nutrition and tuber yield and quality of potato 'Agata' grown in tropical clay soils. The split application of K fertilizer had little influence on plant nutrition and tuber yield and quality. The influence of K fertilization on increasing K and reducing Ca and Mg concentrations in the leaf was more significant in soil with low exchangeable K. In this soil, the maximum tuber yield (33.6 Mg ha^{-1}; 107% higher than the control) was obtained with an estimated rate of 325 kg K_2O ha^{-1}, while in the soils with medium and high exchangeable K, the tuber yield was increased between 22 and 34% and only up to a rate of 200 kg K_2O ha^{-1}. The critical leaf K concentration to reach 95% of the maximum yield was 29.3 g K kg^{-1}, but there was an extreme increase in the tuber yield even with K rates that provided leaf K concentrations above this limit. Potassium fertilization increased the firmness and reduced soluble solids and protein in tubers.

View on

Keep K in Soils to Alleviate Stress

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