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Optimizing Crop Nutrition

Editorial

Dear readers,

With the pandemic creating havoc across the globe, disrupting lives and livelihoods, 2020 was an unusual year for IPI. However, despite the challenges and constraints, our team was able to continue with our activities. Field trials were monitored remotely, farmer meetings became virtual and training events happened online.

We are grateful to IPI coordinators and staff for making such a huge effort to continue research and development by managing work from home – and, if need be, working odd and extended hours to get the job done. They successfully maintained and developed the relationships with our local research partners, despite not being able to meet and talk in person as we would wish.

At IPI, we used modern tools and technologies to follow up field trials remotely, and we are determined to continue efficient use of digital techniques to help us work better, smarter and more effectively.

Together, with resilience and determination, we have done our best to weather the storms caused by the pandemic. We look forward to 2021 when we can continue working to spread the benefits of balanced plant nutrition worldwide.

If anything, the COVID pandemic has shone a spotlight on the vital role of agriculture in keeping everyone fed throughout this crisis. Farmers and food producers keep working so that the world can continue to eat. Their vital contribution to the pandemic response should be cherished.

In this *e-ifc* edition, we present two experiments with polyhalite, from China on kiwifruit and from Vietnam on maize. In addition, there is a paper on the response of maize to potash fertilization in India.

And of course IPI wishes you a happy and healthy year in 2021!

I wish you an enjoyable read and that you stay safe!

Dr. Patricia Imas
IPI Scientific and Communications Coordinator

Photo cover page: Wheat field in southern Israel. Photo by N. Cohen Kadosh.

Research Findings

Photo 1. Winter maize crop grown in northern Vietnam. Photo by the authors.

Polyhalite Effects on Winter Maize Crop Performance on Degraded Soil in Northern Vietnam

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Abstract

Maize (*Zea mays*) production in Vietnam, the major component of livestock feed (90%) in this country, recorded a 12-fold increase from 1981-2014, with an impressive mean annual yield increase (10%). Nevertheless, a substantial yield gap exists between the current local mean yield (4.7 Mg ha^{-1}) and those of leading maize producing countries, such as USA (12.8 Mg ha^{-1}). Degraded soil fertility and commonly imbalanced fertilization practices were suggested among the major reasons for this yield gap. Polyhalite, a natural marine sedimentary mineral consisting of a hydrated sulfate of potassium (K), calcium (Ca), and magnesium (Mg) was examined as a potential partial substitute for muriate of potash (MOP) as the K donor, with the advantage of more balanced mineral nutrition being a four-in-one fertilizer. An experiment was carried out from August until early December 2016 in northern Vietnam, comparing maize crop performance under six fertilizer treatments: farmers' practice (120 kg K_2O ha^{-1}); control (no K applied); 60 kg K_2O ha^{-1}, applied through MOP; and 60, 90, and 120 kg K_2O ha^{-1}, applied

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through combinations of polyhalite and MOP at 1:1 ratio at the K_2O level. All treatments received farmyard manure (FYM) at 10 t ha^{-1}, 180 kg N ha^{-1} (urea) and 90 kg P_2O_5 ha^{-1} (superphosphate). The combinations of MOP and polyhalite gave rise to significantly higher fodder yields, in grains as well as husks and corncobs. Interestingly, the differences between the three combinations were not statistically significant for most of the yield parameters, suggesting that lower K rates, such as 60 or 90 kg K_2O ha^{-1}, might be sufficient to obtain reasonable maize yields. The contribution of polyhalite to prolonged K availability, and to more balanced crop nutrition, was especially demonstrated when treatments with a similar K_2O rate (60 kg ha^{-1}) were compared; the combined fertilizer displayed significantly greater vegetative biomass and kernel yield. An economic analysis showed that under the circumstances of the present study, the polyhalite and MOP combination at a rate of 90 kg K_2O ha^{-1} was the most profitable practice, far above the output from farmers' usual practice. The economic analysis also clearly demonstrated that no K application might lead to a substantial loss on investment. In conclusion, adequate K supply is essential to profitable winter maize production under the climatic and edaphic conditions in northern Vietnam. Furthermore, combinations of polyhalite and MOP can open new horizons in enhancing maize and other crops' performance in Vietnam.

Keywords: Balanced plant nutrition; Polysulphate; polyhalite; potassium; yield gap; *Zea mays*.

Introduction

Maize (*Zea mays* subsp. *mays*), also known as corn, is a cereal grain first domesticated by indigenous peoples in southern Mexico about 10,000 years ago (Kane and Rieseberg, 2005). Maize has spread throughout the world since the 16th Century, and has become a staple food in many countries. In addition to being consumed directly by humans, maize is also used to produce ethanol, animal feed, and other products, such as corn starch and corn syrup. Maize is widely cultivated throughout the world, and a greater weight of maize is produced each year than any other grain. In 2018, total world production was 1.15 billion tonnes (FAOstat, 2020).

In Vietnam, maize is the primary material resource for 90% of livestock and poultry feed. The demand for maize has increased due to the strong expansion of animal husbandry (Kha and Tuong, 2019). Thus, the area under maize cultivation grew substantially from 0.37-1.2 million ha from 1981-2014, and the yearly production rose during that period from 0.42-5.2 million tonnes (Fig. 1A). With significant efforts made by the Vietnamese government to enhance local maize productivity (Huong and Yorobe, 2017), the mean annual yield increased linearly from about 1.1 to 4.7 Mg ha^{-1} between 1981 and 2018 (Fig. 1B). This impressive output growth was triggered by more intensive cultivation, increased areas of planting, enhanced yield, and adoption of both open-pollinated variety (OPV) and hybrid seeds starting in 1991 (Tinh, 2009). The introduction of chemical fertilizers, such as nitrogen (N) and phosphorus (P), also made a substantial contribution to the yield increase (Setiyono *et al.*, 2010; Giang *et al.*, 2015). Nevertheless, and in spite of the impressive advances in the Vietnamese maize industry, the present mean yield (4.7 Mg ha^{-1}) is listed 72nd among the world's maize producing countries, less than 40% that of the USA, which is listed 10th (FAOstat, 2020). This significant yield gap is mainly attributed to serious edaphic constraints (Schweizer *et al.*, 2017), and to the conventional farming practices (Keil *et al.*, 2008).

The nature of the soil may be crucial to maize quality and productivity. Conversion of forest to agricultural land for maize cultivation is known to negatively affect soil fertility. According to Schweizer *et al.*, (2017), soil aggregate stability declined simultaneously with a decrease in soil organic carbon and exchangeable Ca^{2+} and Mg^{2+}, which both declined with increasing time since land use

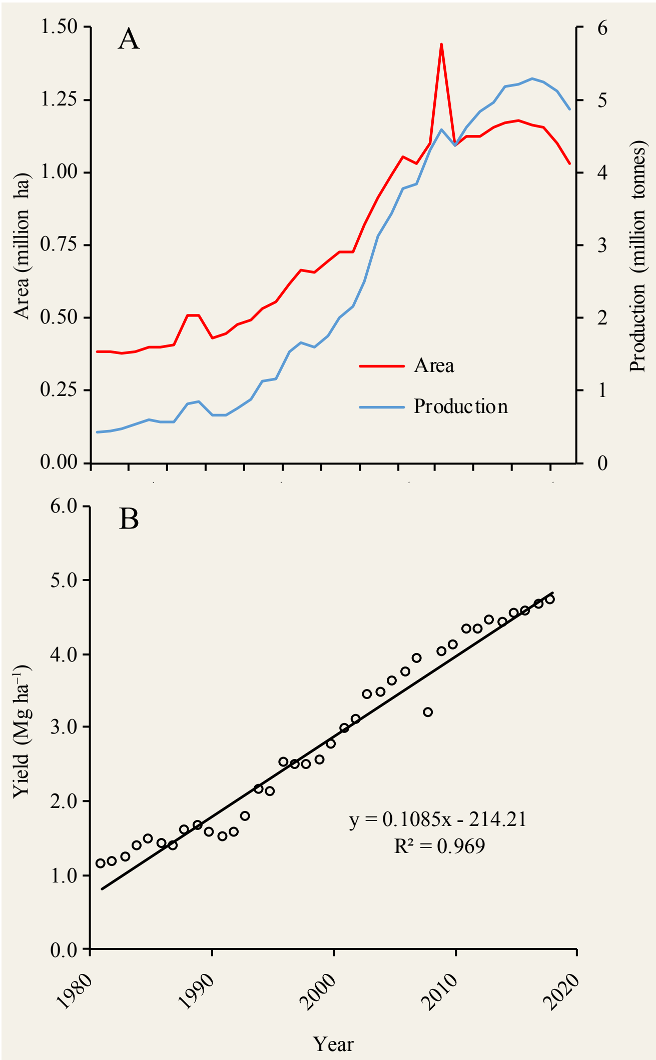
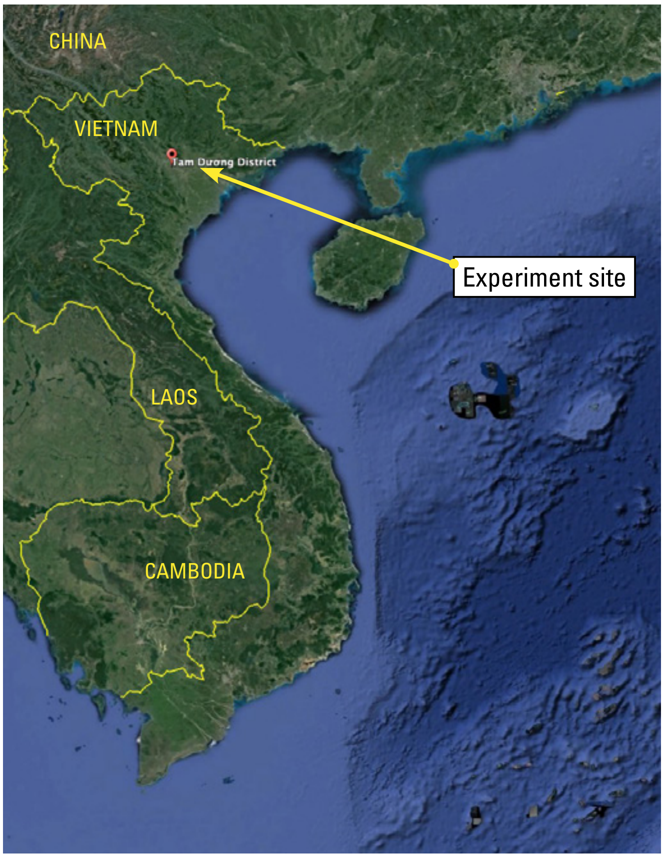


Fig. 1. Maize production in Vietnam 1981-2018. Changes in cultivation area and production (A); and, in maize yield (B). *Source:* FAOstat, 2020.

changed from forest to maize production systems. The Alisol and Luvisol chronosequences were 1.9 times more stable, whereas the Vertisol chronosequence was 2.5 times more stable under primary forest than under maize. Over 18 years' chronosequence, the maize topsoils lost 1.6 kg m^{-2} and 3.2 g kg^{-1} soil organic carbon and Ca^{2+}, respectively. The humid tropic climate of Vietnam creates significant further challenges for soil nutrient availability. During the wet season, the liquid soil phase is prone to swap very frequently, within hours or days, depending on the precipitation regime. This liquid phase contains most of the currently available nutrients, including potassium (K), that are leached away from the rhizosphere. In addition, high precipitation rates intensify soil weathering and significantly increase soil acidity (Sanchez, 2019), which further reduces soil cation exchange capacity (CEC) and K availability (Zörb *et al.*, 2014). Consequently, the opportunity window for plants to acquire K following application events is short and scarce, potentially leading to significant gaps between K application and uptake rates, considerable waste of fertilizer, and to environmental consequences. Consequently, insufficient nutrient availability, particularly K, but also imbalanced mineral nutrition, have been consistently shown to be responsible for the maize yield gap in Vietnam (Witt *et al.*, 2006; Setiyono *et al.*, 2010; Pasuquin *et al.*, 2014; Pandey *et al.*, 2019).



Map 1. Location of the maize field trial at Duy Phien commune, Tam Duong district, Vinh Phuc Province, Vietnam. *Source:* Google maps © 2020.

Potassium is essential for most basic processes in plants' life cycle (Zörb *et al.*, 2014). Many studies have shown that maize is particularly responsive to K application, when the natural nutrient availability cannot fully meet requirements (Jordan-Meille and Pellerin, 2008; Pettigrew, 2008; Samal *et al.*, 2010; Izsáki, 2017; Jiang *et al.*, 2018; Ortas, 2018; Asante-Badu *et al.*, 2020). Potassium application practices were introduced to Vietnam much later than N and P and, therefore, were insufficiently disseminated among farmers (Pandey *et al.*, 2019). Under the climatic and edaphic constraints of Vietnam, K application must be addressed with careful attention to the problem of rapid leaching, which necessitates splitting the fertilizer dose into several application events during the growing season, thus providing better K availability whenever necessary (Joshi *et al.*, 2014; Pandey *et al.*, 2019). Alternatively, less soluble fertilizers that would last for a significantly longer period in the growing season should be considered.

Similar to the danger of K shortage, other alkaline nutrients, Ca and Mg, are at risk of deficiency. Calcium is pivotal to numerous structural and physiological functions from the subcellular to the whole plant scale (White and Broadley, 2003). Magnesium is part of chlorophyll in all green plants and is essential for photosynthesis and carbohydrate partitioning (Cakmak and Yazici, 2010; Farhat *et al.*, 2016). Sulfur (S) is recognized as the fourth major plant nutrient after N, P, and K (Khan *et al.*, 2005), and has been associated with high productivity (Dick *et al.*, 2008), as it often interacts with N to significantly enhance protein metabolism (Jamal *et al.*, 2010).

The recently introduced composite NPK fertilizers are not diverse enough to meet all nutrient requirements at each stage of growth, and on differing soils. Polyhalite is a natural mineral which occurs in sedimentary marine evaporates and consists of a hydrated sulfate of K, Ca, and Mg with the formula: $K_2Ca_2Mg(SO_4)_4{\cdot}2(H_2O)$. The deposits found in Yorkshire, in the UK, and marketed as Polysulphate®, typically consist of K_2O: 14%, SO_3: 48%, MgO: 6% and CaO: 17%. As a fertilizer providing four key plant nutrients – S, K, Mg, and Ca – polyhalite may offer attractive solutions to crop nutrition. In addition, polyhalite is less water soluble than more conventional sources (Yermiyahu *et al.*, 2017; Yermiyahu *et al.*, 2019) and is, therefore, a suitable fertilizer to supply these four nutrients during the rainy growing season. Polyhalite was recognized as an effective crop fertilizer, being at least as effective as equivalent soluble sulfate sources of K, Ca and Mg (Hoang *et al.*, 2016; Yermiyahu *et al.*, 2017).

The objective of the present study was to evaluate the agronomic efficiency of polyhalite on yield, quality, and economic returns of winter maize on degraded soils in Northern Vietnam. Demonstrating the advantages of using polyhalite as an alternative to MOP and, moreover, as a key fertilizer for balanced crop nutrition, will encourage Vietnamese farmers to adopt this strategy for maize and other crops.

Materials and methods

Experiment site

The field experiment was carried out at Duy Phien commune, Tam Duong district, Vinh Phuc Province (Map 1). The climate in this region is subtropical with a mean annual temperature of 23.5°C and a mean annual rainfall of 1,600 mm, of which more than 80% occurs between May and October (Fig. 2).

The soil profile of the research area was classifield as Grey degraded soil or Plinthic Acrisols or as Plinthaquults (Sehgal, 1989). The local topsoil was sandy loam with considerable clay content, acidic (pH 5.2), with high organic matter content, but low nutrient status (Table 1).

Experiment plan

Before sowing, a standard basic fertilizer practice was carried out throughout, which included the spreading of farmyard manure (FYM) or composted cattle dung at 10 t ha^{-1}. The experiment included six treatments (Table 2), with four replications in a randomized complete block design, i.e. 24 plots (24 m^2 plot^{-1}).

The treatments differed in K rate (from 0-120 kg K_2O ha^{-1}) and source: muriate of potash (MOP; KCl, 60% K_2O) and polyhalite (19.2% S, 14% K_2O, 6% MgO and 17% CaO). The first control (K_{120+0} – farmers' practice) included a high K rate, all of which was applied through MOP (K_{120+0}), and served to compare with the other treatments, agronomically and economically. The second control K_0 did not include any K application, providing an evaluation of K contribution to the maize crop performance under the experiment conditions. In treatments K_{60+0} and K_{30+30}, the K rate was reduced to 60 kg K_2O ha^{-1}, applied solely through MOP or through a combination of MOP and polyhalite, respectively. In treatments K_{45+45} and K_{60+60}, K application rates rose to 90 and 120 kg K_2O ha^{-1}, respectively, while maintaining a 1:1 ratio between MOP and polyhalite as the sources of K_2O (Table 2).

Nitrogen and phosphorus were applied evenly to all treatments at 180 kg N ha^{-1} and 90 kg P_2O_5 ha^{-1}, using urea (46% N) and locally available Lam Thao superphosphate (16.5% P_2O_5), respectively. The mineral fertilizers were applied three times during the cropping season: before sowing (30% N, 100% P, 40% K and 40% polyhalite); at 4 to 6 leaves (40% N); and, at pollination (30% N, 60% K and 60% polyhalite).

Crop management

LVN4, a locally recommended maize variety, was used. Maize was cultivated on raised beds (6×4 m), 120 cm width and 30 cm height, spacing between two beds was 30 cm, with a density of 5 plants m^{-2}. Seeding date was 16 August 2016 and the harvest start date was 3 December 2016.

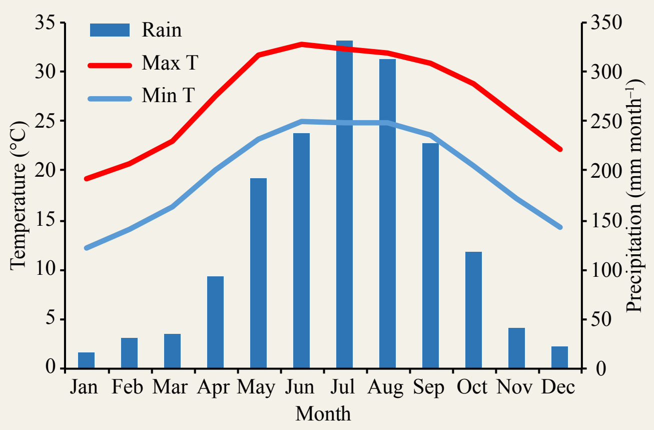


Fig. 2. Climate conditions at the experiment site, including mean monthly maximum and minimum temperature and mean monthly precipitation. *Source:* https://en.climate-data.org/asia/vietnam/vinh-phuc-province/tam-duong-35088/#climate-graph

Field observations, sampling, and measurements

Plant height and the number of leaves were measured four times during crop development. Bloom date and corncob height were determined. The occurrence of pests and diseases was evaluated at 30, 45, and 80 days after sowing. At harvest, a 4 m long section within each plot was used to determine the yield parameters. Corncobs and vegetative parts were separated and weighed. Five randomly sampled corncobs per plot were used to determine the numbers of kernel rows,

Table 1. Major properties of topsoil at the trial location in northern Vietnam

Soil property	
	%
Clay (< 2 µm)	10
Silt (2-30 µm)	65
Fine sand (20-200 µm)	20
Coarse sand (> 200 µm)	5
	g kg^{-1}
pH (KCl 1M)	5.2
Total C	6.0
Total N	1.1
Total P	0.32
Total K	0.50

Table 2. Detailed description of the fertilizer treatments

Treatment	FYM	N	P_2O_5	K_2O	
				KCl	Polyhalite
	t ha^{-1}	--------------------	-kg ha^{-1}-	--------------------	
K_{120+0}	10	180	90	120	0
K_0	10	180	90	0	0
K_{60+0}	10	180	90	60	0
K_{30+30}	10	180	90	30	30
K_{45+45}	10	180	90	45	45
K_{60+60}	10	180	90	60	60

Note: FYM = farmyard manure

kernels per row, and total kernels per corncob. Kernels were dried to 14% moisture and kernel weight (g 1000^{-1} kernels) was determined. A 100 g sample of kernels from each plot was taken for laboratory determinations of dry matter, starch (Clegg, 1956), and protein (Sáez-Plaza *et al.*, 2013) contents. Dry matter content of husks, corncobs and of the vegetative biomass were determined.

Results

Maize growth and development

The duration of the growing period was 107 days for all fertilizer treatments, excluding K_0, which was extended by 4 days. Differences had already emerged at the pollination stage, with a 5-day delay in K_0, compared to the other treatments (63 vs. 58 days after sowing (DAS), respectively). It appears that in the absence of K fertilizer application, crop growth and development is delayed, while the K source (FYM, MOP or polyhalite) has no significant effect if K is adequately applied.

The number of leaves per plant at harvest ranged from 12.7-13.1, with only treatment K_{60+60} displaying slightly but significantly greater number of leaves compared to K_0 ($P < 0.05$). Plant height and dry biomass at harvest were significantly influenced by the fertilizer treatments (Fig. 3). While K application rate had no significant effect on the plant height, a higher polyhalite rate seemed to support greater plant height (Fig. 3A). Furthermore, the replacement of MOP with equivalent K contribution from polyhalite, at any K application rate, gave rise to significantly greater dry biomass production (Fig. 3B). Notably, plant dry biomass was lowest in the absence of K fertilizer (K_0).

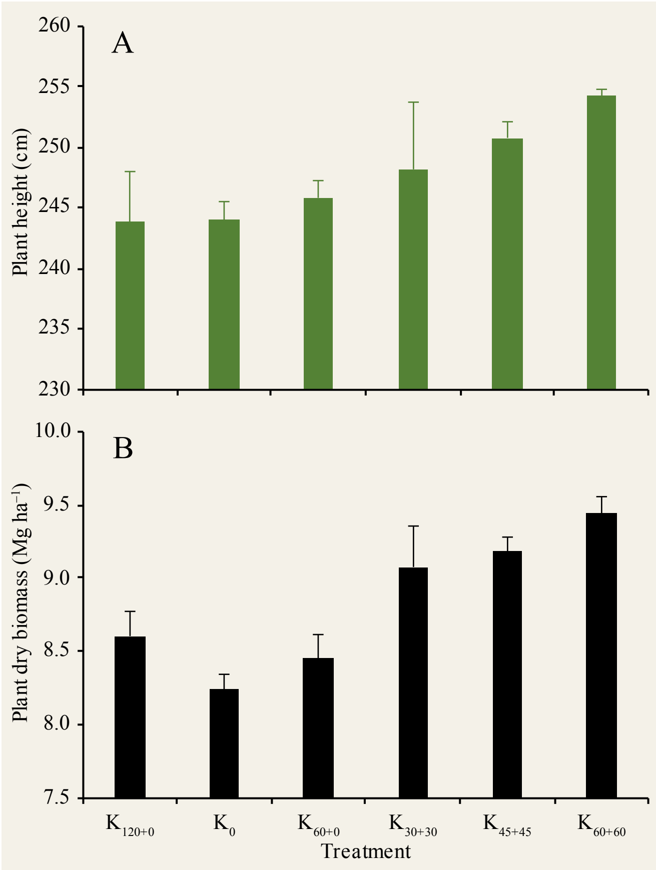


Fig. 3. Effects of fertilizer treatments on plant height (A) and vegetative dry biomass (B) toward harvest in winter maize crop grown in northern Vietnam. Bars indicate SE.

Vulnerability to pests and diseases

During the experiment, the winter maize crop encountered two major pests: corn borer (*Ostrinia nubilalis*) and corn aphid (*Rhopalosiphum maidis*), and two diseases: banded leaf and sheath blight (BLSB) (*Rhizoctonia solani*), and bacterial top and stalk rot (*Erwinia chrysanthemi* pv. Zeae) (Table 3).

The infestation with corn aphids was very mild, not exceeding 1.5% of the plants, and concentrated at the mid cropping season, 45 DAS. Although not statistically significant, the infestation rates of corn aphids were somewhat higher under no K application (K_0), slightly declined where K was applied, and were especially low where polyhalite was part of the fertilization practice (Table 3). BLSB infestation rate was very low, below 2% and 1% at the early and late sections of the growing season, respectively, and considerably higher at the mid cropping season (45 DAS), ranging from 2.5-6.3%, which is perceived as quite low in maize production. Notable, however, was the clear tendency of lower BLSB infestation rates among plants fertilized with polyhalite (Table 3). In the present study, the bacterial top and stalk rot disease only occurred toward the end of the season with very low infestation rates (3.3-4.4%), and with no considerable differences between treatments (Table 3).

Corn borer (*Ostrinia nubilalis*) damage to the stem was very slight during the early crop stage (until 30 DAS), 3.8-5.4% (Table 3). This type of damage increased considerably during the mid-season (45 DAS) to range from 12.9-15.6%, and declined to 3.3-4.4% toward the end of the season (80 DAS). Corn borer damage to the corn occurred only toward the season's end, ranging at rates from 14.8-17.1%. No significant differences were observed between treatments, however, damage rates tended to be consistently lower among the polyhalite-treated plants (Table 3).

Influence of polyhalite on maize yield and quality parameters

On average, the corn yield was very close to 1 corncob $plant^{-1}$, with no differences between treatments. Nevertheless, the fertilizer treatments had significant influences on other quantitative parameters that determine the yield (Fig. 4). The most important one, kernel yield, was significantly greater in plants applied with polyhalite+MOP combinations, ranging from 8-8.5 Mg ha^{-1}. The control (K_0) kernel yield was 5.7 Mg ha^{-1}, far below all K-applied treatments. MOP-applied plants displayed intermediate kernel yields that ranged from 7.2-7.6 Mg ha^{-1} (Fig. 4A). This response pattern to the fertilizer treatments was preserved also with the dry husk and dry corncob yields, however, the differences were much less significant (Fig. 4B, C). The harvest index (HI) also

Table 3. Infestation rates (% of plants) by corn aphid (*Rhopalosiphum maidis*), banded leaf and sheath blight (BLSB) (*Rhizoctonia solani*), corn borer (*Ostrinia nubilalis*), and bacterial top and stalk rot (*Erwinia chrysanthemi* pv. Zeae) during winter maize crop in northern Vietnam, as influenced by fertilizer treatments. DAS (days after sowing).

	Corn aphid (*Rhopalosiphum maidis*)			BLSB (*Rhizoctonia solani*)			Corn borer (*Ostrinia nubilalis*)						Bacterial top and stalk rot (*Erwinia chrysanthemi* pv. Zeae)		
							Damaged stem			Damaged corn					
DAS	30	45	80	30	45	80	30	45	80	30	45	80	30	45	80
Treatment															
	-----	-----	-----	-----	-----	-----	-----	%	-----	-----	-----	-----	-----	-----	-----
K_{120+0}	0	0.8	0	1.7	6.3	0.6	4.8	15.6	3.8	0	0	17.1	0	0	4.2
K_0	0	1.3	0	1.9	5.0	0.8	5.4	15.2	4.4	0	0	16.3	0	0	4.4
K_{60+0}	0	0.8	0	0.8	4.0	0.6	4.0	15.0	4.0	0	0	16.7	0	0	3.8
K_{30+30}	0	0.4	0	0.8	3.5	0.6	4.4	14.0	3.8	0	0	16.3	0	0	3.5
K_{45+45}	0	0.4	0	0.6	2.9	0.6	3.8	13.3	3.3	0	0	15.8	0	0	3.3
K_{60+60}	0	0.4	0	0.4	2.5	0.4	4.0	12.9	3.3	0	0	14.8	0	0	3.3

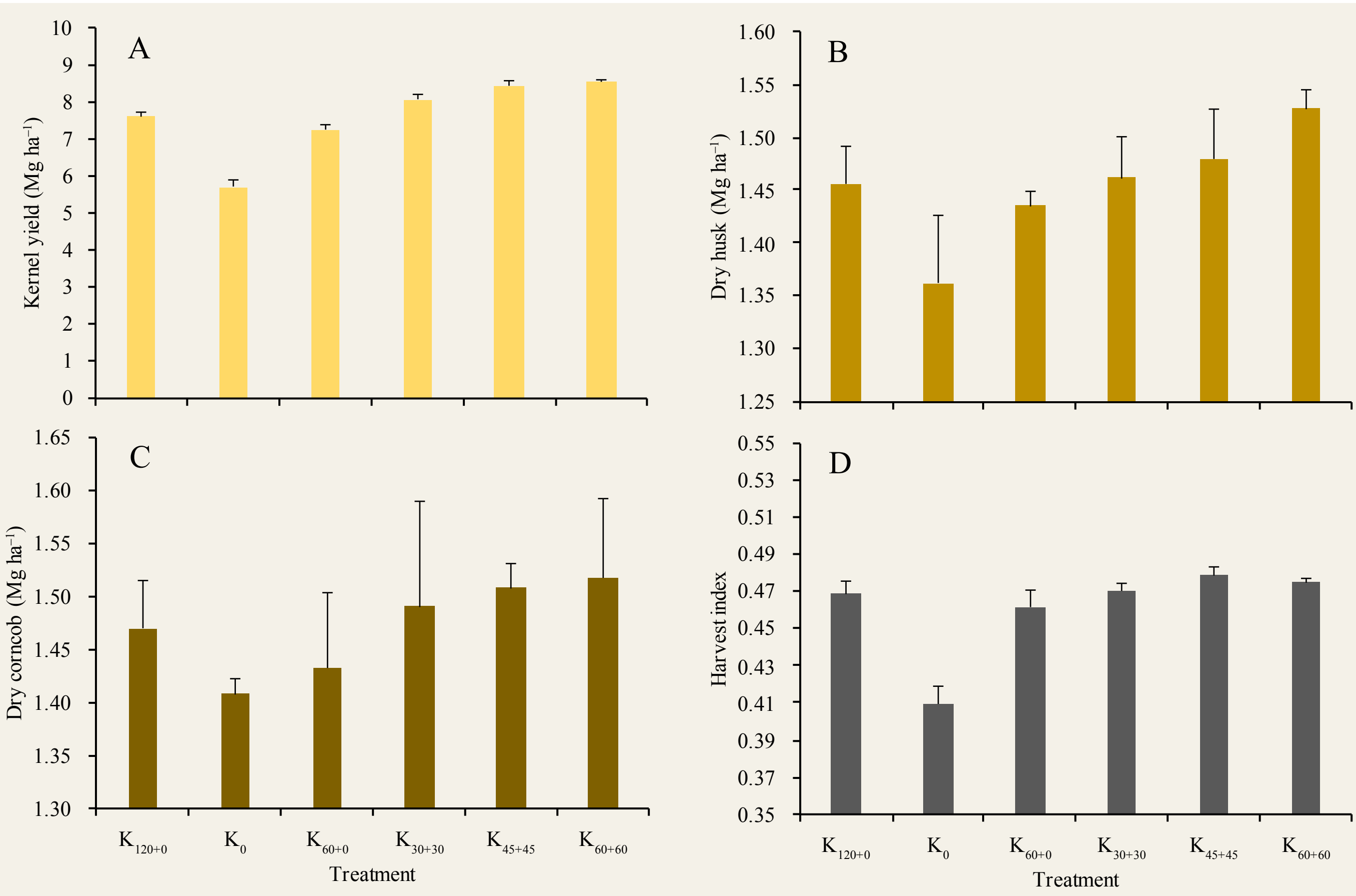


Fig. 4. Effects of fertilizer treatments on yield parameters of winter maize crop grown in northern Vietnam. Kernel yield (A); dry husk yield (B); dry corncob yield (C); and harvest index (D). Bars indicate SE.

tended to be higher among the polyhalite-applied plants, nevertheless, only K_0 plants exhibited significantly lower HI, 0.41, compared to 0.47-0.48 among the K-applied treatments (Fig. 4D).

The polyhalite+MOP fertilizer treatments significantly increased the number of kernel rows in a corncob to about 13.6, compared to 13.3 and 12.9 in the MOP-applied and K_0 plants, respectively (Fig. 5A). Nevertheless, the fertilizer effect on the number of kernels per row was much greater; whereas K_0 and K_{60+0} treatments obtained nearly 35 kernels per row, all other treatments gave rise to significantly higher figures, from 38-41 kernels per row. Noteworthy was the unequivocal advantage of K_{30+30} over K_{60+0} in this yield determinant; with similar low K rates (60 kg K_2O ha^{-1}), the polyhalite+MOP obtained significantly greater numbers of kernels per row. Yet, this advantage was not preserved at the higher K rates (Fig. 5B). Consequently, the total number of kernels per corncob maintained a similar response pattern to the fertilizer treatment, being significantly higher under the higher K rates (Fig. 5C). Kernel size, determined in g $1,000^{-1}$ kernels, was significantly smaller under K_0, compared to K_{60+0} and to the various MOP+polyhalite combinations, while K_{120+0} had an intermediate kernel weight that did not differ from either K_0 or K_{60+0} (Fig. 5D). Grain quality parameters such as dry matter, starch, and protein contents ranged from 58-60%, 40-43%, and 4-5%, respectively, with no significant differences between treatments.

Economic considerations

Replacing MOP with polyhalite brought about a very slight increase in the economic input (cost) per ha of winter maize crop in northern Vietnam, as the fertilizers' prices were 0.09 and 0.11 million VND kg^{-1}, respectively. Outstanding for much lower input was the K_0 control (Fig. 6A), which did not receive any K fertilizer. However, the revenue from this treatment was by far the lowest of all other treatments. Naturally, the revenue response pattern to the fertilizer treatments (Fig. 6A) followed those of the kernel yield and quality (Figs. 4 and 5). The effects of the fertilizer treatments on the farmer's profit was clear (Fig. 6B): while K_0 elicited clear a negative return and the MOP-applied treatments produced very small profits (1.4-1.9 million VND ha^{-1}), the MOP+polyhalite strategy gave rise to considerably higher profits that ranged from 5.1-6.3 million VND ha^{-1}, 170-230% more than the profit obtained from farmer's usual fertilizer practice.

Discussion

An adequate plant K status is essential for maize crop growth and development throughout the growing season (Asante-Badu *et al.*, 2020). This principle is fully demonstrated by the significantly inferior crop performance under the lack of K application (K_0) in almost every parameter measured (Figs. 3-6). Sufficient crop K status is particularly important during the reproductive phase, when carbohydrates are remobilized and translocated from leaf and stem

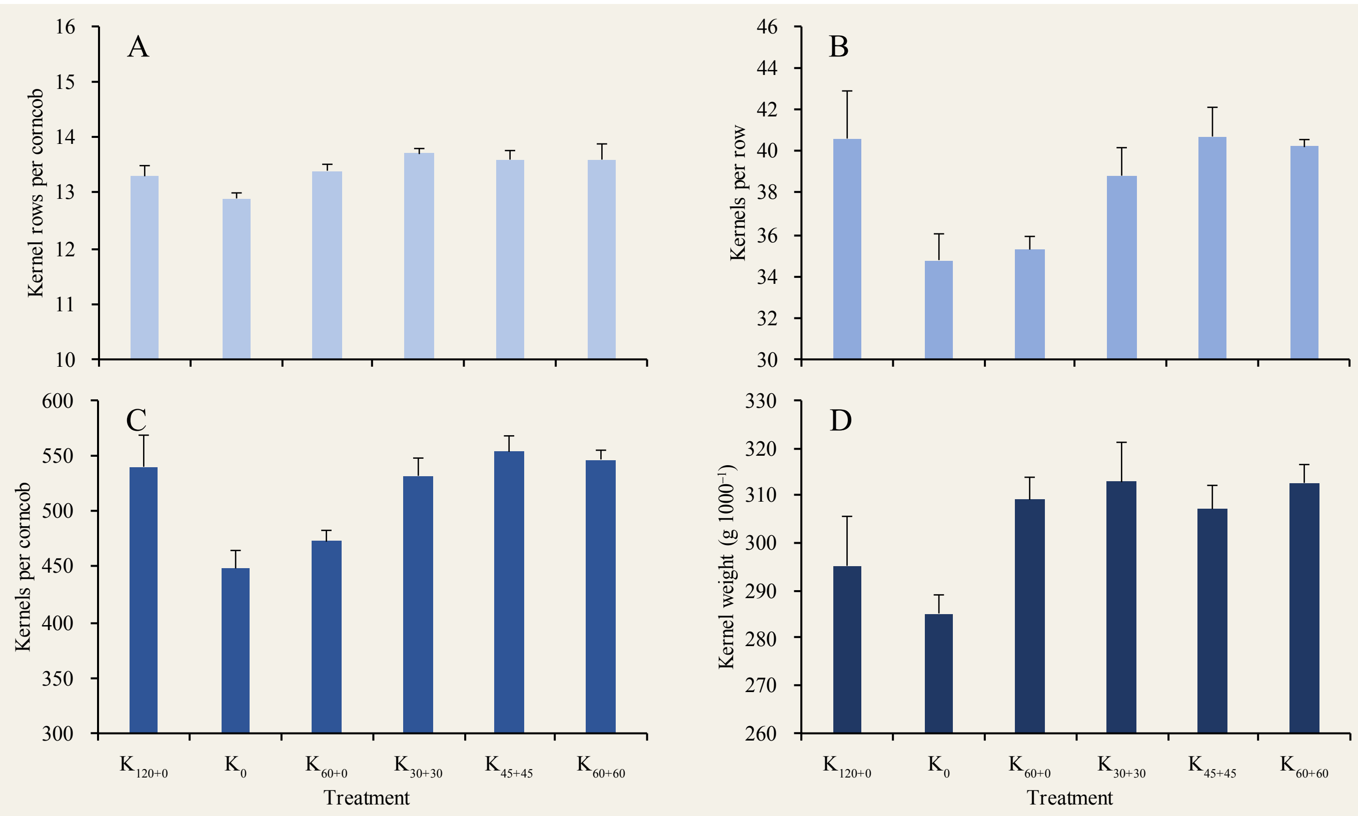


Fig. 5. Effects of fertilizer treatments on kernel yield determinants in winter maize crop grown in northern Vietnam. Kernel rows (A); kernel number per row (B); kernels per corncob (C); and kernel weight in g $1,000^{-1}$ kernels (D). Bars indicate SE.

tissues to the developing corncob and kernels (Pettigrew, 2008). Due to technical and financial reasons, farmers usually perform a pre-planting application of the complete seasonal fertilizer rate. This practice holds two major drawbacks: a transient increase in the soil salinity of the seedbed during the short but salt-sensitive germination and seedling establishment stages, on the one hand, which might be followed by too rapid nutrient depletion typical to the local acidic soils (Table 1) under the heavy rains of August (Fig. 2), on the other hand. Although K fertilizers were split between pre-plant and pollination, the differences in the vegetative biomass at harvest (Fig. 3B) indicate that this might have been the situation under the farmers' practice K_{120+0}, where a high MOP rate was applied. This, in comparison with the three MOP+polyhalite treatments, most of which obtained greater biomass under lower K rates and particularly with less MOP. As a slower-release fertilizer, and with relatively lower salt index (Yermiyahu *et al.*, 2019), polyhalite application seemed to reduce both risks of salt stress during plant establishment and rapid K depletion from the rhizosphere, thus promoting greater biomass.

Furthermore, polyhalite supplies other essential nutrients, such as Ca, Mg, and S that were possibly in deficit on the local soil. Calcium (Ca) is an essential plant nutrient playing multiple roles in the cell. It is important for membrane stability, cell integrity, cell division and elongation (Steward, 1974; Kirkby and Pilbeam, 1984; White and Broadley, 2003) and for multiple signal transduction pathways and activation (Monshausen, 2012). However, Ca can only transfer from one part of a plant to another through the xylem sap and hence, the plant cannot remobilize calcium from older tissues. To provide crop Ca requirements throughout the season, a steady availability level of this nutrient must therefore be preserved in the soil. Magnesium is part of chlorophyll in all green plants and is essential for photosynthesis and carbohydrate partitioning (Cakmak and Yazici, 2010; Farhat *et al.*, 2016). Gransee and Führs (2013) unraveled new insights into the role of Mg in increasing crop tolerance to various stresses that indicate changes in the crop Mg demand under adverse growth conditions. Sulfur (S) is recognized as the fourth major plant nutrient after N, P, and K (Khan *et al.*, 2005), and has been associated with high productivity (Kovar and Grant, 2011). Sulfur often interacts with N to significantly enhance crop productivity (Jamal *et al.*, 2010).

The contribution of polyhalite to prolonged K availability, and to more balanced crop nutrition was especially demonstrated when treatments K_{60+0} and K_{30+30} are compared. Although both treatments held similar K rates (60 kg K_2O ha^{-1}), the latter displayed significantly greater vegetative biomass (Fig. 3B) and kernel yield (Fig. 4A). The larger plant biomass under the polyhalite-applied treatments enhanced the reproductive potential of the maize crop, as indicated by the greater corncob dimensions (Fig. 4C), thus allowing additional kernel rows (Fig. 5A), significantly more kernels per row (Fig. 5B), and consequently, higher total kernel numbers (Fig. 5C). In addition, polyhalite application enhanced kernel weight (Fig. 5D), another indication of the higher capacity that this fertilizer provided to the maize crop productivity.

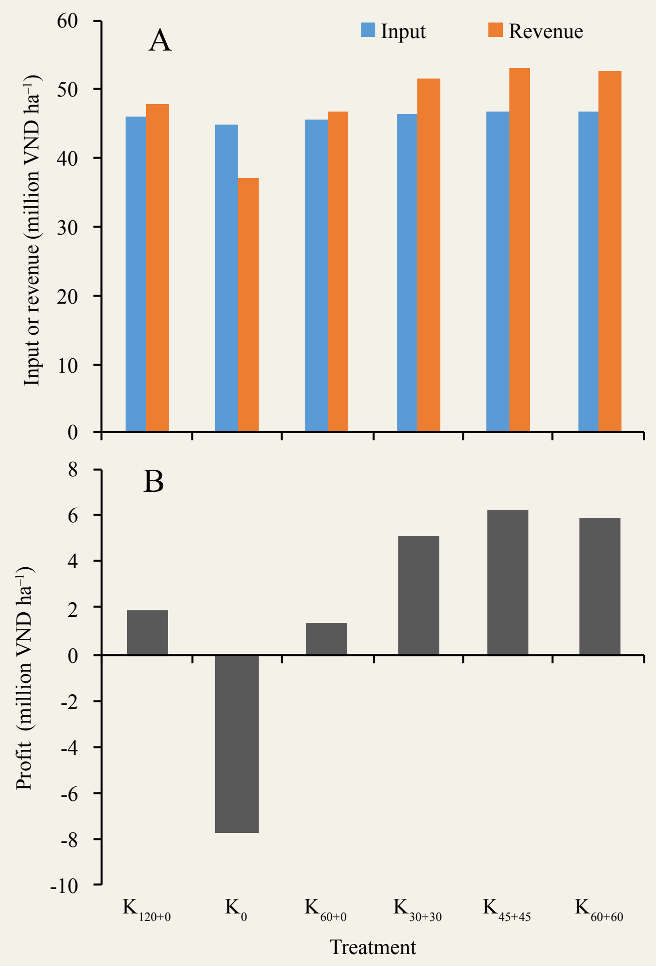


Fig. 6. Effects of fertilizer treatments on the input costs and revenue (A), and on the consequent profit (B) of winter maize crop in northern Vietnam, in local terms.

Winter maize crops in tropical regions commonly suffer from various pests and diseases due to the high temperature and humidity. Among pests, *Ostrinia nubilalis* is a stalk boring pest, whose feeding injury in maize might result in yield loss, increased infection of secondary pathogens that cause stalk and ear rots, ear drop, stalk breakage and lodging, all of which impedes harvest (Mason and Sappington, 2018). Corn aphids (*Rhopalosiphum maidis*) might also cause severe damage to tropical maize crops (Kuo *et al.*, 2006). Among microbial and fungal diseases, the bacterial stalk rot disease (*Erwinia chrysanthemi* pv. Zeae) has emerged in the recent years as one of the most important diseases in winter sown maize crops in India (Kumar *et al.*, 2017). Winter maize has the most susceptible stage coinciding with the annual monsoon rainfall, which aggravates the disease's development. This might have been the situation in northern Vietnam, where the maize winter crop encounters the peak of the rainy season (Fig. 2). BLSB (*Rhizoctonia solani*) is also considered as one of the emerging and severe pathogens limiting maize crop production under a changing climatic scenario (Singh and Shahi, 2012). Balanced mineral nutrition was often shown to enhance crop tolerance to various pests and diseases, simply because the healthier the plant the less vulnerable it is (Dordas, 2008; Huber *et al.*, 2012). Such a tendency was observed in the present study with all mentioned pathogens, with somewhat lower infestation rates occurring under the MOP+polyhalite treatments (Table 3). Nevertheless, no significant advantages could be elucidated for polyhalite regarding any of those pathogens. For unknown reasons, none of the pests or diseases reached infestation rates high enough to challenge the hypothesis.

Altogether, the combinations of MOP and polyhalite gave rise to significantly higher fodder yields, in grains as well as husks and corncobs (Fig. 4). Interestingly, the differences between the three combinations were not statistically significant for most of the yield parameters, suggesting that low K rates, such as 60 or 90 kg K_2O ha^{-1}, might be sufficient to obtain reasonable maize yields. However, this may be true under very few fertilizer application events. Assumingly, where fertilizer dose could be split into multiple application events, higher K rates might support greater yields (Witt *et al.*, 2006; Joshi *et al.*, 2014; Pandey *et al.*, 2019). Anyway, the economic analysis, which lacks statistical considerations, showed that under the circumstances of the present study, the polyhalite and MOP combination at a rate of 90 kg K_2O ha^{-1} was the most profitable practice, leaving the farmers' usual practice far behind. The economic analysis also clearly demonstrated that no K application (K_0) might lead to substantial loss of investment (Fig. 6B). In agreement with an increasing number of recent studies (Hoang *et al.*, 2016; Pavuluri *et al.*, 2017; Foxhoven and Below, 2018; Lillywhite *et al.*, 2020), the results obtained in the present one strongly support the inclusion of polyhalite in maize nutrition practices.

Conclusions

Adequate K supply is essential to profitable winter maize production under the climatic and edaphic conditions in northern Vietnam. Combining polyhalite and MOP at a K source ratio of 1:1 enhanced most of the aspects of maize crop performance, compared to local farmers' usual fertilizer practice. Moreover, the fertilizer input can be reduced from 120 to 90 kg K_2O ha^{-1}, with its positive environmental consequences.

Acknowledgement

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The paper "Polyhalite Effects on Winter Maize Crop Performance on Degraded Soil in Northern Vietnam" also appears on the IPI website.

Research Findings

Photo 1: Xu Xiang kiwifruit on the vine. Photo by the authors.

Impact of Alternative Polyhalite Fertilizers on 'Xu Xiang' Kiwifruit Yield and Quality in Shaanxi Province, China

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Abstract

China is the world-leading kiwifruit (*Actinidia deliciosa*) producer, however the mean fruit yield in China lags far behind other countries. This research examines possible reasons for this, and investigates the impact more balanced mineral nutrition could have on kiwifruit production. The polyhalite fertilizers Polysulphate® and MegaPoly™ were integrated into the common farmers' fertilization practice in Zhouzhi County, Xi'an City, Shaanxi Province – the main kiwifruit producing region in China. These fertilizers partly replaced the potassium (K) usually supplied through chemical fertilizers, and enriched the orchard with calcium (Ca), magnesium (Mg), and sulfur (S). Fertilizer application was split between two events: at budding and towards fruit enlargement. Total fruit yield was between 10.5 and 13.9 Mg ha^{-1}, with a tendency of yield enhancement in some of the polyhalite treatments. This tendency became highly significant within the yield of commercial-grade fruit, which ranged

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from 3.5 to 6.1 Mg ha^{-1}, compared to 2.0 Mg ha^{-1} for the control. Economic analysis showed that most of the polyhalite treatments gave rise to considerably higher profits for the farmer. However, the relatively low yields (approximately one third of the mean kiwifruit yield in New Zealand), and particularly the poor rates of commercial-grade yields (only 18-44% of the total yield), raise serious concerns about the consequences of excess nitrogen (N) fertilizer use in the experiment, a practice common in the region. The possibility that excess N has masked many of the benefits expected from the polyhalite fertilizers, including improved fruit size, yield, and fruit postharvest quality parameters, is discussed. Further investigation of the effects of polyhalite fertilizer on kiwifruit performance would be required under a more appropriate N fertilization regime.

Keywords: *Actinidia deliciosa*; balanced plant nutrition; MegaPoly; nitrogen; Polysulphate.

Introduction

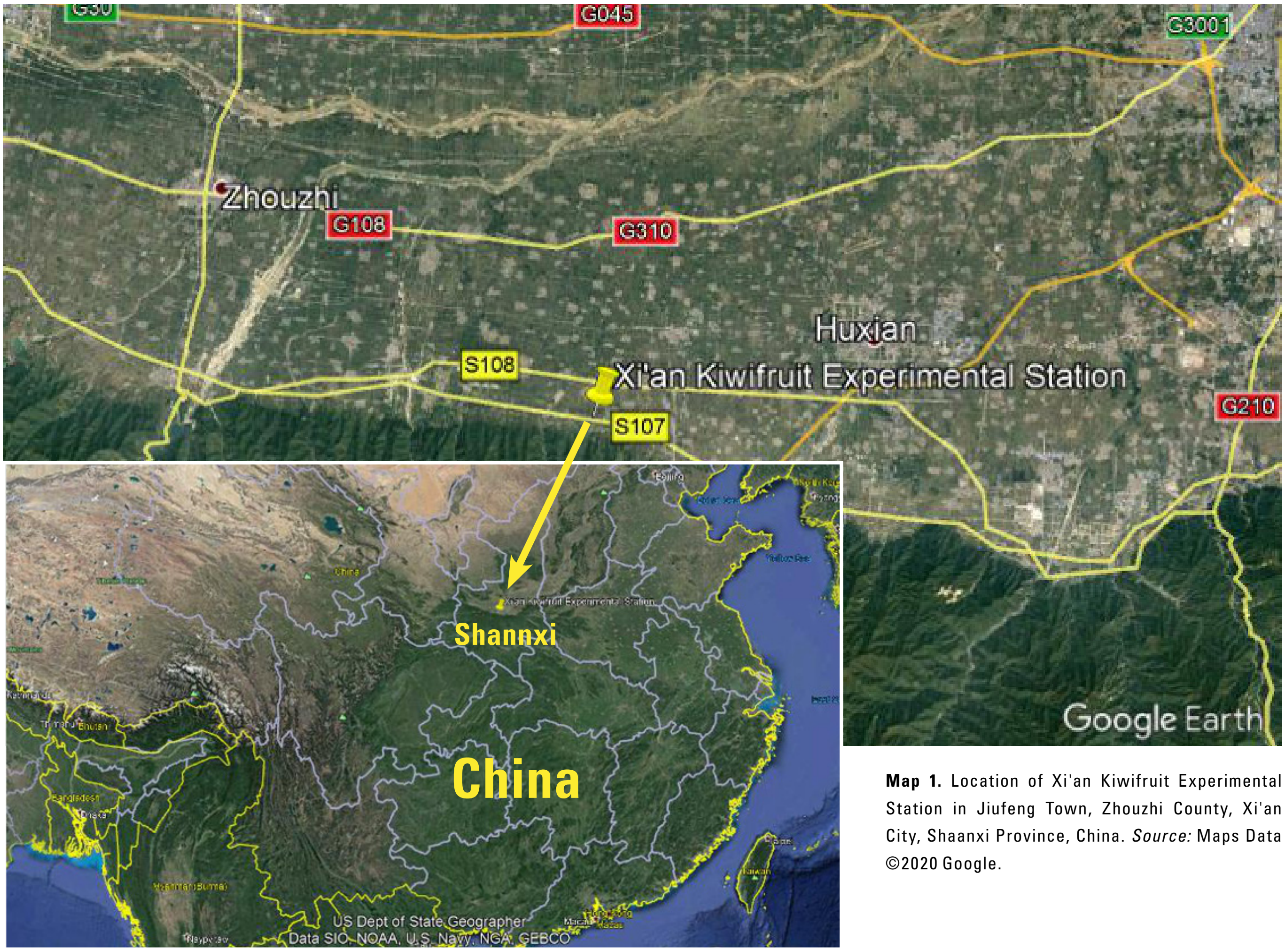
Kiwifruit or Chinese gooseberry is the edible berry of the woody vine *Actinidia deliciosa*, a species native to central and eastern China (Morton, 1987). In the early 20th century, cultivation of kiwifruit spread from China to New Zealand, where the first commercial plantings occurred. The fruit became popular during World War II, and has spread and been exported throughout the world (Morton, 1987) ever since. At present (2018), China is the world-leading annual kiwifruit producer, producing more than 2 million tonnes, about half the world's production, followed by Italy, New Zealand, Iran, Greece, and Chile (FAOstat, 2018). Nevertheless, the current mean kiwifruit yields in China, 12.1 Mg ha^{-1}, lag well behind that of New Zealand (36.8 Mg ha^{-1}) or those of other key kiwifruit producing countries (20.0-27.8 Mg ha^{-1}). There may be various reasons for this considerable yield gap. Assuming that no significant differences occur in the plant material between countries (similar cultivars and clones), that chilling requirements are fulfilled (Wang *et al.*, 2017), and that suitable climate conditions prevail during plant and fruit development, then improved agronomic practices may be the key to closing the yield gap.

Both viticulture and kiwifruit management are complex and require a high degree of precision to guarantee sufficient fruit set from pollination (Gianni and Vania, 2018; Mu *et al.*, 2018), and to maintain an appropriate ratio between vegetative and fruit growth (Minchin *et al.*, 2011). After considerate pruning and fruit thinning (Burge *et al.*, 1987; Boyd and Barnett, 2011), balanced crop mineral nutrition is an important tool for controlling vine growth and development, and providing timely nutrient supply for fruit development (Ferguson and Eiseman, 1983; Kotzé and de Villiers, 1989). After decades of surplus nitrogen (N) fertilization by the Chinese fruit industry in general, and by the kiwifruit industry in particular, significant attempts were made to reduce N application doses, thus minimizing its substantial environmental consequences (Tong *et al.*, 2004; Lu *et al.*, 2018) and increasing N use efficiency (Zhao *et al.*, 2013). With the growing awareness of the benefits of balanced mineral nutrition for kiwifruit (Pacheo *et al.*, 2008; Parent *et al.*, 2015), efforts have recently been made to promote a more balanced N, phosphorus (P), and potassium (K) nutrition in the kiwifruit orchards of China (Zhao *et al.*, 2017; Wang *et al.*, 2019).

The Chinese kiwifruit industry has paid little attention so far to the status of other essential macronutrients such as calcium (Ca), magnesium (Mg), and sulfur (S). Ferguson and Eiseman (1983) estimated the removal of Ca and Mg in a moderately productive kiwifruit orchard in New Zealand to be 100 and 25 kg ha^{-1}, respectively. In South Africa, Kotzé *et al.* (1989) described the distribution of the macronutrients N, P, K, Ca, and Mg among the organs of the kiwifruit vine during the growing season. Higher Ca concentration in several fleshy fruit, including kiwifruit, is a pre-requisite for lower incidence of Ca-related diseases and improved fruit nutritional value. Moreover, approximately 80% of the total Ca content of fruit is accumulated during the early weeks after fruit-set, suggesting that failure to deliver good fruit Ca nutrition at that time may lead to poor fruit Ca content at harvest (Montanaro *et al.*, 2014). An adequate Mg supply is essential for kiwifruit vine development and fruit yield (Smith *et al.*, 1987; Clark and Smith, 1988). This nutrient is pivotal to the photosynthesis apparatus and sugar metabolism, as demonstrated in analysis of kiwifruit leaves (Dimassi-Theriou and Bosabalidis, 1997). Sulfur interacts with N to significantly enhance protein metabolism (Jamal *et al.*, 2010) and has often been associated with high productivity (Dick *et al.*, 2008). With the increasing utilization of chemical NPK fertilizers in the Chinese orchards, other macro- and micronutrients were left behind (Zhao *et al.*, 2017). Recently, the growing motivation to explore and enhance kiwifruit nutritional values (Ma *et al.*, 2019), has encouraged the search for new sources of secondary macronutrients.

Polyhalite is a natural mineral which occurs in sedimentary marine evaporates and consists of a hydrated sulfate of K, Ca, and Mg with the formula: $K_2Ca_2Mg(SO_4)_4 \cdot 2(H_2O)$. The deposits found in Yorkshire, in the UK, typically consist of K_2O: 14%, SO_3: 48%, MgO: 6%, CaO: 17%. As a fertilizer providing four key plant nutrients – S, K, Mg, and Ca – polyhalite may offer attractive solutions to crop nutrition. In addition, polyhalite is less water soluble than more conventional sources (Yermiyahu *et al.*, 2017; Yermiyahu *et al.*, 2019) and is, therefore, a suitable fertilizer to supply these four nutrients during rainy growing seasons. Polyhalite is available in its natural form as Polysulphate®. Due to its relatively low K content, fortified polyhalite formulations are also available, among which is MegaPoly™, comprising of 32, 6.7, 24.3, and 8.6% K_2O, MgO, SO_3, and CaO, respectively.

The objectives of the present study were to evaluate the effects of Polysulphate and MegaPoly on kiwifruit fruit yield and quality, and to determine appropriate application doses and timing for these fertilizers for the kiwifruit production system at Zhouzhi County, Xi'an City, Shaanxi Province, China.



Map 1. Location of Xi'an Kiwifruit Experimental Station in Jiufeng Town, Zhouzhi County, Xi'an City, Shaanxi Province, China. *Source:* Maps Data ©2020 Google.

Materials and methods

The experiment was carried out in 2019 at Xi'an Kiwifruit Experimental Station (34°3'49.54"N, 108°26'41.44"E), which is in the main kiwifruit cultivation area in Jiufeng Town, Zhouzhi County, Xi'an City, Shaanxi Province (Map 1). The region is defined as having a warm temperate continental monsoon climate (Fig. 1). The annual average rainfall is 660 mm, annual mean temperature is 13.2°C, with 1,867.5 hours of sunshine annually. In 2019, July and August were the warmest months, with average maximum temperatures of 34°C, and average minimum night temperatures of 24 and 23°C, respectively. January was the coldest month, with average maximum and minimum temperatures of 7 and 0°C, respectively. The dry season occurred from December to March, and the wet season from April to November, with rainfall peaking in August and September with 110 and 161 mm, respectively (Fig. 1). The region's kiwifruit growing season begins with budding in early April and ends at harvest in November, corresponding with the wet season. The soil at the experiment location was sandy loam with a fertile nutrient status.

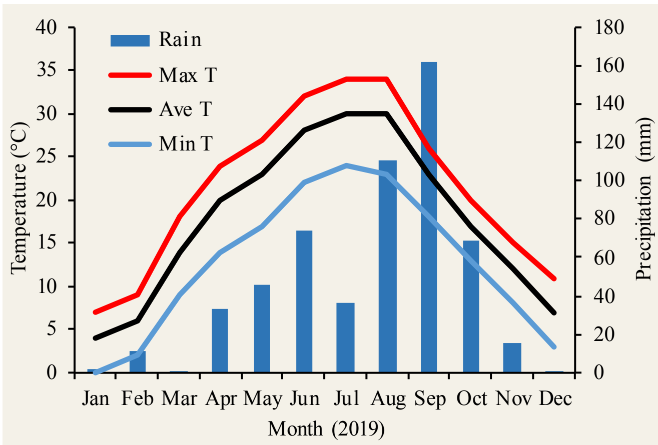


Fig. 1. Weather conditions during the experiment in 2019 at Zhouzhi, near the experiment location, including monthly mean maximum, average and minimum temperature, and monthly precipitation.
Source: www.worldweatheronline.com

Table 1. Detailed description of the fertilizer treatments. The amount of K_2O applied each time through each fertilizer is given in parentheses.

Treatment	Plant developmental stage upon fertilizer application					Total K_2O
	Budding		Fruit enlargement			
	Compound NPK 25:5:5	Polysulphate	Compound NPK 20:5:15	K_2SO_4	MegaPoly	
	kg ha^{-1}					
Control	750 (37.5)	-	750 (112.5)	300 (150)	-	300.0
T_1	750 (37.5)	375 (52.5)	750 (112.5)	300 (150)	-	352.5
T_2	750 (37.5)	375 (52.5)	750 (112.5)	-	300 (96)	298.5
T_3	750 (37.5)	375 (52.5)	750 (112.5)	-	600 (192)	394.5
T_4	750 (37.5)	375 (52.5)	450 (67.5)	-	300 (96)	253.5
T_5	750 (37.5)	750 (105)	450 (67.5)	-	300 (96)	306.0
T_6	750 (37.5)	750 (105)	750 (112.5)	-	300 (96)	351.0

The experiment was conducted using the region's main cultivar, 'Xu Xiang', on plants 8 years after grafting, with 4×2 m spacing and trellised on a greenhouse frame, common to the region. Crop management was consistent with the regional professional recommendations.

Fertilizers were delivered twice during the growing season: on budding in early April, and at the fruit enlargement in July. Upon budding, all treatments received compound NPK fertilizer (25:5:5 of $N:P_2O_5:K_2O$) at 750 kg ha^{-1}; Polysulphate was applied at 0, 375, and 750 kg ha^{-1} to the control, T_1-T_4, and T_5-T_6 treatments, respectively (Table 1). At fruit enlargement, a second application of compound NPK fertilizer with slightly reduced N and increased K_2O ratios (20:5:15) was carried out at 750 kg ha^{-1} to the control, T_1-T_3, and T_6 treatments, and 450 kg ha^{-1} to T_4-T_5; additionally, K_2SO_4 was applied to the control and T_1 (300 kg ha^{-1}); and MegaPoly was applied at 600 kg ha^{-1} to T_3 and 300 kg ha^{-1} to T_2 and T_4-T_6 (Table 1).

The experiment was designed in random blocks with 3 replicates. Each replicate covered 111 m^2 and consisted of 14 plants (333 m^2 and 42 vines per treatment). Statistical analysis was carried out using SPASS 17.0.

Soil samples were taken from each plot at early, mid, and late season stages on 12 April, 20 July, and 25 October 2019, respectively, from the upper (0-20 cm) and the deeper (20-40 cm) layers of the rhizosphere. Soil status measurements included pH, organic matter content, alkali-hydrolyzed N, available P, available K, exchangeable Ca, and exchangeable Mg.

At harvest, fruit were picked separately from each vine, weighed, and the number of fruit per plant and the total yield were determined. Fruit were sorted by size and shape to determine mean fruit size, and the absolute and rate of the commercial-grade yield. Representative commercial-grade fruit were selected from each treatment and photographed. Fruit quality parameters were determined at harvest using 10 fruit per treatment. Fruit firmness was determined using a penetrometer. Fruit were peeled and homogenized, and the total soluble solids (TSS) and titratable acids (TA) were determined, as well as the content of vitamin C (ascorbic acid). Twenty representative commercial-grade fruit were stored in ambient conditions to determine fruit firmness and TSS, as relevant fruit quality measures, after 5 and 10 days of shelf life.

Economic analysis was carried out, based on the commercial-grade yield, taking into account the total costs and the farmer's revenue to determine the farmer's profit per hectare.

Results

Significant changes were recorded in the soil properties of the experimental vineyard during the kiwifruit growing season of 2019. Soil pH was significantly higher in the upper layer (0-20 cm) compared to the deeper layer (20-40 cm), at 6.31 and 5.33, respectively. In the upper layer, the average pH was quite constant throughout the season, while it consistently decreased in the deeper layer from 5.69 at budding to 5.24 toward harvest. In contrast to the average pH across treatments, significant changes occurred within and between treatments (Table 2). At both early and mid-season measurements, control soil pH was significantly higher than in most of the other treatments. However, at the late stage, the control soil pH became the lowest among all treatments in both soil layers (Table 2).

Soil organic matter (OM) contents were very high, ranging from 8-41% (Table 2). The upper layer displayed much higher OM contents, with 26.9, 36.9, and 28.6% at the early, mid, and late season stages, respectively, compared to the decreasing average OM contents in the deeper layer, with 14.7, 11.3, and 8.7%, respectively. Soil OM content significantly differed between treatments at the early season measurements. The differences were significant also at the mid-season stage but

Table 2. Effects of fertilizer treatments on soil pH, organic matter, alkali-hydrolyzable N, and available P contents during the 2019 kiwifruit growing season at Xi'an Kiwifruit Experimental Station in Jiufeng Town, Zhouzhi County, Xi'an City, Shaanxi Province, China. Refer to Table 1 for detailed description of the fertilizer treatments.

Crop phase	Soil layer	Treatment	pH	Organic matter	Alkali-hydrolyzable N	Available P
				g kg^{-1}	*mg kg^{-1}*	*mg kg^{-1}*
Early (12 Apr)	0-20 cm	Control	6.88 a	29.4 ab	116.7 abc	200.9 a
		T_1	5.87 b	20.0 c	103.8 c	222.5 a
		T_2	5.96 b	24.5 bc	113.2 abc	235.3 a
		T_3	5.88 b	22.3 bc	102.7 c	222.2 a
		T_4	6.44 ab	26.0 abc	107.3 bc	220.5 a
		T_5	6.40 ab	33.3 a	133.0 a	286.1 a
		T_6	6.43 ab	32.5 a	131.8 ab	230.7 a
	20-40 cm	Control	7.00 a	15.1 bc	77.0 b	90.3 b
		T_1	5.21 c	9.1 d	49.0 c	84.7 b
		T_2	4.87 c	13.1 bcd	67.7 bc	141.5 ab
		T_3	5.20 c	11.4 cd	58.3 bc	112.7 ab
		T_4	5.22 c	15.0 bc	72.3 bc	182.0 a
		T_5	6.28 ab	16.3 b	73.5 b	132.1 ab
		T_6	6.06 b	22.8 a	113.2 a	184.7 a
Mid (20 Jul)	0-20 cm	Control	7.14 a	27.4 c	141.2 b	192.3 b
		T_1	5.89 c	39.1 a	180.8 a	315.1 a
		T_2	5.86 c	38.1 ab	185.5 a	308.5 a
		T_3	6.28 bc	34.0 b	173.8 a	319.5 a
		T_4	6.33 b	39.7 a	185.5 a	253.0 a
		T_5	6.55 b	40.6 a	184.3 a	268.7 a
		T_6	6.58 b	39.4 a	182.0 a	269.0 a
	20-40 cm	Control	6.90 a	14.7 a	78.1 a	52.1 d
		T_1	5.03 cd	10.0 b	71.2 ab	159.7 a
		T_2	4.41 d	10.3 b	78.2 a	149.7 ab
		T_3	5.27 bc	10.7 b	60.7 b	124.0 bc
		T_4	4.77 cd	10.9 b	67.7 ab	157.2 a
		T_5	5.94 b	11.9 ab	73.5 ab	114.1 c
		T_6	5.47 bc	10.8 b	63.0 ab	93.7 c
Late (25 Oct)	0-20 cm	Control	6.13 b	27.8 a	154.0 a	266.4 a
		T_1	6.26 b	26.0 a	157.5 a	274.8 a
		T_2	6.17 b	25.5 a	152.8 a	265.0 a
		T_3	5.94 b	27.4 a	166.8 a	294.9 a
		T_4	6.30 b	30.5 a	170.3 a	294.6 a
		T_5	6.20 b	30.7 a	162.2 a	311.9 a
		T_6	6.83 a	32.0 a	161.0 a	289.9 a
	20-40 cm	Control	4.98 b	7.8 b	63.0 ab	163.4 ab
		T_1	5.01 b	8.6 b	77.0 ab	137.3 b
		T_2	5.25 b	8.2 b	66.5 ab	185.9 ab
		T_3	4.91 b	8.7 ab	73.5 ab	153.5 ab
		T_4	5.08 b	9.2 ab	82.8 a	152.2 ab
		T_5	5.17 b	9.7 a	73.5 ab	217.1 a
		T_6	6.31 a	8.4 ab	57.2 b	132.6 b

Different letters indicate significant differences within a column at $P<0.05$.

were inconsistent with the former one, and almost disappeared at the late stage of crop development (Table 2).

Similar to soil pH and OM content, the average alkaline-hydrolyzable N content was substantially higher in the upper than in the deeper soil layer, 151 vs. 71 mg kg^{-1}, respectively. In the upper layer, the alkaline-hydrolyzable N content increased from 115 mg kg^{-1} at budding to 176 mg kg^{-1} at the mid-season check, and remained quite stable until the end of the season. In the deeper layer, this parameter was very stable at 70-73 mg kg^{-1} throughout the season. Although significant differences did occur in soil available N between treatments (Table 2), these were inconsistent and, furthermore, could

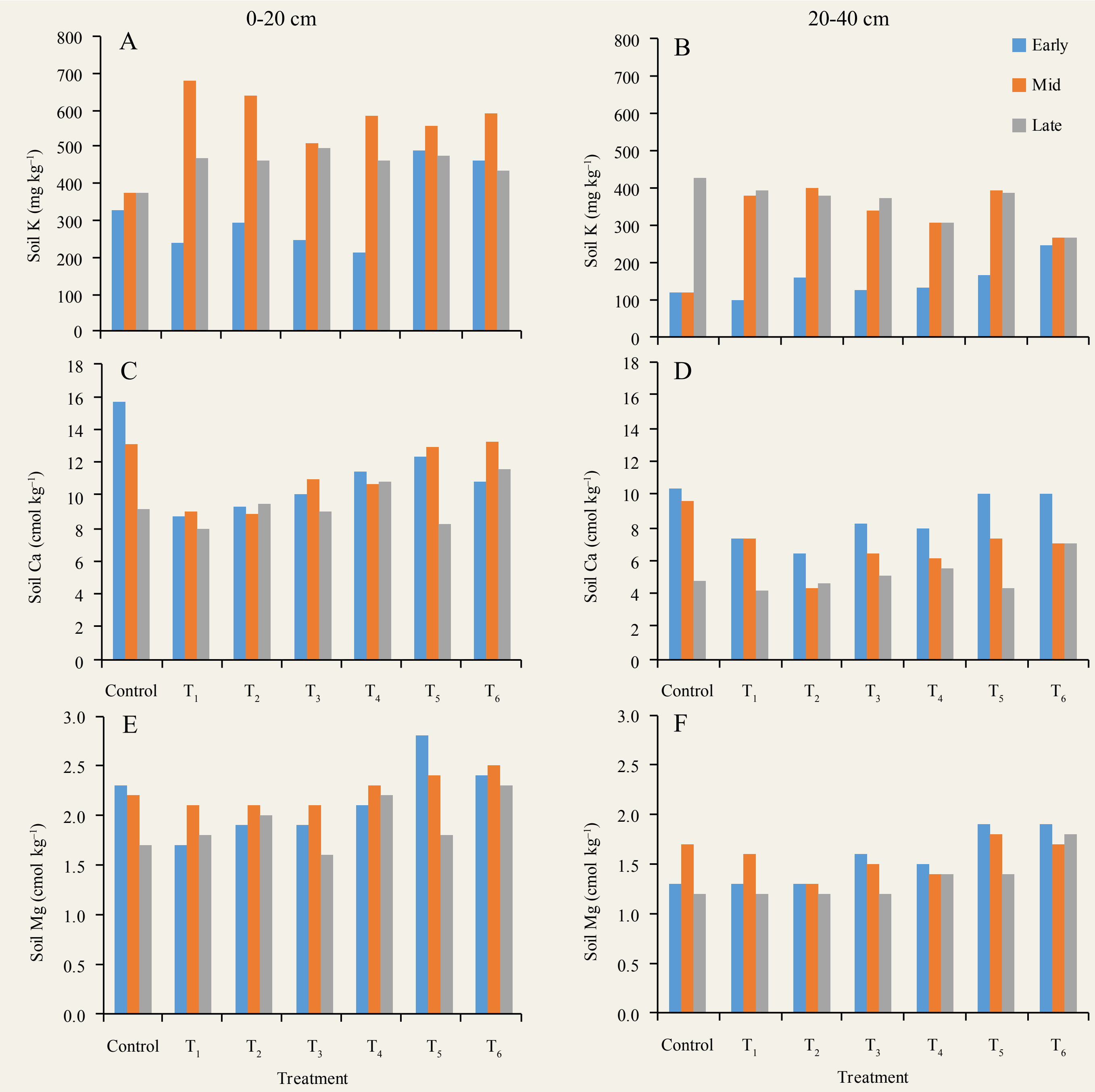


Fig. 2. Effects of fertilizer treatments on the soil available K (A, B), Ca (C, D), and Mg in the upper (0-20 cm; A, C, E) and deeper (20-40 cm; B, D, F) layers at the early, middle, and late stages (12 Apr, 20 Jul, and 25 Oct, respectively) of the kiwifruit growing season at Xi'an Kiwifruit Experimental Station in Jiufeng Town, Zhouzhi County, Xi'an City, Shaanxi Province, China. Refer to Table 1 for detailed description of the fertilizer treatments.

Table 3. Effects of fertilizer treatments on kiwifruit yield parameters. Values express means ± SE. Refer to Table 1 for detailed description of the fertilizer treatments.

Treatment	Mean fruit weight	Fruit number	Yield		Commercial yield	
	g fruit⁻¹	*Fruit plant⁻¹*	*kg plant⁻¹*	*Mg ha⁻¹*	*Mg ha⁻¹*	*%*
Control	61.42 ± 0.34	124 b	7.69 b	10.90 b	1.971 e	18.08
T_1	62.62 ± 2.73	125 b	7.90 b	11.21 b	3.258 d	29.06
T_2	67.88 ± 3.63	144 a	9.78 a	13.87 a	6.107 a	44.03
T_3	63.22 ± 3.58	116 c	7.43 c	10.54 c	3.476 c	32.98
T_4	66.01 ± 2.75	125 b	8.38 b	11.88 b	4.868 b	40.98
T_5	63.88 ± 0.40	144 a	9.32 ab	13.22 ab	3.877 d	29.33
T_6	67.57 ± 3.24	114 c	7.97 b	11.31 b	4.762 ab	42.10

Different letters indicate significant differences within a column at P<0.05.

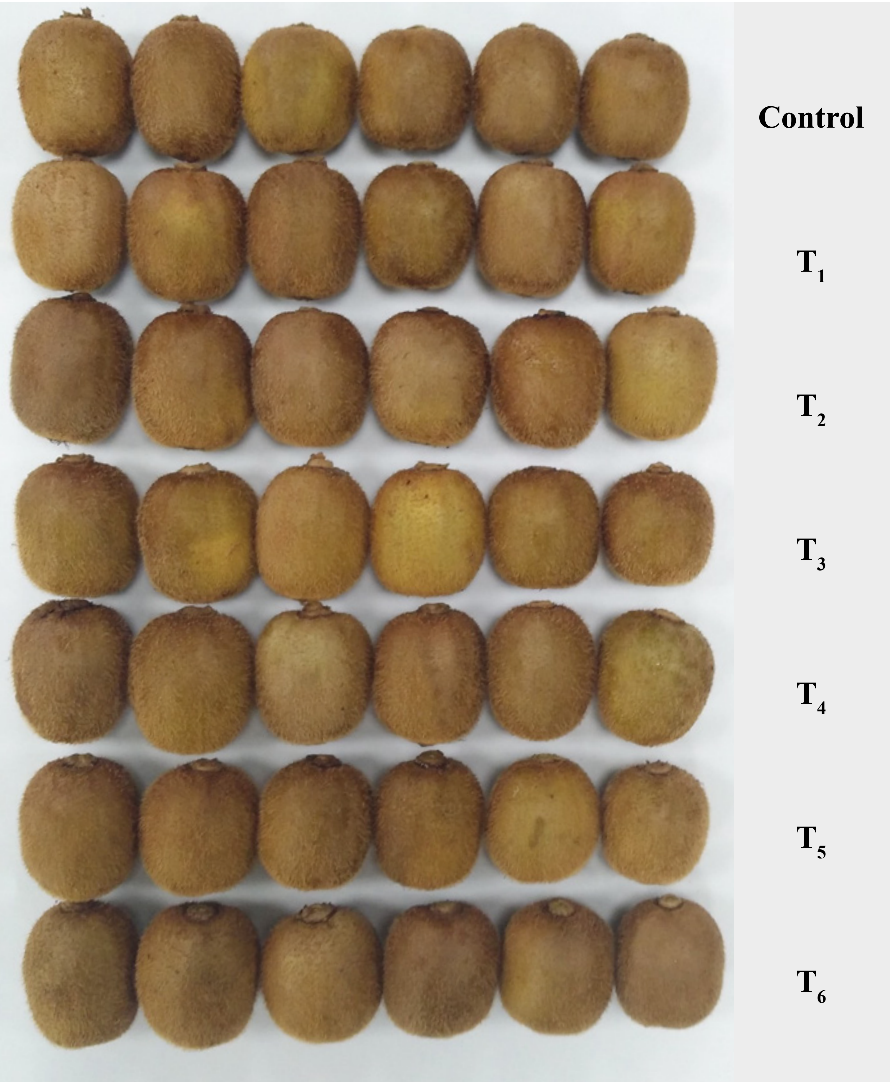


Fig. 3. Effects of fertilizer treatments on appearance of commercial-grade fruit at harvest. Refer to Table 1 for detailed description of the fertilizer treatments.

not be associated with the differences in N application rate between treatments. For example, T_3 and T_4, which received 337.5 and 277.5 kg N ha^{-1}, respectively, showed no significant differences in their soil alkaline-hydrolyzable N content (Table 2).

Soil available K was significantly higher at the earliest sampling date (12 Apr) in T_5 and T_6, probably due to the higher Polysulphate application rate during the early season. This effect was much clearer in the upper soil layer, but could be identified in the deeper one as well (Fig. 2A, B). Soil available K was greatly affected by the second K application of polyhalite fertilizers at the fruit enlargement stage, expressed as significantly higher values compared to the control, which received compound NPK and K_2SO_4. The effects of the second fertilizer application was very clear in the deeper soil layer, although the nutrient levels were generally higher in the upper layer. Interestingly, the strategy of an early high Polysulphate application strengthened by a later MegaPoly application, as practiced in T_5 and T_6, seemed to support high and stable levels of soil available K throughout the season (Fig. 2A, B).

Soil available Ca and Mg levels were significantly higher in the upper than in the deeper soil layer (Fig. 2C-F). Treatments T_5 and T_6 displayed significantly higher soil available Ca compared to T_1 and T_2, while T_3 and T_4 exhibited intermediate levels. Surprisingly, the control showed high soil available Ca levels, at least during the early stages of the growing season (Fig. 2C, D). Soil available Mg levels tended to be higher in treatments T_5 and T_6, particularly during the earlier stages (Fig. 2E, F).

While fertilizer treatments did not show any clear impact on the mean fruit weight, the number of fruit per plant was highest (144) in treatments T_2 and T_5, lowest at T_6 and T_3 (114 and 116, respectively), and intermediate (124-125) in the other treatments (Table 3). Consequently, the total yield was highest at T_2 (13.87 Mg ha^{-1}), lowest at T_3 (10.54 Mg ha^{-1}), and intermediate at the control, T_1, T_4, and T_6. Although T_5 exhibited a high yield, 13.22 Mg ha^{-1}, it did not statistically differ from the highest and the intermediate levels (Table 3).

The commercial yield, following fruit sorting according to size distribution and external appearance, was much smaller, ranging from 1.971-6.107 Mg ha^{-1}, or 18-44% of the total yield. Thus, T_2 displayed the highest commercial yield, T_4 and T_6 were second best, while T_1, T_3, and T_5 had low to intermediate levels, and the control exhibited the least commercial yield level (Table 3).

At harvest, fruit appearance (Fig. 3), as well as quality parameters of the commercial-grade fruit were very slightly affected by the fertilizer treatments (Table 4). Fruit firmness ranged from 48.7-52.7 N, with T_6 fruit significantly firmer than T_1 fruit, whereas fruit of all other treatments demonstrated intermediate firmness values that did not differ from the T_1 and T_6 treatments (Table 4). Fruit TSS varied from 8.4-9.13%, with no statistical differences between treatments. Titratable acidity (TA) ranged from 0.77-0.84%, and the TSS/TA ratio from 10-11.87, with no significant differences between treatments, at this stage. Fruit vitamin C content at harvest was 99.3 mg 100 g^{-1} in T_3 fruit, significantly higher than in the control, T_1, T_2, and T_6 fruit that ranged from 69.8-74.4 mg 100g^{-1}, while T_4 and T_5 exhibited intermediate vitamin C content of about 85 mg 100 g^{-1} that did not differ significantly from the other treatments (Table 4).

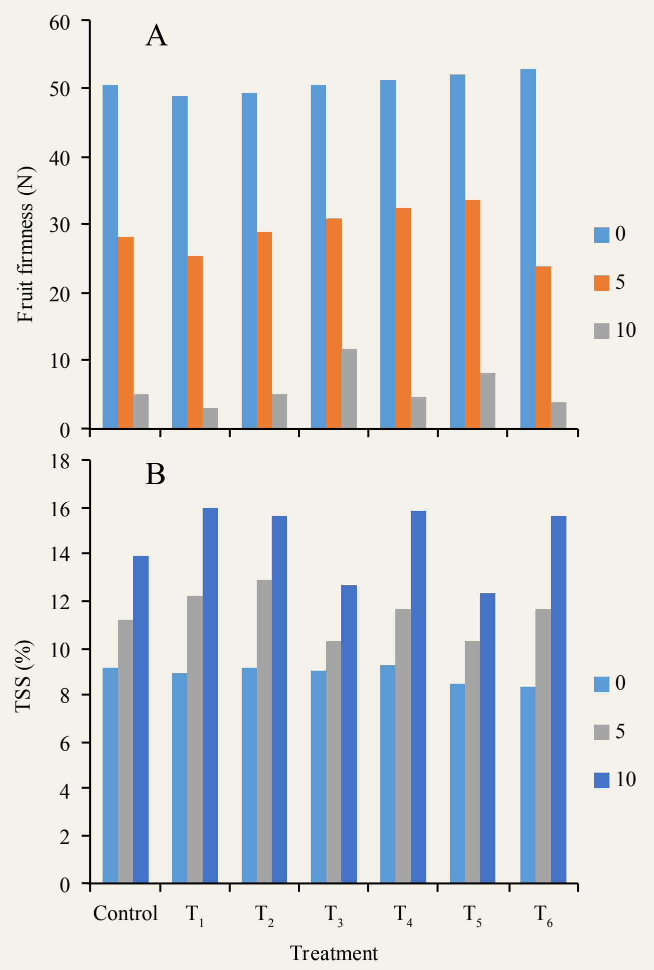


Fig. 4. Effects of fertilizer treatments on fruit firmness degradation (A), and on the rise of the total soluble solids (B) in Xu Xiang kiwifruit at harvest (day 0), and after 5 and 10 days of shelf-life at 20°C. Refer to Table 1 for detailed description of the fertilizer treatments.

Table 4. Effects of fertilizer treatments on fruit quality parameters (fruit firmness; total soluble solids [TSS]; titratable acids [TA]; and vitamin C content) of Xu Xiang kiwifruit at harvest. Refer to Table 1 for detailed description of the fertilizer treatments.

	Firmness	TSS	TA	TSS/TA	Vitamin C
	N	------------%	------------		*mg 100g^{-1}*
Control	50.6 ab	9.13	0.81	11.27	71.08 b
T_1	48.7 b	8.89	0.78	11.40	69.81 b
T_2	49.2 ab	9.12	0.77	11.84	72.53 b
T_3	50.5 ab	9.03	0.77	11.73	99.31 a
T_4	51.3 ab	9.32	0.8	11.65	85.7 ab
T_5	52.2 ab	8.48	0.78	10.87	84.37 ab
T_6	52.7 a	8.4	0.84	10.00	74.4 b

Different letters indicate significant differences within a column at P<0.05.

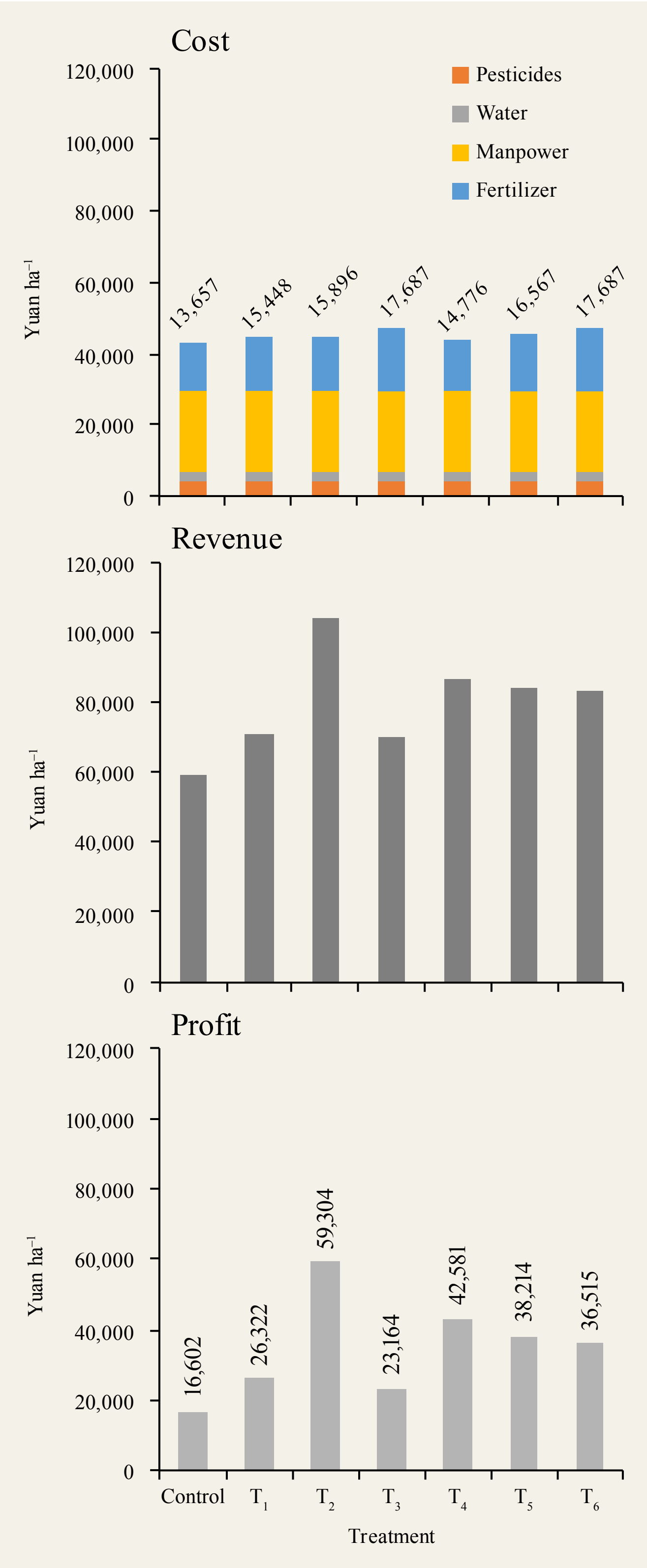


Fig. 5. Economic analysis of fertilizer treatments in kiwifruit production in China. Refer to Table 1 for detailed description of fertilizer treatments.

Fruit firmness declined rapidly under shelf-life conditions after harvest. This decline was slightly slower among T_3-T_5 fruit. After 10 days, fruit firmness was significantly higher in T_3 fruit (Fig. 4A). Fruit of treatments T_3 and T_5 also exhibited the lowest TSS rates among all treatments (Fig. 4B), indicating a slower ripening processes.

Economic analysis carried out using the experiment results showed that the effects of the fertilizer treatments on the total costs of kiwifruit production was very small, adding no more than 4K Yuan ha^{-1} (Fig. 5). The differences in the yield of commercial-grade fruit had consequent impacts on the farmer's revenue. Treatment T_2 obtained 104K Yuan ha^{-1}, while revenue from treatments T_4-T_6 varied from 83-86.5K Yuan ha^{-1}, T_1 and T_3 generated about 70K Yuan ha^{-1}, and the control returned the least, with just below 60K Yuan ha^{-1} (Fig. 5). Nevertheless, the differences in the farmer's profit were much more pronounced between treatments. T_2 obtained the highest profit, 59.6K Yuan ha^{-1}, 257% greater than the control, 57% of it's revenue, and 132% of it's total costs. The profits of treatments T_4-T_6 varied from 36.5-42.6K Yuan ha^{-1}, indicating intermediate performance levels, only 120-160% better than the control. Treatments T_1 and T_3 exhibited substantially inferior profits of 23-26.3K Yuan ha^{-1}, only 40-60% above control (Fig. 5).

Discussion

The present study was carried out in the heart of a major kiwifruit production region in China, on a very fertile soil, as indicated by the high OM contents (Table 2). On such soils, fertilizer application, and particularly N dose application, should be considered very carefully to maintain balanced crop nutrition. A recent study carried out in the same region (Lu *et al.*, 2018) concluded that the current level of N fertilization in kiwifruit orchards (900 kg N ha^{-1}) was very excessive, and reducing the N fertilizer rate by 25-45% could not only guarantee fruit yield, but also reduce N accumulation and loss. Zhao *et al.* (2017) suggested an annual N dose of 450 kg ha^{-1} as an optimum to obtain high kiwifruit yields, however these authors did not examine any lower N dose. In the present study, N application dose was reduced further and ranged from 277.5-337.7 kg N ha^{-1}. However, Pacheo *et al.* (2008) found that kiwifruit N requirements were much smaller, no more than 60 kg ha^{-1}. Ferguson and Eiseman (1983) showed that annual N removal by fruit and pruning was 78 kg ha^{-1} under kiwifruit yield of 16 Mg ha^{-1}. Assumingly, heavier yields would require greater N inputs, however, with considerably lower yield levels in the present study, an annual dose of about 300 kg N ha^{-1} appears substantially higher than required.

Excessive N application not only causes serious environmental consequences (Tong *et al.*, 2004; Lu *et al.*, 2018; Wang *et al.*, 2019), but also leads to imbalanced vine growth at the expense of the reproductive development (Minchin *et al.*, 2011). In addition, the temperature regime during the summer in Shaanxi seems considerably warmer (Fig. 1) than the optimum of 17°C for high kiwifruit yield and quality (Snelgar *et al.*, 2005), thus promoting further vegetative growth. These conditions may provide a partial explanation to the relatively low yield. Moreover, the average fruit size of all treatments ranged from 61-68 g (Table 3), far below the desired commercial range of 80-120 g fruit^{-1}. Although excess N application was not shown to directly cause decreased fruit size in kiwifruit (Morton, 2013), indirect effects of the surplus vegetative growth might have occurred. Excess foliage might have disrupted the pollination, leading to small numbers of seeds and consequently, to small fruit size and fruit developmental disorders (Gianni and Vania, 2018). In addition, overage shading is also known to restrict fruit size (Grant *et al.*, 1984; Blattmann *et al.*, 1988; Testoni *et al.*, 1990). So, excess N application alone can provide explanations for the poor rates of commercial-grade fruit, 18-44%, in the present study (Table 3).

In spite of the restrictions of excess N application, the polyhalite fertilizer treatments had significant influences on the yield (Table 3). Interestingly, T_3, with the highest seasonal K dose (Table 1), obtained the lowest fruit yield (Table 3). When K doses were reduced from about 400 to 350 kg ha^{-1}, yields were enhanced. A further reduction in K dose to 300 kg K_2O ha^{-1}, excluding the control, gave rise to the highest yields, and a further reduction to 250 kg K_2O ha^{-1} did not result in a great difference ot the yield (Table 3). In spite of the pivotal role of K in the remobilization and translocation of carbohydrate reserves and produced sugars to the developing fruit (Zörb *et al.*, 2014), this nutrient did not seem to be a yield-limiting factor in the present study. However, some advantage may be attributed to the increase in the available soil K content following polyhalite fertilizer application, particularly during the fruit development stage (Fig. 2), partially explaining the significantly higher commercial-grade yields of all treatments compared to the control (Table 3).

The polyhalite fertilizer treatments had much more significant effects on the rate of commercial-grade yield, with T_2, T_6, and T_4 obtaining 40-44%, compared to 18% in the control, and 29-33% in the other treatments (Table 3). The differences among treatments T_1-T_6 did not provide any adequate explanation for the differences in the commercial-grade yields between the two groups, neither did the soil analyses carried out during the experiment (Table 2; Fig. 2). It may be postulated, however, that the greater supply of Ca, Mg, and S to treatments T_2-T_6 (and S to T_1) enhanced fruit growth and development (Smith *et al.*, 1987; Clark and Smith, 1988).

The duration of fruit storage and shelf life, which are pivotal for the assessment of kiwifruit produce quality, are evaluated through the reduction of fruit firmness, and by the increase in TSS resulting from starch degradation; the slower the rate of change the better (Johnson *et al.*, 1995). While excess N accelerates postharvest fruit degradation (Johnson *et al.*, 1995; Vizzotto *et al.*, 1999; Morton, 2013), improved K, and moreover, Ca and Mg nutrition tend to extend kiwifruit shelf life (Clark and Smith, 1988). In the present study, treatments T_3 and T_5 exhibited a clear tendency to delay fruit firmness and starch degradation (Fig. 4). Unfortunately, fruit nutrient content at harvest was not examined and hence, the association of polyhalite application with postharvest kiwifruit performance, and especially, the direct mechanisms involved, awaits further research.

An economic analysis founded on the commercial-grade yields unequivocally showed that T_2, with moderate doses of Polysulphate and MegaPoly, at budding and at fruit enlargement, respectively, gave rise to the highest profit for the farmer (Fig. 5). However, understanding the reasons for the advantage of T_2 over T_4-T_6 would require further investigation. T_1 and the control, on the one hand, and T_3, on the other, all of which exhibited relatively low profits, might have represented the effect on profit from the deficient and or excess K, Ca, Mg, and S application rates, respectively.

In conclusion, application of polyhalite fertilizers, Polysulphate at budding and MegaPoly at fruit enlargement, demonstrated remarkable potential to enhance kiwifruit yield and quality. Nevertheless, the real contribution of these fertilizers should be revisited with a more balanced N fertilization approach.

Acknowledgements

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The paper "Impact of Alternative Polyhalite Fertilizers on 'Xu Xiang' Kiwifruit Yield and Quality in Shaanxi Province, China" also appears on the IPI website.

Research Findings

Photo 1: Maize demonstration plot in Andrah Pradesh. Photo by the authors.

Response in Maize to Applied Potassium: Results from Field Demonstrations in the States of Andhra Pradesh, Chhattisgarh and Maharashtra

Bansal, S.K.[(1)*], P. Imas[(2)], B. Pal[(3)], and J. Nachmansohn[(4)]

Abstract

Under the project 'Potash for Life (PFL)' launched by Indian Potash Limited, New Delhi in collaboration with ICL Fertilizers, Beer Sheva, Israel, large scale field experiments were conducted to evaluate the potassium (K) response in maize (*Zea mays*) and demonstrate the profitability of K fertilization on the K-depleted soils. Comprehensive pairwise (adjacent –K and +K) plot trials were carried out on 9 sites in Andhra Pradesh, 4 sites in Chhattisgarh and 22 sites in Maharashtra. The methodology used was simple and straight-forward. Two identical plots, side by side (in pairs) were selected. One was fertilized with K and other did not receive any K. As revealed by the data, significant yield increases due to K application were obtained at each and every site. Mean yield increase due to K application was 407 and 664 kg ha^{-1} in Andhra Pradesh and Maharashtra, respectively which was 7.0 and 19.8% higher than the control (-K). For Chhattisgarh, these values were

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1,053 kg ha^{-1} or 19.0% more, but this increase was not statistically significant. Additional average profit accrued from K application was Rs. 4,568; 7,662 and 12,997 ha^{-1} in Andhra Pradesh, Maharashtra and Chhattisgarh, respectively.

Keywords: Potash fertilization, field demonstrations, maize, Potash for Life.

Introduction

In terms of its cultivated area and contribution to the nation's total grain production, maize ranks as India's third most important cereal crop after rice and wheat (Ranjit kumar *et al.*, 2014). Maize is not only used for human food and animal feed, but it also acts as an important basic raw material for thousands of industrial products, such as starch, oil, protein, alcoholic beverages, food sweeteners, pharmaceuticals, cosmetics, film, textile, gum, package and paper industries, etc. (APEDA, 2018). Predominantly a kharif crop (with 85% of the total area under cultivation being in kharif only), maize contributes around 10% to the country's total food grain production. Grown in almost all the agro-ecological regions of the country, it is now being cultivated throughout the year in many of the states for various purposes (Anonymous, 2018). The rate of increase in smallholder-based maize production in India has been high for the last two decades. However, despite the production strength, maize yields in India are much lower than the yields realized in the major maize-producing countries. There is, thus, an immense scope for substantially increasing maize production in the country by bringing more area under fertilizer-responsive hybrids and composites, adopting improved agronomic practices, and building a competitive maize supply chain (FICCI, 2014).

Selective implementation of the nutrient based subsidy (NBS) scheme on P&K fertilizers in April 2010 led to a sharp rise in the prices of muriate of potash (MOP). This price escalation made farmers either reduce or skip K application. This imbalanced fertilizer use widened the N:P_2O_5:K_2O ratio which had adverse consequences for soil health. Against these negative developments

Photo 2: Farmers at demonstration plot in Maharashtra, India. Photo by the authors.

which led to the reduction in MOP use in the country, Indian Potash Limited (IPL) in collaboration with ICL Fertilizers, Beer Sheva, Israel launched a project "Potash for Life (PFL)" to support and advise Indian farmers to make agriculture more profitable with judicious use of MOP.

Recognizing the importance of maize and realizing the fact that India is one of the largest producers of maize in the world, the crop was included in the PFL project. Currently, PFL is engaged with maize demonstration plot trials in three states: Andhra Pradesh, Chhattisgarh and Maharashtra. Andhra Pradesh and Maharashtra are among the top maize producing states in the country, while the yield levels in Chhattisgarh are somewhat lower (Anonymous, 2018). This paper reports the results on yield responses to applied K on farmers' fields in these states.

Materials and methods

Experimental setup

Verification trials for K response in maize were conducted on the farmers' fields in the states of Andhra Pradesh, Chhattisgarh and

Table 1. Fertilizer type and dose applied to the two treatments in the maize demonstration plot trials in the states of Andhra Pradesh and Chhattisgarh.

Fertilizer source	Andhra Pradesh		Chhattisgarh	
	-K	+K	-K	+K
	kg ha⁻¹			
N (from urea + DAP)	120[a]	120[a]	120	120
P_2O_5 (from DAP)	70[b]	70[b]	60	60
K_2O (from MOP)	0	75	0	60

[a] Average N dose was 120 kg ha^{-1}; however, the N dose in the state ranged between 100 and 140 kg ha^{-1}. Regardless of variation, dose and procedure were always the same for both the –K and +K treatments.

[b] Average P_2O_5 dose was 70 kg ha^{-1}; however, the P_2O_5 dose in the state ranged between 60 and 80 kg ha^{-1}. Regardless of variation, dose and procedure were always the same for both the –K and +K treatments.

Maharashtra. All nine trials in Andhra Pradesh were conducted in Kurnool district. Likewise, all 4 trials in Chhattisgarh were conducted in farmers' fields in the Durg district. Out of the 22 trials in Maharashtra, 1 trial was in Latur district and remaining 21 were conducted in Solapur district. The farmers grew maize, but in some cases, they grew other crops as well in a multi-cropping system. For the maize trials, two plots per farmer were laid out side by side, with one receiving K (+K) and the other a control (-K). These two plots were separated by a 1m wide path. Plots within a state could be considered to be relatively similar; however, the similarity could not be assumed for plots in different states. All the plots in the states were irrigated in accordance with the crop requirements, with exact details in irrigation practice varying from state to state. However, regardless of the differences, the irrigation practices were the same for both treatments in each individual trial. Plot size for the demonstration plots varied from trial to trial, primarily depending on state. However, it was always kept the same for both plots in a pair. In Andhra Pradesh, the plot size varied from 1 to 2.5 ha, while it was 0.4 ha in the states of Chhattisgarh and Maharashtra. Different improved varieties of maize recommended for the areas were used. All recommended agronomic practices, such as seed rates, planting distances, irrigation schedules and plant protection measures were followed according to the local recommendations.

Treatments

There were only two treatments: i) control (-K), where the common fertilizer practice of applying urea, DAP and manure was followed, and ii) K treatment (+K), where muriate of potash (MOP) was applied, in addition to the urea, DAP and manure applied in the control. Thus, the control and the treatments were identical at each location, except for the MOP input in the '+K' treatment. However, the local fertilizer practices, primarily the MOP dose, was different for each state (Table 1 and Table 2).

Table 2. Fertilizer type and dose applied to the two treatments in the maize demonstration plot trials in Maharashtra.

Fertilizer source	Maharashtra	
	-K	+K
	----------*kg ha^{-1}*----------	
N (from urea + DAP)	120	120
P_2O_5 (from DAP)	60	60
K_2O (from MOP) FYM[a]	0 x[b]	120 x[b]

[a] FYM (Farmyard manure) was derived from different kinds of domesticated animals depending on location and production.
[b] Dose varied between 1 and 2 t ha^{-1}, with an average of 0.7 t ha^{-1}. The letter 'x' signifies that whatever dose and procedure of manure were followed, these were same for both the -K and +K treatments.

Statistical inferences

Statistical analysis was performed using paired t-tests for two sets of data. In first case, all the data for the states was pooled and in the second case data was used separately for each state. In addition, the datasets were analyzed from different angles to have an insight into the observed variations. When comparing these secondary factors, two kinds of tests were used depending on purpose:

1. When comparing more than two groups or statistical populations, the one-way-ANOVA-test was used, with Bonferroni corrected post-hoc tests.
2. When comparing only two groups or statistical populations, other kinds of t-tests were used, as the samples had different sample sizes; either one of the two t-tests were used: (i) two-sample assuming *equal* variance, or (ii) two-sample assuming *unequal* variance. The assumption of same or different variance, preceding the t-test, was based on the results from an F-test.

Table 3. Mean maize yield levels with MOP application in the states of Andhra Pradesh, Chhattisgarh and Maharashtra as well as for all the states.

	All states	Andhra Pradesh	Chhattisgarh	Maharashtra
Control yield (kg ha^{-1})	4,261± 275*	5,909 ± 607	5,541 ± 1,013	3,354 ± 67
Yield with MOP (kg ha^{-1})	4,903 ± 290	6,315 ± 636	6,593 ± 1,342	4,018 ± 82
Increase in yield with MOP (kg ha^{-1})	642 ± 60	406 ± 46	1,052 ± 490	664 ± 62
Relative increase in yield with MOP (%)	15.1 ± 1.2	7.0 ± 0.7	19.0 ± 7.4	19.8 ± 0.2

* Values are means ± SE (Standard error of the mean)

Table 4. Average net profit increase and average benefit:cost (B:C) ratios with MOP application in maize.

	All states	Andhra Pradesh	Chhattisgarh	Maharashtra
Net profit (Rs. ha^{-1})	7,471	4,568	12,997	7,662
Benefit:Cost (B:C) ratio	6:1	5:1	13:1	6:1

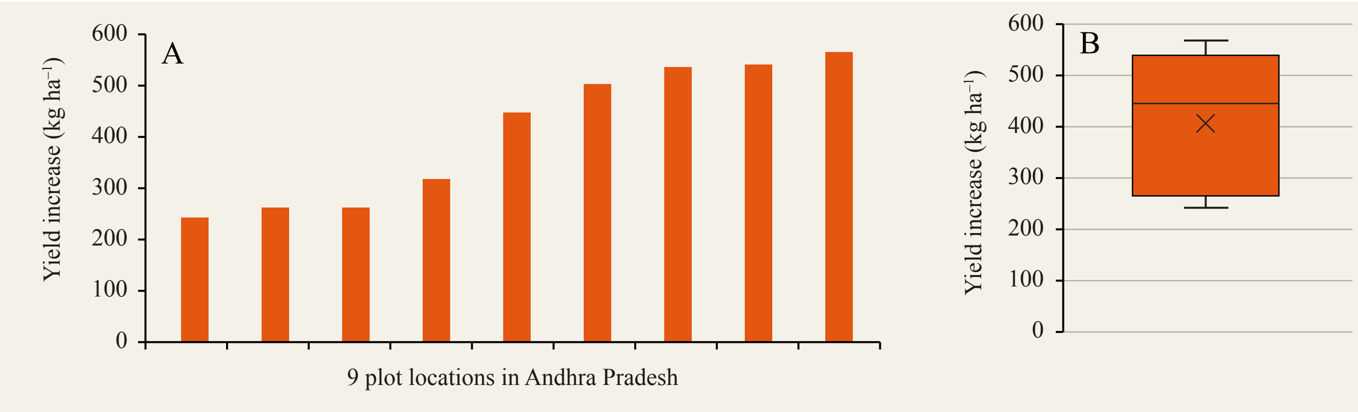

Fig. 1. Maize yield increase in 9 plot pairs across Andhra Pradesh obtained in 2015-2016. Absolute yield increase (A) in the plots fertilized with potash in comparison to control plots with no potash fertilization. Boxplot diagram (B) illustrates the distribution of the data. The middle line represents the median, the upper and lower edge of the box represent the 25th and the 75th percentiles respectively. The mean is signified by the x-marker. The bars reach the maximum and minimum values.

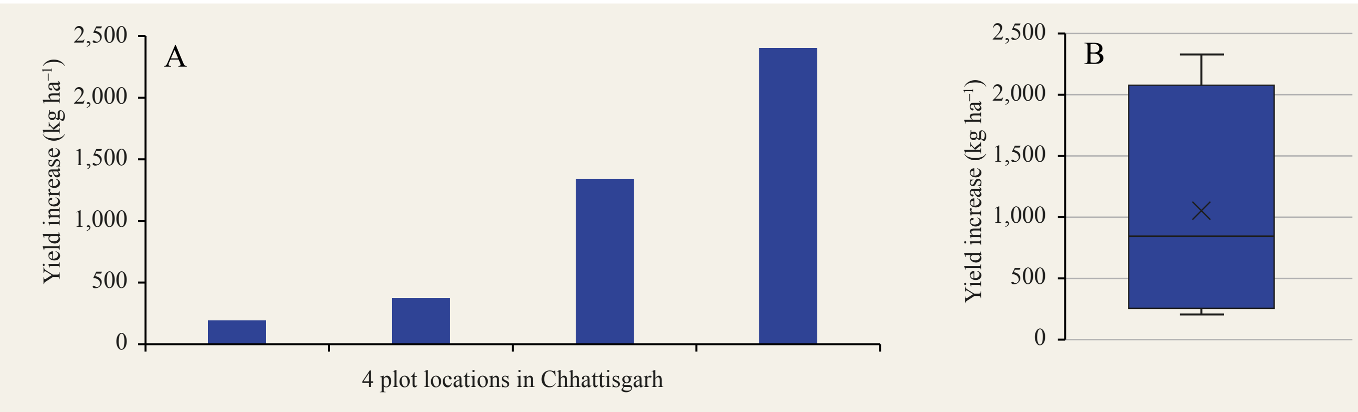

Fig. 2. Maize yield increase in 4 plot pairs in Chhattisgarh obtained in 2015-2016. Absolute yield increase (A) in plots fertilized with potash in comparison to control plots with no potash fertilization. Boxplot diagram (B) illustrates the distribution of the data.

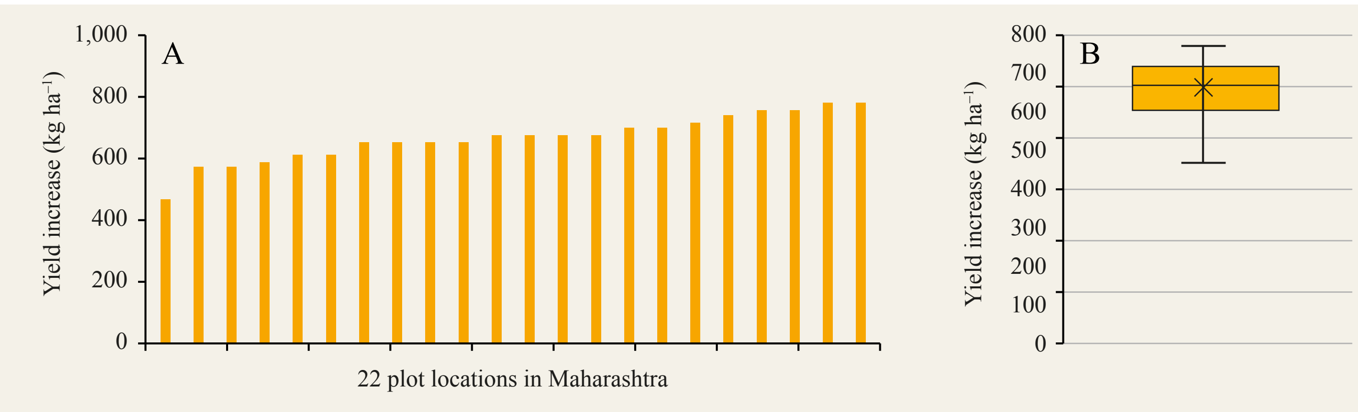

Fig. 3. Maize yield increase in 22 plot pairs in Maharashtra obtained in 2015-2016. Absolute yield increase (A) in plots fertilized with potash in comparison to control plots with no potash fertilization. Boxplot diagram (B) illustrates the distribution of the data.

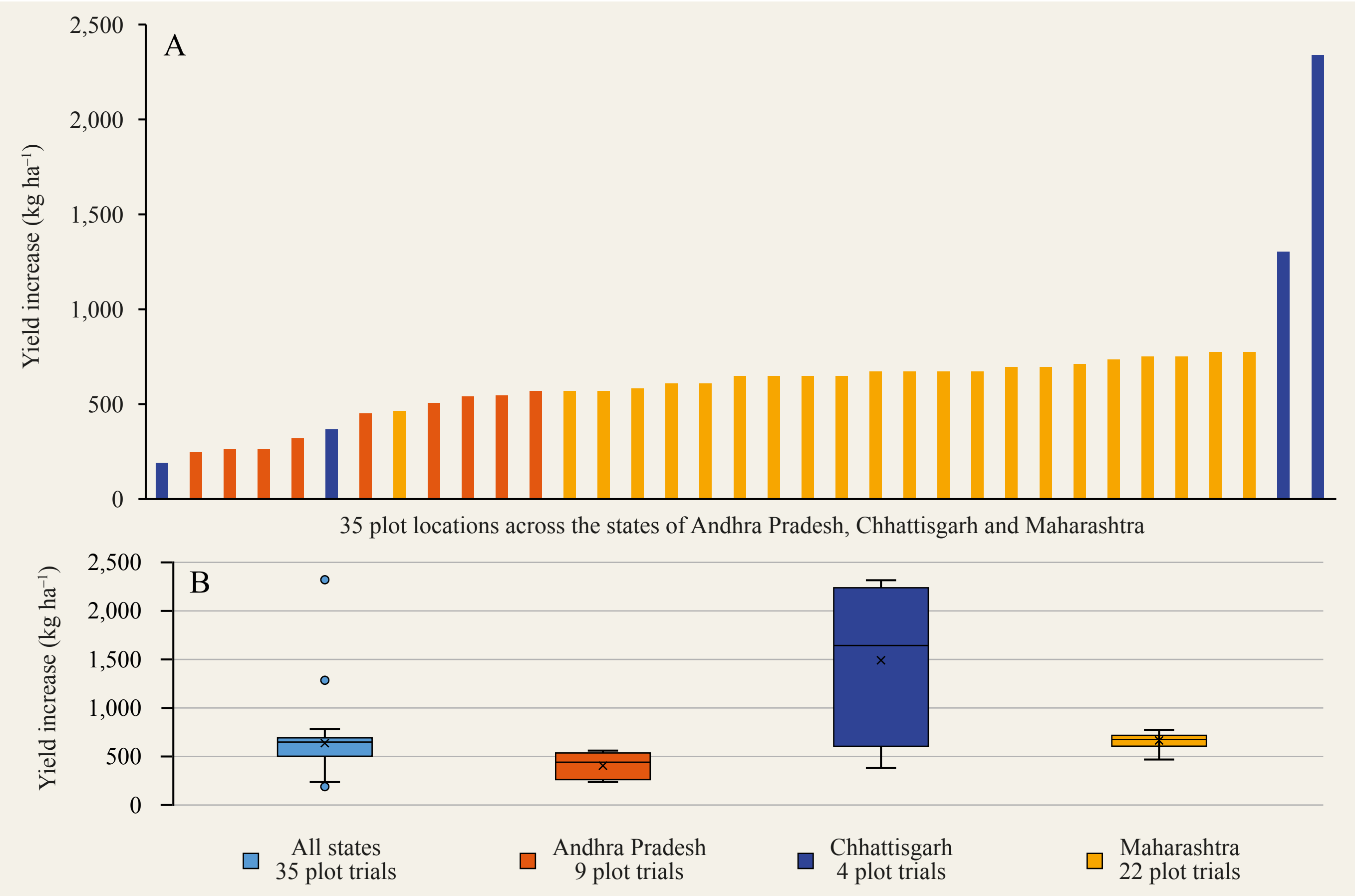

Fig. 4. Absolute yield increase (A) in plots fertilized with potash in comparison to control plots with no potash fertilization, in 35 plot pairs across the states of Andhra Pradesh, Chhattisgarh and Maharashtra, harvested in 2015-2016. Boxplot diagram (B) illustrates the distribution of the data. In the boxplot the middle line represents the median, the upper and lower edge of the box represent the 25th and the 75th percentiles, respectively. The mean is signified by the x-marker. The bars reach the maximum and minimum values, outliers excluded, which are signified by small coloured circles. Each district, as well as the state as a whole is represented by a specific colour.

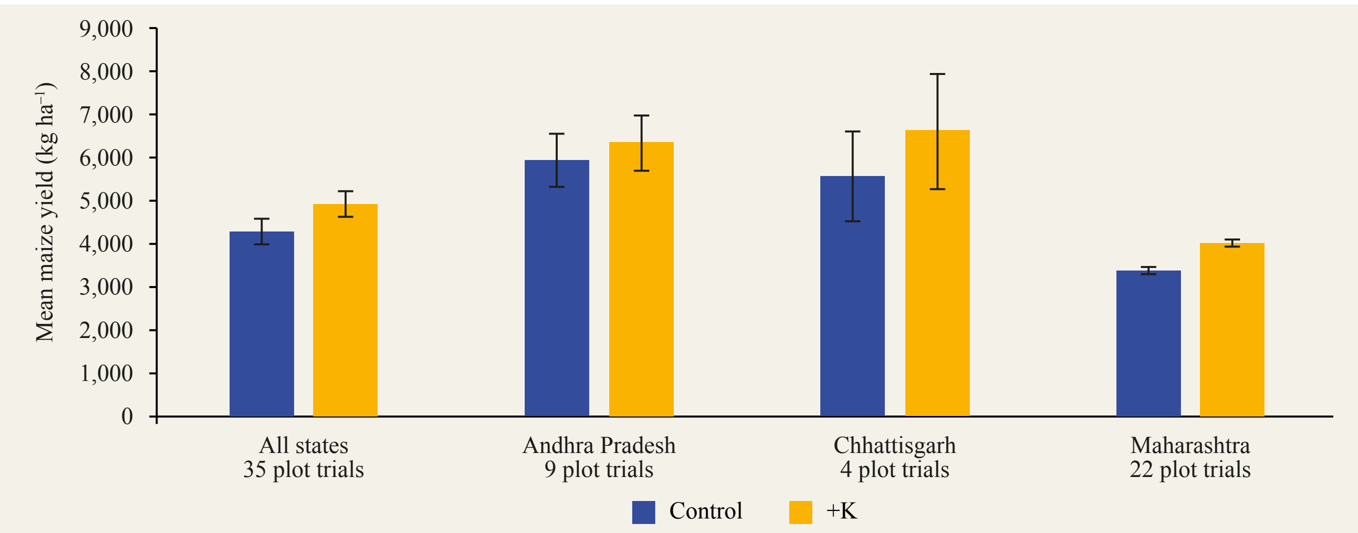

Fig. 5. Mean maize yield levels for control and '+K treatment' plots in the states of Andhra Pradesh, Chhattisgarh and Maharashtra. Error bars signify the standard error of the mean.

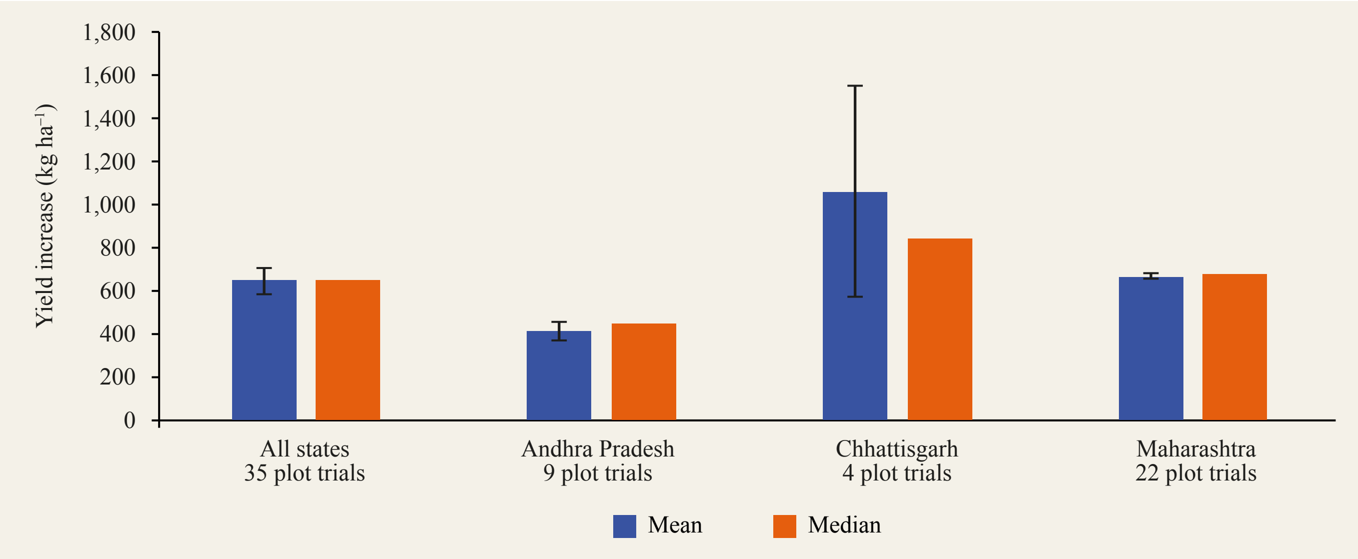

Fig. 6. Average yield increase illustrated both as mean and median in Andhra Pradesh, Chhattisgarh and Maharashtra.

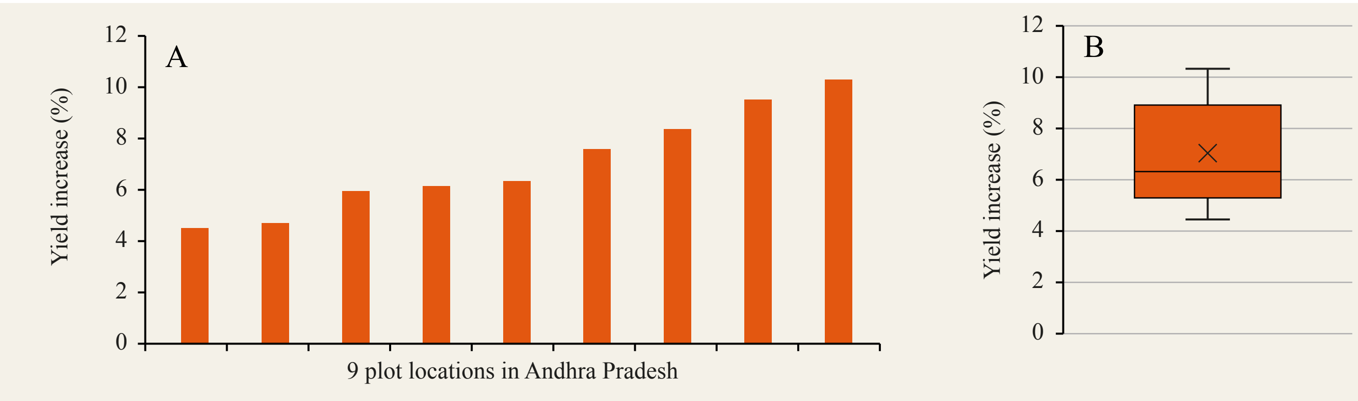

Fig. 7. Maize yield increase in 9 plot pairs across Andhra Pradesh obtained in 2015-2016. Relative yield increase (A) in plots fertilized with potash in comparison to control plots with no potash fertilization. Boxplot diagram (B) illustrates the distribution of the data.

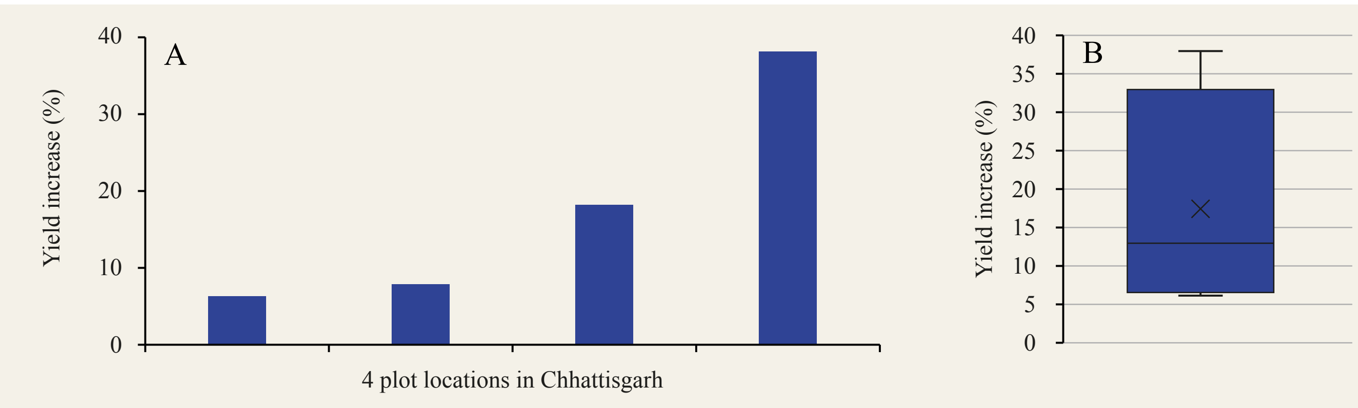

Fig. 8. Maize increase in 4 plot pairs across Chhattisgarh obtained in 2015-2016. Relative yield increase (A) in plots fertilized with potash in comparison to control plots with no potash fertilization. Boxplot diagram (B) illustrates the distribution of the same data.

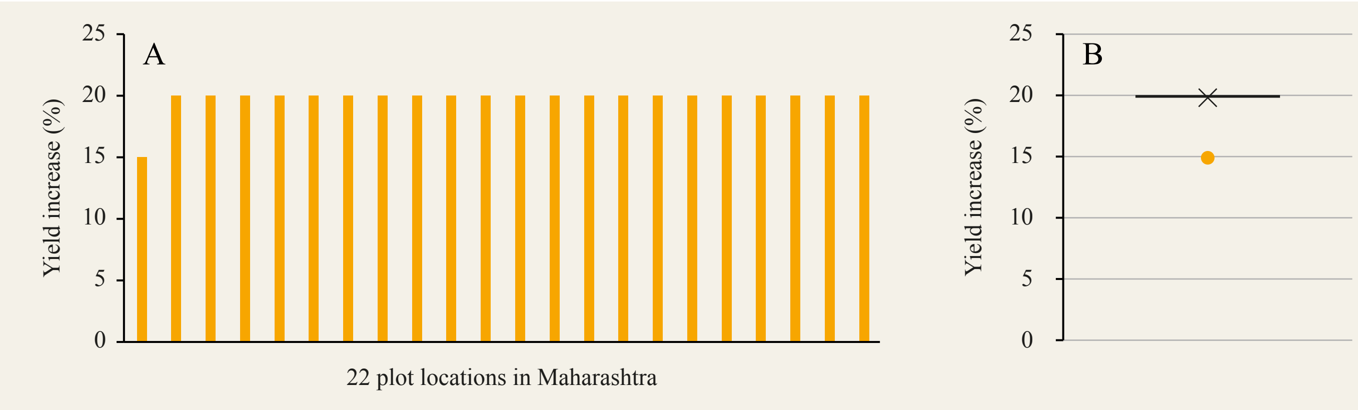

Fig. 9. Maize yield increase in 22 plot pairs in Maharashtra obtained in 2015-2016. Relative yield increase (A) in plots fertilized with potash in comparison to control plots with no potash fertilization. Boxplot diagram (B) illustrates the distribution of the data. In the boxplot the middle line represents the median, the upper and lower edge of the box represent the 25th and the 75th percentiles respectively. The mean is signified by the x-marker. The bars reach the maximum and minimum values, outliers excluded, which are signified by small coloured circles. However, due to extremely uniform results, no box edges or bars are discernable, as they have the same value as the median, which is why all these parameters are displayed as the flat line in the graph.

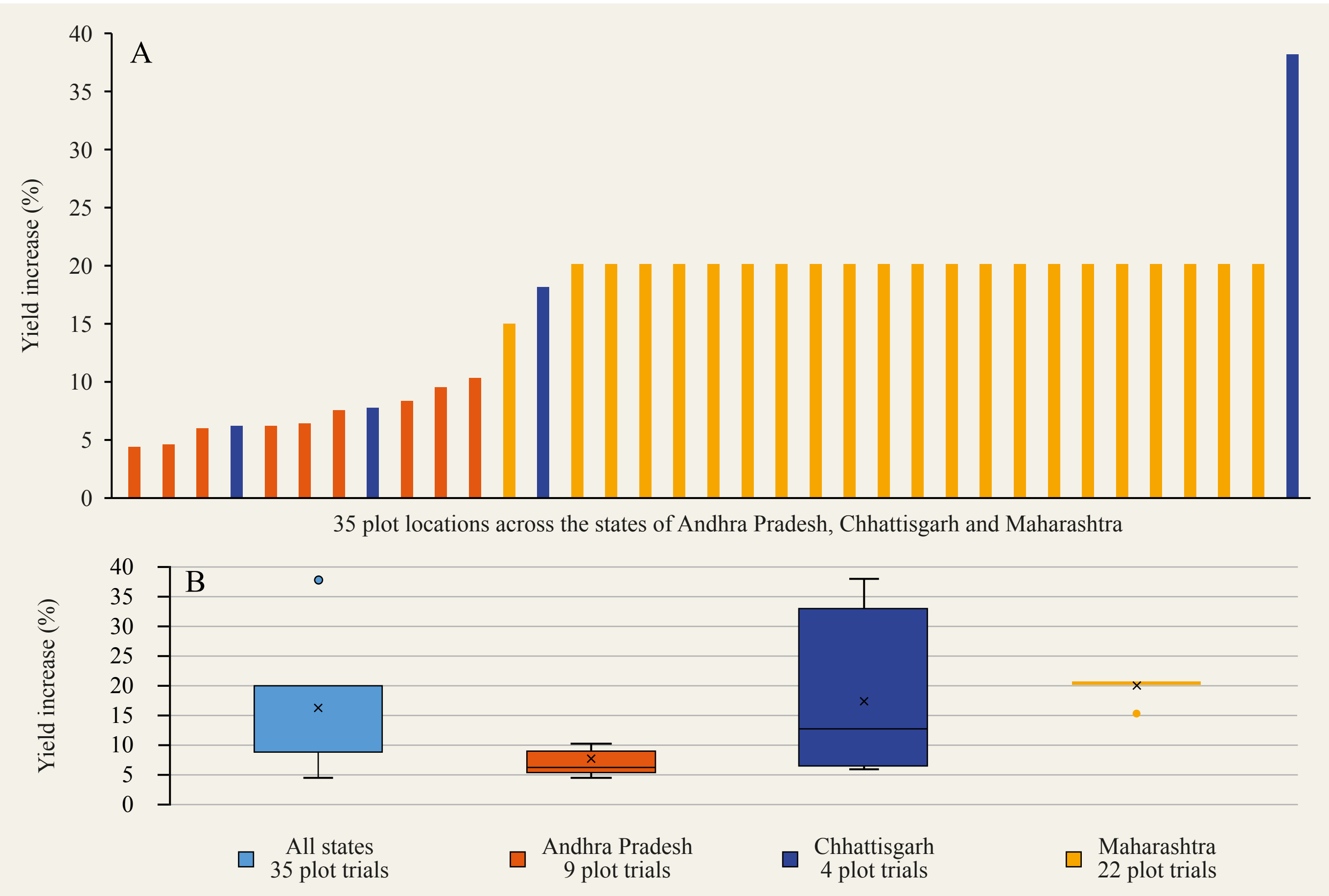

Fig. 10. Relative yield increase (A) in plots fertilized with potash in comparison to control plots with no potash fertilization across the states of Andhra Pradesh, Chhattisgarh and Maharashtra. Boxplot diagram (B) illustrates the distribution of the data.

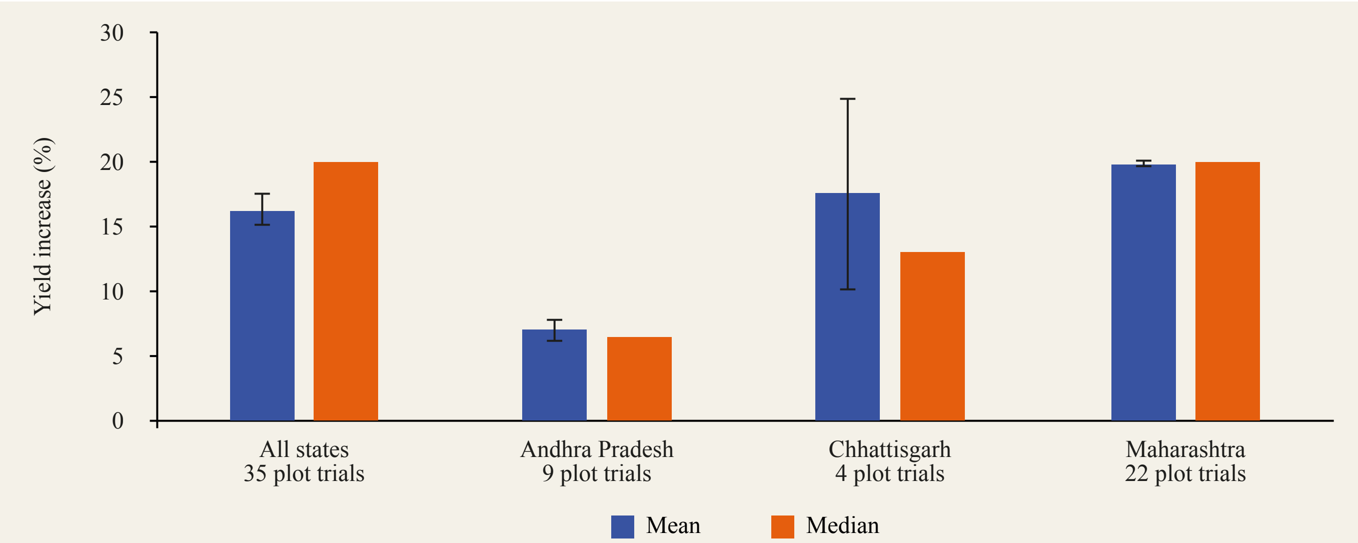

Fig. 11. Average maize yield increase illustrated both as mean and median in Andhra Pradesh, Chhattisgarh and Maharashtra.

Results and discussion

Absolute yield increase

Application of MOP over and above urea, DAP and manure gave an average grain yield increase of 406, 1,052 and 664 kg ha^{-1} and additional net profit of Rs. 4,568, 12,997 and 7,662 ha^{-1}, in the states of Andhra Pradesh, Chhattisgarh and Maharashtra, respectively. This clearly demonstrated to the maize-growing farmers the benefits accruing from the MOP application (Table 3 and 4). Yield increases were statistically significant in the states of Andhra Pradesh and Maharashtra; however, for Chhattisgarh, yield increases were not significant. Perhaps the small sample size and larger variance in Chhattisgarh were responsible for the observed lack of significance. Average values in Andhra Pradesh and Maharashtra were found to be stable, and are representative of the datasets (Fig. 1, 2, 3 and 4). This is clearly indicated by a low standard error of the means, and the proximity between the median and mean values (Table 3; Fig. 5 and Fig. 6).

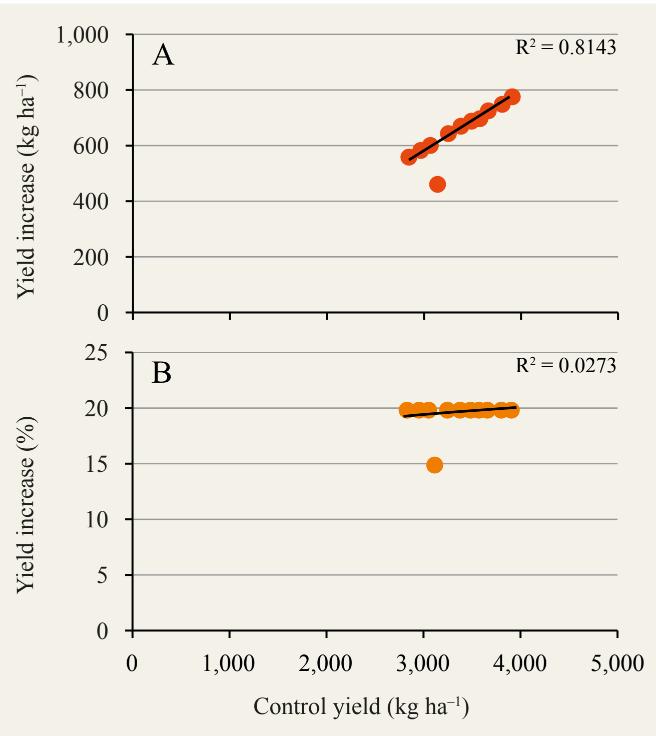

Fig. 12. Absolute (A) and relative (B) yield increase plotted as a function of the control yield. The circles represent the data points of the plot. The linear regression line is illustrated in black, and the R^2-value is specified.

Yield response to muriate of potash in Andhra Pradesh roughly ranged from 250 to 550 kg ha^{-1}. The corresponding range for Chhattisgarh and Maharashtra was 200 to 2,300 and 470 to 770 kg ha^{-1}, respectively. In Andhra Pradesh, the yield increase was evenly distributed between the lowest to the highest response value, almost exhibiting a linear relationship (R^2 = 0.93). The slope of this increase was moderate (Fig. 1A), which is also illustrated by the proximity of the upper and lower quartiles in the boxplot diagram (Fig. 1B). For Maharashtra, distribution was different. It was approximately linear (R^2 = 0.91) but uniform, with only a slight distribution slope (Fig. 3A). This is also illustrated by the close proximity of the whole boxplot distribution to the average value (Fig. 3B).

For Chhattisgarh no trend can be established due to the small sample size and the large variation. Comparison of the results pooled for the states indicates that the upper response values from Chhattisgarh are outliers (Fig. 4A). Otherwise there is a clear even response distribution, and a uniform response range for the states. This is also clear from the boxplot comparison (Fig. 4B), in which the upper

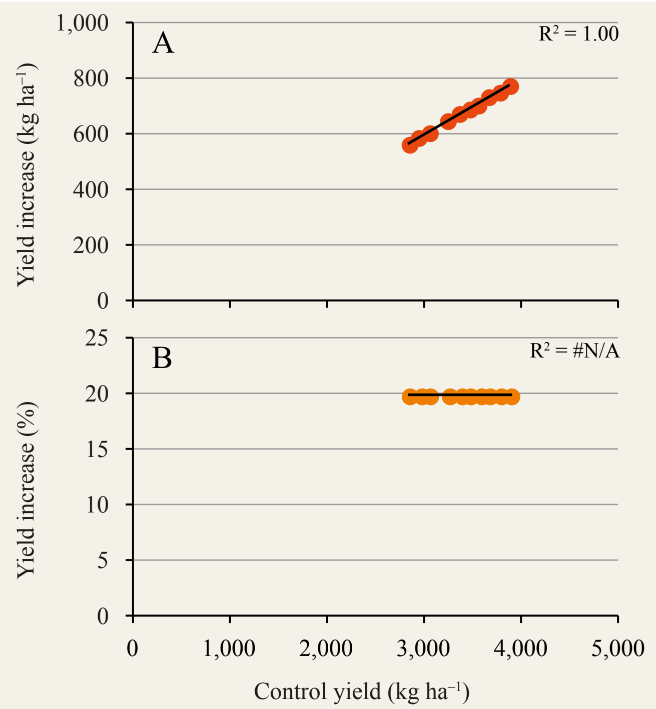

Fig. 13. Absolute (A) and relative (B) yield increase plotted as a function of the control yield for the plot trials conducted in Solapur district, Maharashtra.

outliers correspond to the two upper response values in Chhattisgarh. The mean yield increase levels were similar for Andhra Pradesh and Maharashtra (Fig. 5). In spite of the high variance, the same pattern was also observed for Chhattisgarh. It is also clear that the differences between the mean and the median values tend to be low, as do the differences in the standard error of the mean (Fig. 6).

Relative yield increase

In relative terms, the application of K (MOP) caused an average maize yield increase of 7.0, 19.0 and 19.8% in the states of Andhra Pradesh, Chhattisgarh and Maharashtra, respectively, giving an average benefit:cost (B:C) ratio of 5:1, 13:1 and 6:1 in these states. All average relative yield increase values were stable and representative of the datasets (Fig. 7, Fig. 8, Fig. 9 and Fig. 10), which is indicated by a low standard error of the means, and the proximity between the median and the mean values (Fig. 11, Table 3). Differences between the average relative yield increases associated with K application were statistically verifiable for Andhra Pradesh and Maharashtra.

In both Andhra Pradesh and Maharashtra, there were clear trends in the response pattern to the MOP application. In Andhra Pradesh the pattern was similar to the absolute yield increase trend; the relative yield increase was evenly distributed, and increased from the lowest to the highest response value almost linearly ($R^2 = 0.97$) with a moderate slope (Fig. 7). In Maharashtra the relative yield increase response trend was virtually constant; all plot trials except one in Latur district had the same response (Fig. 9).

Comparison of the results for the three states shows that only the upper response values from Chhattisgarh deviated from the other results (Fig. 10A). The rest of the results fell into a moderate and well-defined response range (4 to 20%). This is also clear from the boxplot comparison (Fig. 10B), in which the upper outlier corresponded to the highest response value in Chhattisgarh.

For Andhra Pradesh and Chhattisgarh, no clear cut relationship between control yield and yield increase response could be established. However, for Maharashtra, a very clear correlation was observed; yield increase response was almost a linear function of the control yield (Fig. 12). When adjusted for districts, the linear regression was perfect in the district of Solapur ($R^2 = 1.00$) (Fig. 13).

Observed trends and their implications

Application of MOP produced statistically significant and quantifiable increases in maize yields which implies that the soils of the experiment locations have undergone nutrient depletion. These results give us confidence to effectively popularize the use

Photo 3: Impact of K application on maize from plot in Maharashtra, India. Photo by the authors.

of MOP to increase maize productivity and profitability in the states of Andhra Pradesh and Maharashtra. Overall response trends, with reasonably narrow response range and stable yield increase response averages from Andhra Pradesh are significant and provide a reliable economic incentive to include MOP application in maize production (Fig. 1, Fig. 7; Table 3, Table 4). For Maharashtra, the benefits are even more significant, with higher and narrower response ranges (Fig. 3, Fig. 9; and Table 4). In relative terms, the average yield increase is both high and stable (19.8 ± 0.2%). For Chhattisgarh, no statistically justified conclusions can be drawn because of the paucity of data.

Inferences of practical significance

It can be easily extrapolated that if a maize farmer in Andhra Pradesh applies MOP according to the PFL recommendations, he would get a yield increase of about 260 to 540 kg ha^{-1}. Given the average B:C ratio of 5:1, this turns out to be a profitable proposition. In Maharashtra, the corresponding figures would be between 610 and 720 kg ha^{-1} and a B:C ratio of 6:1. It is really impressive indeed.

Conclusions

Application of muriate of potash in addition to the commonly applied N and P fertilizers had an unequivocal effect in increasing the maize yields in Andhra Pradesh and Maharashtra. These results indicate that there is a critical need for the development of K fertilization practices for maize in these states. As an immediate measure, the dose successfully employed in this study should be recommended to the maize farmers for maximizing their yields and profits.

Acknowledgements

The authors express grateful thanks to Indian Potash Limited and its regional officers and field staff, field staff of Project ‘Potash for Life’ and participating farmers. Special thanks are due to ICL Fertilizers for extending financial assistance for the project. All the support, kind advice and guidance in successful implementation of the project activities rendered by the Managing Director, IPL and Chairman, PFL are gratefully acknowledged.

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The paper “Response in Maize to Applied Potassium: Results from Field Demonstrations in the States of Andhra Pradesh, Chhattisgarh and Maharashtra” also appears on the IPI website.

We dedicate this paper to the memory of Dr. Bhisham Pal.

Dr. Pal was deeply involved in the ‘Potash for Life’ project under which this research was carried out.

He provided valuable advice and timely guidance on the agronomic activities of the project, always with a smile and great professionalism. His tremendous enthusiasm, endless dedication and his knowledge and experience will be missed by those in India – and from further afield – who knew and worked with him.

Events

23rd September 2020

Delegates at the FAI-IPI webinar.

FAI-IPI Webinar
Water Soluble Fertilizers in India – Status and Way Forward

The Fertiliser Association of India (FAI) and International Potash Institute (IPI) jointly organized a one-day webinar '**Water Soluble Fertilizers in India – Status and Way Forward**' on 23rd September 2020 at the FAI House, New Delhi. About 100 delegates, representing Indian Council of Agricultural Research (ICAR), State Agricultural Universities (SAUs), Ministry of Agriculture and Farmers Welfare, Indian and International Fertilizer Industry as well as FAI and IPI, reviewed the use of water soluble fertilizers (WSFs) in India to date and what could accelerate adoption by more farmers.

In his opening remarks, Mr. Hillel Magen, Director of IPI in Switzerland, mentioned that IPI has had a very fruitful collaboration with FAI for the last 15-16 years. He stated that the market for specialty fertilizers is witnessing global growth of 10% per year and is currently valued at USD 15-25 billion. Among specialty fertilizers, growth in demand for WSFs, which have been on the market for 50 years, is significant and fast.

Gain knowledge of WSFs to share it

Dwelling on the challenges to faster adoption of WSFs, Mr. Magen highlighted that the fertilizer industry extension staff often lack expertise on use of these products. He feels that they ought to understand the synergistic interactions between water and nutrients operating in the soil-plant continuum and their gainful exploitation for increasing crop production, enhancing farm income, sustaining soil health, and maintaining environmental quality. Extension personnel need to know how the controlled application of water and nutrients together achieves the twin objectives of enhancing use efficiency of both these critical inputs. They will in turn be able to advise farmers on usefulness of application of WSFs dissolved in irrigation water. Mr. Hillel acknowledged that in India, it is the subsidy schemes for

Excerpt from Indian Journal of Fertilisers 16(11):1188-1191 with permission from FAI, India.
Contact: Dr. Adi Perelman, IPI Coordinator for India: adi.perelman@icl-group.com.

Mr. Satish Chander, Director General (DG), FAI delivered the introductory address.

micro-irrigation that have incentivized the use of WSFs.

In his presentation, FAI Director General Mr. Satish Chander mentioned that fertilizer and water are two vital inputs for agriculture and use efficiency of both is abysmally low in India. Lower water and fertilizer use efficiencies not only adversely affect the crop yields and farm profits but also contribute to the degradation of environmental quality. Unutilized nutrients leach or emit into the environment, polluting both air and water. Leakage of nitrogen as nitrous oxide, which is about 300 times more lethal than carbon dioxide as a greenhouse gas, is a matter of global concern in this era of climate change.

Greater nutrient and water use efficiencies with WSFs

Mr. Chander stated that scientists all over the world are developing alternative technologies, products and practices for achieving higher input use efficiency. Drip fertigation is one such efficient technology which enhances substantially the use efficiency of both water and fertilizers. For example, drip irrigation gives a water saving of 30-40% over surface irrigation methods. Fertilizer application through drip fertigation at least doubles the use efficiencies of applied NPK. FAI is well aware of the problem of low fertilizer use efficiency. It has been relentlessly pursuing and collaborating with different organizations to evolve the research and development strategies to enhancing fertilizer use efficiency. FAI has been consistently stressing on the need to offer farmers a more comprehensive choice of fertilizer through inclusion of new, innovative, more efficient products, principal among them being the WSFs. The general specifications of water-soluble mixture of fertilizers (with or without secondary or micronutrients) have been notified in the Fertilizer (Control) Order and it gives freedom to manufacture or import any grade of water-soluble mixture of fertilizers by just following the general specifications. FAI is also lobbying the Indian government to apply the same level of Goods and Services Tax/Customs Duty to all types of fertilizers.

Even higher target set for annual food grain production

Agriculture Commissioner of the Government of India Dr. S.K. Malhotra presented next and began with the announcement that India has achieved record food grain production of 296 million tonnes during 2019-2020 and a target of 301 million tonnes has been fixed for 2020-2021. He stated that there is record crop coverage in the current kharif season and climatic conditions are good for the coming rabi season. Highlighting the role of fertilizers, Dr. Malhotra mentioned that fertilizers feed the world through feeding the soils, which in turn feed the plants. If our world is not to go hungry, then fertilizers will continue to play an important role in raising food production. He advocated scientific use of fertilizers under good management practices because imbalanced and inefficient use of fertilizers may have an adverse effect on farmers' income and the wider environment.

Dr. Malhotra stated that fertigation is one of the key technologies to increase the use efficiency of water and fertilizer nutrients. He said that there has been a rapid expansion in the area under micro-irrigation. Currently in India, 12.7 million hectares benefit from micro-irrigation. He expressed that increasing water and nutrient use efficiency is a top priority to reduce the cost through optimal utilization of resources. He added that under the Pradhan Mantri Krishi Sinchai Yojana, fertigation has been made compulsory for each and every farmer who takes benefit of Government of India's scheme for micro-irrigation installation.

Dr. Malhotra stated that use of WSFs has increased considerably during the last 2-3 years, particularly in high value crops and under protected cultivation. The Government is launching a scheme to encourage use of fertigation to increase nutrient use efficiency. He expressed happiness that as the Chairperson of Central Fertiliser Committee (CFC), he has an opportunity to address the issues under Schedule-I of FCO. He specifically acknowledged the role of FAI as an important knowledge point for CFC constituted under FCO to advise the Central Government on different issues. Dr. Malhotra said that attempts have been made to promote multi-nutrient products containing primary, secondary and micronutrients through a systematic process on the basis of soil fertility data which includes 100% water soluble specialty fertilizers. As a part of customized combination products, CFC has been liberally supporting the inclusion of these products in FCO. Efforts are being made to ensure that the area under WSFs increases substantially. He mentioned steps initiated by the Government to encourage

Dr. S.K. Malhotra, Agriculture Commissioner, Government of India, was the Chief Guest at the inaugural ceremony.

the production of WSFs by indigenous manufacturers and made a specific mention of WSFs developed by IFFCO gaining popularity among farmers.

Dr. Malhotra listed a number of priority areas needing immediate attention. These include:

- standardization of optimum nutrient consumption ratios for different crops at different stages of growth.
- development of guidelines for tissue analysis for different fruit and vegetable crops for optimization of fertilizer doses and time of application.
- development by the fertilizer industry of situation and location-specific products, and multiple micronutrient mixtures and formulations.
- establishing fertigation schedules for different crops for producing quality products.
- having a robust system for quality control of specialty and Water Soluble Fertilizers.

Dr. Malhotra requested the discuss of these issues during the subsequent technical sessions. He was optimistic that useful recommendations would emerge from these deliberations which would help in devising a strategy to promote the use of WSFs in Indian agriculture.

Technical analysis of use of WSFs

Two structured technical sessions followed. Firstly, three papers were presented in technical session-I:

1. Use of Water Soluble Fertilizers and Fertigation in Israel by Dr. Uri Yermiyahu, Deputy Director for R&D, Agricultural Research Organization, Israel.
2. Improving Nutrient Use Efficiency and Farmers' Income with Progressive Shift to Water Soluble Fertilizers by Mr. N.D. Deshmukh, Vice President-Marketing & Strategy, Smartchem Technologies Limited, Pune.
3. Use and Production of Water Soluble Fertilizers in India: Changing Landscape by Mr. Mahadev Suvarna, Vice President Specialty Plant Nutrition, Shriram Farm Solution, New Delhi.

Next, there were six papers presented in technical session-II:

1. Micro-irrigation and Fertigation in India: Status, Scope and Policy by Dr. S.K. Chaudhari, Deputy Director General (NRM), ICAR, New Delhi.
2. Nutrivant – A Foliar Fertilizer for Rice by Mr. She Cheng Siang, Agronomy Lead Asia/Global Fertigation Specialist, ICL IAS, Malaysia.
3. Water Soluble Fertilizers in India: Challenges and Suggested Solutions by Mr. Sanjay Naithani, Chief Agronomist, ICL India.
4. Role of WSFs in Protected Cultivation Technology by Dr. Murtaza Hasan, Principal Scientist, Centre for Protected Cultivation Technology, IARI, New Delhi.
5. Chloride for Disease Prevention and Other Associated Benefits by Dr. Adi Perelman, India Coordinator, IPI, Israel.
6. Role of Industry in Driving Growth in Water Soluble Fertilizers by Dr. Surender Roperia, Head, Sales and Marketing, K+S Fertilizers (India) Private Limited, Gurugram, Haryana.

As the conclusion to the webinar, Mr. Hillel Magen summarized the main points. About 7% of arable land in India is under micro-irrigation and the penetration is better in horticultural crops (20%). An area of 200,000 ha is targeted to be brought under fertigation in the next 2 years. It is predicted there will be a dramatic increase in demand for WSFs and India ranks number one in the world in terms of growth of use of WSFs. Precision nutrient management, together with advanced technology, can further enhance the nutrient use efficiency. Large scale experiments using potash as foliar

In the concluding session Mr. Hillel Magen, IPI Drector, summarized the salient points which had emerged from the webinar.

application on cotton are being conducted by IPI and there is a wider scope of using WSFs for foliar sprays.

Solubility, compatibility and EC are important considerations in case of WSFs. There is a need to select the right nutrient source and crop-specific recommendations. Chloride was recognized as an essential nutrient in 1954 and has been a subject of discussion since then. FCO puts limits on the use of chloride due to fear of toxicity in some crops. He underlined the need for easing FCO restrictions and allowing innovations. Finally, Mr. Magen reminded the delegates that reaching out to and informing farmers on the use of WSFs is a real challenge and joint efforts should be made by all the stake-holders to reach the unreached.

Conclusions

1. Fertigation involves simultaneous application of water and nutrients via the drippers. Plant roots receive water + nutrients at the same time and location. Optimization of yields, production of better-quality produce, and minimization of environmental pollution are its main objectives. Fertigation sans WSFs is unthinkable.
2. Due to attractive monetary returns and minimum environment footprints,

farmers have accepted WSFs at the market-determined prices without any subsidy.

3. Consumption of WSFs in India has increased more than 5-fold from 50,000 tonnes in 2010-2011 to 265,000 tonnes in 2019-2020. However, WSFs represent less than 0.5% of the total fertilizer consumption in India, compared to 5-6% achieved globally. The present level of consumption is still very low and there is a vast potential to increase it.
4. Fertigation scheduling and dosage of WSFs is very important for farmers/growers. In situ monitoring of the nutrient profile, pH and electrical conductivity in the active root zone of the fertigated field further helps in improving the effectiveness of this technology.
5. Not all the area under micro-irrigation has adopted fertigation. Six states account for 87% of total area under drip irrigation and six high value crops are grown on 60% of the total drip irrigated area. But only 20% of the area under drip irrigation is fertigated.
6. Growth of WSFs depends on the acceptance of fertigation, which in turn is directly proportional to the size of the micro-irrigation network. Facilitated by the subsidy scheme initiated by the Government of India, nearly 12.7 million hectares of arable land has already been brought under micro-irrigation. With fertigation made compulsory for each and every farmer who takes benefit of GOI's scheme of micro-irrigation installation under the 'Pradhan Mantri Krishi Sinchayee Yojana' initiative, prospects for the growth of the WSFs segment are bright.
7. Precision Farming tools such as soil sensors, variable rate prescriptions, yield maps, decision support software, soil mapping, multispectral imaging and auto guidance systems can help farmers to precisely monitor and meet crops' nutrient needs.
8. Drip fertigation offers scope to customize nutritional supply to the crop through use of technology, and also addresses the economic, social and sustainability issues. Direct benefits of drip fertigation include water saving (25-75%), fertilizer saving (20-40%), energy and labor saving, high crop production, good crop quality, and high crop water productivity.
9. With more area coming under sprinkler irrigation and foliar feeding gaining acceptance as a cost-effective nutrient-saving technology, there is a need for developing foliar fertilizers that contain a crop specific nutrient mix, and built-in fertivant adjuvant which ensures better spreading and penetration.
10. Companies engaged in WSFs are focusing on educating the farmers on crop-specific fertigation schedules and grades. They are giving farmers product-specific training to increase crop yields and improving the produce quality.
11. Companies manufacturing/importing WSFs have embraced the non-subsidy regime. Differential GST rates for WSFs vis-à-vis bulk fertilizers, being in favor of the latter, are retarding the growth of WSF sector.

Recommendations

1. Growth of WSFs depends on the acceptance of fertigation, which in turn is directly proportional to the size of the micro-irrigation network. Popularizing micro-irrigation by changing from canal irrigation should be the top priority. Operation of micro-irrigation systems should be increasingly done with solar power-aided pump sets to reduce the energy requirement and carbon footprint.
2. Sensor-aided controllers and automated irrigation systems should be developed to regulate the water and nutrient applications. Integration of GIS, GPS and hyper-spectral imaging with precise application of water and fertilizers through micro-irrigation systems is an exciting area for future research.
3. Fertigation allows and enables higher nutrient use efficiency while improving produce quality. Development and optimization of fertigation schedules for different crops, both for field and protected environments, should be undertaken by different crop-based ICAR Institutes and SAUs with the active participation of the fertilizer industry.
4. With more land coming under sprinkler irrigation, use and customization of WSFs for application through sprinklers needs immediate attention. Foliar fertilization through WSFs also offers an exciting area of investigation.
5. Chloride nutrition has long been neglected because of the fear of its toxicity in some crops, including soybean, citrus, and grapevine. Reports on the role of chloride in imparting disease resistance to crops, and responses to its application on some soils and areas remote from the sea, especially light textured ones, need further investigation.
6. Fertigation should be popularized, making use of modern information technology and other extension techniques. Wherever developed, fertigation schedules should be included in the package of state recommended practices.
7. Fertigation is an example of putting into practice the 4R Nutrient Stewardship (applying the Right nutrients, at the Right rate, at the Right time, and in the Right place) and increasing productivity and nutrient use efficiency. Industry has to work on developing, introducing, customizing and popularizing efficient products for fertigation.
8. Policy makers should work towards simplification under broader FCO compliance. Laboratory requirement for importers of WSFs should be done away with. Of the samples taken by inspectors at ports and in the states, one sample should be sent to the accredited private lab for ensuring transparency. States should compile consumption statistics of WSFs similar to subsidized fertilizers. WSFs should be treated on a par with subsidized fertilizers with respect to GST rates.

Publications

IPI Bulletin No. 23: Maize
Fertilizing for High Yield and Quality

Boletim IPI No. 23: Milho
Para Qualidade e Produtividade

Author: Godofredo Cesar Vitti, and Acácio Bezerra de Mira. 2020. 66 p.

Language: English and Portuguese

Maize is the second most produced grain in the world. Growing two crops of maize a year (spring/summer and summer/autumn) has helped lift production in Brazil to make it the world's third largest producer.

IPI bulletin No:23 has an explanation of the challenges to successful second crop maize, including lower temperature and limited solar radiation and less rainfall. It signposts that, while farmers cannot change these climatic factors, what producers can do is adopt a more strategic and balanced approach to maize nutrition.

You will find detailed analysis of macronutrient and micronutrient needs for optimum maize productivity through the growth cycle and as a second crop, including when cultivated after soybean, which is the most common succession in Brazil.

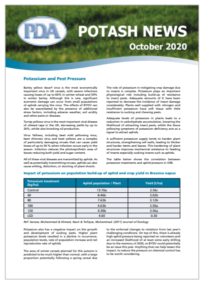
This IPI bulletin reports the process of combining three things – knowledge of crop needs, measurements of residual soil fertility and crop anticipated yield – to create a complete and balanced nutrition strategy for second crop maize.

Inoculating maize with *Azospirillum* and intercropping it with *Brachiaria* to improve nutrient use efficiency are outlined. You can also see the detailed recommendations for fertilizer applications to correct deficiencies and build soil nutrient availability that ensures adequate, prolonged and fully balanced maize nutrition throughout this important crop's growth.

To download the bulletin go to the IPI wesite for the English version at www.ipipotash.org/publications/ipi-bulletin-no-23-maize and for the Portuguese version at: www.ipipotash.org/publications/boletim-ipi-no-23-milho. For hardcopies, please contact ipi@ipipotash.org.

Publications by the PDA

Potassium and Pest Pressure
POTASH News, October 2020



The role of potassium in mitigating crop damage due to insects is complex. Potassium plays an important physiological role including build-up of resistance to insect pests. Adequate amounts of K have been reported to decrease the incidence of insect damage considerably. Plants well supplied with nitrogen and insufficient potassium have soft tissue with little resistance to sucking and chewing pests.

Adequate levels of potassium in plants leads to a reduction in carbohydrate accumulation, lowering the likelihood of attracting insect pests, whilst the tissue yellowing symptoms of potassium deficiency acts as a signal to attract aphids. Read more on the PDA website.

Soil Sampling under Different Cultivation Practices
POTASH News, December 2020

Soil sampling always has been the starting point for nutrient recommendations. Despite changes in cultivation practices over the years, since the index system was first developed, and the interest in cover cropping and greater focus on soil health, there is no getting away from the basics. When material is removed from a field, nutrients are removed, which will need to be replaced through manures or fertiliser. It is often commented that there are vast reserves of phosphate and potassium in soils, and although this statement is correct, it is the quantities in an available form that are of critical importance. Read more on the PDA website.

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

Scientific Abstracts

K in the Literature

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Flanking Support: How Subsidiary Cells Contribute to Stomatal Form and Function

Gray, A., L. Liu and M. Facette. 2020. Front. Plant Sci. 11:881. DOI: 10.3389/fpls.2020.00881.

Abstract: Few evolutionary adaptations in plants were so critical as the stomatal complex. This structure allows transpiration and efficient gas exchange with the atmosphere. Plants have evolved numerous distinct stomatal architectures to facilitate gas exchange, while balancing water loss and protection from pathogens that can egress via the stomatal pore. Some plants have simple stomata composed of two kidney-shaped guard cells; however, the stomatal apparatus of many plants includes subsidiary cells. Guard cells and subsidiary cells may originate from a single cell lineage, or subsidiary cells may be recruited from cells adjacent to the guard mother cell. The number and morphology of subsidiary cells varies dramatically, and subsidiary cell function is also varied. Subsidiary cells may support guard cell function by offering a mechanical advantage that facilitates guard cell movements, and/or by acting as a reservoir for water and ions. In other cases, subsidiary cells introduce or enhance certain morphologies (such as sunken stomata) that affect gas exchange. Here we review the diversity of stomatal morphology with an emphasis on multi-cellular stomata that include subsidiary cells. We will discuss how subsidiary cells arise and the divisions that produce them; and provide examples of anatomical, mechanical and biochemical consequences of subsidiary cells on stomatal function.

Macronutrient Management Effects on Nutrient Accumulation, Partitioning, Remobilization, and Yield of Hybrid Maize Cultivars

Ray K., H. Banerjee, S. Dutta, S. Sarkar, T.S. Murrell, V.K. Singh, and K. Majumdar. 2020. Front. Plant Sci. 11:1307. DOI: 10.3389/fpls.2020.01307.

Abstract: It is critical to understand nutrient dynamics within different plant parts to correctly fine-tune agronomic advices, and to update breeding programs for increasing nutrient use efficiencies and yields. Farmer's field-based research was conducted to assess the effects of nitrogen (N), phosphorus (P), and potassium (K) levels on dry matter and nutrient accumulation, partitioning, and remobilization dynamics in three popular maize (*Zea mays* L.) hybrids (P3522, P3396, and Rajkumar) over two years in an alluvial soil of West Bengal, India. Experimental results revealed that NPK rates as well as different cultivars significantly ($p \leq 0.05$) influenced the dry matter accumulation (DMA) in different plant parts of maize at both silking and physiological maturity. The post-silking dry matter accumulation (PSDMA) and post-silking N, P, and K accumulations (PSNA, PSPA, PSKA) were highest in cultivar P3396. However, cultivar P3522 recorded the highest nutrient remobilizations and contributions to grain nutrient content. Total P and K accumulation were highest with 125% of the recommended dose of fertilizer (RDF) while total N accumulation increased even after 150% RDF (100% RDF is 200 kg N, 60 kg P_2O_5, and 60 kg K_2O ha^{-1} for the study region). Application of 125% RDF was optimum for PSDMA. The PSNA continued to increase up to 150% RDF while 125% RDF was optimum for PSPA. Cultivar differences significantly affected both remobilization efficiency (RE) and contribution to grain nutrient content for all tested macronutrients (N, P, and K). In general, RE as well as contribution to grain nutrient content was highest at 125% RDF for N and K, and at 100% RDF for P (either significantly or at par with other rates) for plots receiving nutrients. For all tested cultivars, nutrient remobilization and contribution to grain nutrient content was highest under nutrient-omission plots and absolute control plots. Both year and cultivar effects were non-significant for both grain and stover yields of maize. Application of 75% RDF was sufficient to achieve the attainable yield at the study location. The cultivar P3522 showed higher yield over both P3396 and Rajkumar, irrespective of fertilizer doses, although, the differences were not statistically significant ($p \geq 0.05$). The study underscores the importance of maize adaptive responses in terms of nutrients accumulation and remobilization at different levels of nutrient availability for stabilizing yield.

Seed Priming Improved Antioxidant Defense System and Alleviated Ni-Induced Adversities in Rice Seedlings Under N, P, or K Deprivation

Khan F., S. Hussain, S. Khan, and M. Geng. 2020. Front. Plant Sci. 11:565647. DOI: 10.3389/fpls.2020.565647.

Abstract: Excess nickel (Ni) concentration in the growing medium severely hampers the plant growth by disturbing oxidative metabolism and nutrient status. The present study was carried out to investigate the individual and interactive effects of Ni toxicity (0.25 mM $NiSO_4.6H_2O$) and nutrient deprivation (no-N, no-P, or no-K) on growth, oxidative metabolism, and nutrient uptake in primed and non-primed rice seedlings. Rice seed was primed with distilled water (hydropriming), selenium (5 mg L^{-1}), or salicylic acid (100 mg L^{-1}). The Ni toxicity and deprivation of N, P, or K posed negative effects on the establishment of rice seedlings. The shoot length and fresh biomass were severely reduced by Ni toxicity and nutrient stresses; the minimum shoot growth was recorded for rice seedlings grown under Ni toxicity and no-N stress. The Ni toxicity

reduced the root fresh biomass but did not significantly affect the root length of N-deprived seedlings. The rice seedlings with no-P or no-K recorded similar root fresh biomass compared with those grown with sufficient nutrient supply. The Ni toxicity alone or in combination with nutrient stresses triggered the production of reactive oxygen species (ROS) and caused lipid peroxidation in rice seedlings. Among antioxidants, only glutathione reductase and vitamin E were significantly increased by Ni toxicity under different nutrient stress treatments. The Ni toxicity also reduced the concentrations of N particularly in shoot of rice seedlings. The N-deprived (no-N) seedlings recorded maximum Ni concentration in shoot, while K-deprived (no-K) seedlings showed higher Ni concentrations in root. Seed priming with selenium or salicylic acid was effective to alleviate the detrimental effects of Ni toxicity and/or nutrient stresses on rice seedlings. The better growth and greater stress tolerance of primed seedlings was coordinately attributed to lower ROS production, higher membrane stability, strong antioxidative defense system, and maintenance of mineral nutrient status.

Comparison of Soil Extractants and Spectral Reflectance Measurement for Estimation of Available Soil Potassium in Some Ethiopian Soils

Demiss M., Sh. Beyene, and S. Kidanu. 2020. Eurasian Soil Science 53:1100-1109. DOI: 10.1134/S1064229320080049.

Abstract: A study was conducted with the purpose of comparing the efficiency of ammonium acetate (NH_4OAc), Mehlich 3 (M-3), Calcium Chloride ($CaCl_2$) and alpha MIR spectroscopy measurement, for the determination of available potassium (K) on 58 Ethiopian agricultural soils. Four soil reference groups were sampled for the study. The NH_4OAc extractant was used as standard method against which K values estimated by other methods were compared. Results showed that generally highly significant correlations existed among all the methods used for available K extraction. The coefficients of determination (R^2) values between NH_4OAc method and the other methods were 0.90 (M-3), 0.70 ($CaCl_2$), and 0.37(spectral). A statistically poor relationship ($R^2 = 0.07$) was found between $CaCl_2$ and spectral methods. On an average, the K extracted by M-3 and $CaCl_2$ amounted to 106 and 49% of NH_4OAc K, respectively while the spectral method detected 196% of the NH_4OAc K. The highly significant correlation between different soil extraction methods indicated that any of the methods can be used to accurately predict the concentration of available K in the soil. The correlations between K concentration estimated by different methods and plant uptake (product of plant K concentration and dry matter yield) of K were the highest with M-3 and the lowest with spectral methods with R^2 values of 0.65, 0.64, 0.54 and 0.16 for M-3, NH_4OAc, $CaCl_2$ and spectral methods, respectively. It can, therefore, be generalized that the M-3 is a suitable extractant for K in Ethiopian soils, but further study is recommended to determine how these relationships could be translated to plant K uptake under field condition. Besides, the spectral measurement of K as a soil test method for heterogeneous group of soils warrants further investigation and refinement.

Assessment of the Effect of the Mineral Fertilization System on the Nutritional Status of Maize Plants and Grain Yield Prediction

Gaj R., P. Szulc, I. Siatkowski, and H. Waligóra. 2020. Agriculture 10(9):404. DOI: 10.3390/agriculture10090404.

Abstract: A strict field experiment with maize was carried out in the years 2009-2011 at the Experimental Station of the Poznań University of Life Sciences. The impact of mineral fertilization levels on the nutritional status of plants at an early development stage 5-6 leaves (BBCH 15/16) was assessed, as well as the possibility of using biomass and the current state of nutrient supply to predict grain yield. The adopted assumptions were verified on the basis of field experiments with nine variants of mineral fertilization and two maize varieties (EURALIS Semences, Lescar, France) (ES Palazzo and ES Paroli SG—"stay-green" (SG)). Regardless of the variety tested, the plants were under-nutritioned with calcium and magnesium. Plant nutritional status and the accumulation of minerals at the BBCH 15/16 stage were the main factors determining the variability of maize grain yields. In addition, it was shown that maize biomass in the BBCH 15/16 stage, calcium content and the N:K ratio significantly determined grain yield of traditional variety. The yield of the "stay-green" hybrid was largely shaped by plant biomass in the BBCH 15/16 stage, potassium, calcium, magnesium contents and N:Mg ratio. Regression analysis showed that grain yield of the tested maize varieties was determined by plant biomass and its content from 59% to 69%.

The Effect of Macronutrient Availability on Pomegranate Reproductive Development

Lazare S., Y. Lyu, U. Yermiyahu, Y. Heler, G. Kalyan, and A. Dag. 2020. Plants 9(8):963. DOI 10.3390/plants9080963.

Abstract: Pomegranate cultivation has expanded significantly in the last two decades. However, there is limited information on its fertilization requirements and the effect of macronutrient availability on its reproductive development. Two commercial pomegranate cultivars – "Wonderful" and "Emek" – were grown in 500-L containers for 3 years, using a fertigation system. Development and reproduction indices were measured to explore the trees' responses to elevated levels of nitrogen (N), phosphorus (P) and potassium (K) in the irrigation solution. Andromonoecy rate was affected by nutrient levels only in the first year of the experiment, with higher levels of N and P leading to a greater proportion of hermaphrodites out of total flowers. P level had a positive effect on the total number of hermaphrodites per tree in both varieties. Differences recorded between hermaphroditic and staminate flowers included nutrient

concentrations and dry weight. Fruit set and aril number were positively affected by N concentration in the irrigation solution. We conclude that only a severe deficiency of N and P affects the andromonoecy trait, and that at the levels examined in this study, K hardly influences pomegranate reproduction.

Potassium Deficiency Reconfigures Sugar Export and Induces Catecholamine Accumulation in Oil Palm Leaves

Cui J., E. Lamade, G. Tcherkez. 2020. Plant Science 300:110628. DOI: 10.1016/j.plantsci.2020.110628.

Abstract: Metabolic effects of potassium (K) deficiency have been described for nearly 70 years but specific effects of low K availability on sugar composition, sugar export rate and its relationship with other leaf metabolites are not very well documented. Having such pieces of information is nevertheless essential to identify metabolic signatures to monitor K fertilization. This is particularly true in oil-producing crop species such as oil palm (*Elaeis guineensis*), which is strongly K-demanding and involves high sugar dependence for fruit formation because of low carbon use efficiency in lipid synthesis. Here, we used metabolic analyses, measured sugar export rates with 13C isotopic labeling and examined the effects of K availability on both leaflet and rachis sugar metabolism in oil palm seedlings. We show that low K leads to a modification of sugar composition mostly in rachis and decreased sucrose and hexose export rates from leaflets. As a result, leaflets contained more starch and induced alternative pathways such as raffinose synthesis, although metabolites of the raffinose pathway remained quantitatively minor. The alteration of glycolysis by low K was compensated for by an increase in alternative sugar phosphate utilization by tyrosine metabolism, resulting in considerable amounts of tyramine and dopamine.

Utilizing Soil Phosphorus and Potassium Reserves for Soybean Production on a Claypan Soil

Sweeney D.W., A.R.D. Dorivar. 2020. Agronomy Journal 112(5):4386-4394. DOI: 10.1002/agj2.20389.

Under temporary economic stress, producers may elect to grow crops without fertilization. However, information is lacking regarding crop and soil response to growing multiple crops without phosphorus (P) and potassium (K) fertilization on claypan soils in the eastern Great Plains. The objective of this study was to determine the effect of utilizing soil-test P (STP) and soil-test K (STK) reserves on yield of 5-yr continuous soybean [*Glycine max* (L.) Merr.] grown on a claypan soil and on soil-test values. In the first two low-yielding years, soybean yield and yield components were unaffected by STP and STK concentrations. In the subsequent three average-yielding years, soybean yields were up to 0.35 Mg ha^{-1} less when STP was initially 5 mg kg^{-1} or STK was initially 57 mg kg^{-1} than at greater STP or STK. Greater STP increased pods plant^{-1}, whereas greater STK increased pods plant^{-1}, seed pod^{-1}, and seed weight. Even though P and K uptake at R2 (full bloom) did not correlate directly with yields, greater P uptake at R2 in average-yielding years increased pods plant^{-1} and greater K uptake at R2 increased seed pod^{-1}. Both STP and STK declined at more than 3 mg kg^{-1} yr^{-1} for larger initial STP and 15 mg kg^{-1} yr^{-1} for larger initial STK. While using residual soil P and K of varying concentrations in this claypan soil to grow soybeans marginally affected yields, the 5-yr decline in STP and STK values may greatly affect subsequent sensitive crops and require high rates of fertilization.

Irrigated Soybean Response to Granular Fertilizer Potassium Application Timing

Slaton N.A., T.L. Roberts, W.J. Ross, T.L. Richmond. 2020. Agronomy Journal 112(5):4344-4357. DOI: 10.1002/agj2.20342.

Abstract: Amelioration of K deficiency during the growing season requires knowledge of critical tissue concentrations and crop yield response to fertilization time. Our objectives were to characterize the yield and uptake responses of K-deficient irrigated soybean [*Glycine max* (L.) Merr.] to in-season fertilizer-K application time and rate, evaluate fertilizer-potassium-recovery efficiency (FKRE), and evaluate how leaflet-K concentration responds to K-fertilization time. Six trials were established on silt loam soils. Muriate of potash was applied pre-plant and compared to an equivalent K rate applied post-emergence on six or seven dates. Grain yield, trifoliolate-K concentration, and K uptake were measured. Relative soybean yields were regressed across days after planting (DAP) for two situations of K-responsive soybean: season-long K-deficiency symptoms or few symptoms (hidden hunger). The maximum yield increases from K fertilization ranged from 524 to 1948 kg ha^{-1} among trials producing relative yields that were 59−90% of the maximum yield produced with the greatest pre-plant-applied K rate. A linear-plateau model showed maximal yields of soybean with hidden hunger could be produced with in-season fertilizer K applied as late as 83 DAP or 44 d after R1 stage (DAR1). For soybean experiencing season-long K deficiency, K fertilization from pre-plant until 60 DAP or about 20 DAR1 produced similar relative yields. The FKRE of pre-plant-applied fertilizer K ranged from 36 to 75% among trials. Regardless of the severity of K deficiency, fertilizer K applied post-emergence into the R2 development stage was taken up efficiently and produced similar yields as equal pre-plant-applied K rates.

Dry Matter and Nutrient Partitioning Changes for the Past 30 years of Cotton Production

Pabuayon I.L.B., K.L. Lewis, G.L. Ritchie. 2020. Agronomy Journal 112(5):4373-4385. DOI: 10.1002/agj2.20386.

Abstract: Modern cotton (*Gossypium hirsutum* L.) cultivars are more productive and have unique growth and fruiting characteristics

due to optimization of genetics and management practices in the past 30 yr. The most recent work evaluating nutrient uptake and partitioning by cotton was conducted in the early 1990s, necessitating a re-evaluation of nutrient accumulation and requirements in modern high productivity cultivars. Modern cultivar (FiberMax [FM] 958 and Deltapine [DP] 1646) resource allocation, including dry matter production, yields, and accumulation and partitioning of N, P, K, Ca, Mg, and S to different organs, was compared with that of a 1990s cultivar (Paymaster [PM] HS26) in 2018 and 2019. The modern cultivars tested in this study partitioned a greater percentage of dry matter, N, P, K, and S into the fruit than the older cultivar, highlighting the importance of partitioning for increased production potential of these cultivars from the 1990s to the 2010s. Greater efficiencies in partitioning and remobilization of N, P, K, and S resulted in 66, 88, 64, and 30% increase in the amount of lint yield produced for every unit of uptake, respectively, under favorable growing conditions. These findings suggest that existing fertility paradigm in cotton may underestimate the accumulation expectations during the middle and latter part of the growing season. These results can be a basis for optimizing nutrient application to address partitioning changes. Adjusting nutrient recommendations to the shift in cultivar growth characteristics may improve both yield and application efficiency of fertilizers.

Influence of Different Potassium Fertilization Regimes on Quality Aspects and Yield of Cocktail Tomato Cultivars

Frederike Sonntag née Wenig. 2020. Doctoral Thesis, Georg-August-Universität Göttingen.

The tomato (*Solanum lycopersicum* L.) is a worldwide important vegetable, with an annual production of 170.8 million tons in 2014. Potassium (K) has several physiological functions in plants, such as translocation of assimilates, activation of enzymes, maintenance of turgescence, and stomata regulation and thereby contributes to fruit yield and quality. The aim of all experiments was to investigate the impact of increasing K application on tomato fruit quality for a better understanding of K's physiological functions. Therefore, different cocktail tomato cultivars (Primavera, Resi, and Yellow Submarine) were studied in two consecutive years in outdoor pot experiments. Total soluble solids (TSS), titratable acids (TA), dry matter (DM), color, and firmness are important consumer-related quality traits. Especially high concentration of TSS and TA are taste beneficial. In all studied cultivars TSS, TA, and partly DM increased with rising K fertilization. Other parameters, such as color, firmness and yield increased in Primavera in both years, whereas in Resi no further changes were detected. This clear cultivar dependence shows that high K fertilization not necessary enhance these traits. Tomatoes contain several important water- and fat-soluble antioxidants, like ascorbic acid, phenolics, carotenoids, and tocopherols. The antioxidant concentrations in tomato fruit are affected by K fertilization, but other abiotic factors may alter or even reverse those effects in an outdoor environment. Nevertheless, the tendencies of ascorbic acid, naringenin, pcoumaric acid, and caffeic acid are similar in both years for Primavera and Resi, indicating a strong K fertilization effect. The metabolome analysis provides a comprehensive overview of the induced changes by increasing K fertilization on low weight metabolites in tomato fruits. The cultivarindependent increase of TCA cycle metabolites and decrease of amines with rising K fertilization was most prominent. Several other metabolites showed a cultivar-specific effect. Indicating that the reaction towards macronutrient stress is quite different between cultivars of one species.

Evaluation of Different Potassium Management Practices on Potassium Status of Soil, Profitability and Productivity of Aerobic Rice

Raj M., R. Kumar, M.R. Ashrafi, K. Lal, M. Ghosh, Sarita. 2020. J. Pharmacogn Phytochem 9(5):2933-2936.

Abstract: The present study was carried out on aerobic rice during 2019-20 at research farm of Bihar Agricultural University, Sabour, Bhagalpur (Bihar) to study the impact of different potassium (K) management practices on K status of soil, profitability and productivity of aerobic rice. The study comprised 10 treatments in Randomized block design (RBD) and replicated thrice. The aim of the study was to find the suitable potassium dose for getting optimum productivity and higher profitability. Among all treatments K_8 (KSB inoculated with 150% RDK at basal) and K_5 (150% RDK incorporation with two equal split) performed better in terms of productivity and profitability of rice and 60 kg K_2O (150% RDK) is the new recommendation of K in the Indo Gangetic plain to obtain optimum yield and monetary value. Split application and KSB (*Frateuria aurantia*) ensure the continuous supply of K throughout the crop cultivation and also reduces the K losses. K management in DSR become a challenging due less availability of water so most of K has fixed in the inter layer clay lattice. K is a crucial macronutrient that plays an important role in the yield attributes components apart from this, it regulates the ionic balance, opening and closing of stomata and also act as co factor to activate the more than 60 enzymes.

Controlled-release Potassium Chloride Containing Mepiquat Chloride Improved Bioavailability of Soil Potassium and Growth of Cotton Plants

Jianqiu Chen, Xiuyi Yang, Jibiao Geng, Yingjian Wang, Qianjin Liu, Hanyu Zhang, Xiaodong Hao, Zongduan Guo & Haining Chen. 2020. Archives of Agronomy and Soil Science. DOI: 10.1080/03650340.2020.1817902

Abstract: Cotton is an important cash crop with an indeterminate growth characteristic. The labor costs of multiple management

practices, including repeated foliar applications of mepiquat chloride (MC) and topdressing with potassium (K) fertilizers, restrict its planting area and benefits. To help address this problem, a field experiment was performed to evaluate the effects of controlled-release potassium chloride containing mepiquat chloride (CRKMC) on soil K forms and cotton yield. CRKMC, 70%CRKMC (30% reduced K dosage), CRK (coated potassium chloride), KCl and no K fertilizer used treatments were carried out. Results showed that MC and K from CRKMC exhibited a trend of slow release, followed by fast release and eventually stabilization. Soils maintained more non-exchangeable K than available K. The contents of all soil K forms for the CRKMC treatment were significantly higher than these for KCl. Plant heights, SPAD values and stem diameters in CRKMC and 70%CRKMC were larger than those in KCl. Cotton yield, K use efficiency and net profit in the CRKMC treatment were increased than KCl. The successive release pattern of MC and K from CRKMC corresponded well to the demands of cotton, sufficiently manipulated the plant canopy and provided adequate K nutrition.

Foliar Application of Potassium to Improve the Freezing Tolerance of Olive Leaves by Increasing some Osmolite Compounds and Antioxidant Activity

Saadati S., B. Baninasab, M. Mobli, M. Gholami. 2020. Scientia Horticulturae 276. DOI: 10.1016/j.scienta.2020.109765.

Abstract: Freezing damage is an important factor that limits olive production. The main aim of the present research was to investigate the possible impacts of the foliar application of potassium sulphate (K; K_2SO_4; 0.0, 0.5, 1.0, and 2.0 %) fertilization on the freezing tolerance (FT). Further, this research evaluated some physiological and biochemical changes of 'Rashid' olive (*Olea europaea* L.) at six sampling dates; these included November, December, January, February, April, and July. For this purpose, K was sprayed three times at 1-week intervals starting on 22 August 2016, on 16-year-old olives that had been located in a research orchard at Isfahan University of Technology (Iran), based on randomized complete block design. The results revealed that the effect of K sprays on the olives FT was significant at six stages of sampling. This was such that the highest ($LT_{50} = -11.17$ °C) and lowest FT ($LT_{50} = -6.98$ °C) was recorded in 2.0 % K-treated and control untreated olives during January, respectively. In addition, K application, particularly at 2.0%, led to high increases of carbohydrate, proline, protein and total phenol concentration, antioxidant enzyme activity and DPPH (1, 1-diphenyl-2-picrylhydrazyl) scavenging capacity, as well as the ratio between unsaturated fatty acids and saturated fatty acids (UFA/SFA). It could be concluded that the foliar application of K could contribute to enhancing the olives FT by changing UFA/SFA ratio, in addition to the changes in other metabolites, like the accumulation of soluble carbohydrate, proline, protein, total phenol content and activation of the antioxidant system.

Target of Rapamycin Regulates Potassium Uptake in *Arabidopsis* and Potato

Kexuan Deng, Wanjing Wang, Li Feng, Huan Yin, Fangjie Xiong, Maozhi Ren. 2020. Plant Physiology and Biochemistry 155:357-366. DOI: 10.1016/j.plaphy.2020.07.044.

Abstract: Potassium (K) is an essential inorganic nutrient needed by plants for their growth and development. The conserved target of rapamycin (TOR) kinase, a well-known nutrition signaling integrator, has crucial roles in regulating growth and development in all eukaryotes. Emerging evidence suggests that TOR is a core regulator of nutrient absorption and utilization in plants. However, it is still unclear whether there is a causative link between the TOR pathway and potassium absorption. Here, we show that the expression of some potassium transporters and channels was regulated by TOR, and the suppression of TOR activity significantly affected potassium uptake in *Arabidopsis* and potato. Furthermore, we discovered that a Type 2A phosphatase-associated protein of 46 kDa (TAP46), a direct TOR downstream effector, could interact with CBL-interacting protein kinase 23 (CIPK23) in *Arabidopsis* and potato. In *Arabidopsis*, the K^+ channel AKT1 conducting K^+ uptake was significantly regulated by Calcineurin B-like Calcium Sensor Protein 1/9 (CBL1/9)-CIPK23 modules. We found that the *cbl1cbl9*, *cipk23* (*lks1-2* and *lks1-3*), and *akt1* mutants were more hyposensitive to the TOR inhibitor than the wild-type, and the TOR inhibitor induced the downregulation of K^+ uptake rate in the wild-type more than in these mutants. In addition, the overexpression of *CIPK23* could effectively restore the defects in growth and potassium uptake induced by the TOR inhibitors. Thus, our work reveals a link between TOR signaling and CIPK23 and provides new insight into the regulation of potassium uptake in plants.

Different Potassium Fertilization Levels Influence Water-Use Efficiency, Yield, and Fruit Quality Attributes of Cocktail Tomato – A Comparative Study of Deficient-to-Excessive Supply

Daoud B., E. Pawelzik, and M. Naumann. 2020. Scientia Horticulturae 272:109562. DOI: 10.1016/j.scienta.2020.109562.

Abstract: Tomato is the foremost vegetable in the world in terms of production and consumption and has considerable nutritional benefits in addition to its economic importance. High yield, water-use-efficiency (WUE), and desirable fruit quality are strongly influenced by potassium (K). So far, the effect of excessive supply of K on those parameters has not been studied in cocktail cultivars. Thus, and for a comprehensive view, we evaluated the effect of six different K fertilization regimes; from deficient K1, moderate K2, optimal K3 and K4, to excessive K5 and K6 on two cocktail tomato cultivars.

With increasing K supply, the fruit's content of K, Magnesium

(Mg), and Iron (Fe) increased while that of Calcium (Ca), Sodium (Na), and Zink (Zn) decreased. WUE, marketable yield, and total soluble solids (TSS) increased until K4, color and dry matter (DM) until K3, while Titratable acid (TA) reached its highest value at K5 in cultivar (cv.) Primavera. In cv. Yellow Submarine, marketable yield, color, TSS, and TA were the highest at K4, while WUE and DM increased following the highest K supply at K6.

Optimal K application – 3.66-4.00 g plant^{-1} – enhanced WUE, marketable yield, and fruit quality attributes such as color attributes a* and b*, TSS, TA, DM of cocktail tomatoes, whereas excessive K fertilization increased the surplus of K and the studied attributes remained unaffected. The results of this study, therefore, indicate that K fertilization should be implemented at the lowest possible efficient concentrations.

Distribution and Content of Calcium and Potassium in Eucalyptus leaves Infected with *Calonectria pteridis*

Thaissa de Paula Farias Soares, Maria Alves Ferreira, Adélia Aziz Alexandre Pozza, Edson Ampélio Pozza, and Reginaldo Gonçalves Mafia. 2020. Journal of Phytopathology 168(9):551-558. DOI: 10.1111/jph.12933.

Abstract: Calonectria leaf spot, caused by *Calonectria pteridis*, is a serious problem in *Eucalyptus* crops in both nursery and the field. Under ideal conditions, the disease can cause severe defoliation. It is known that calcium and potassium are directly related to the plant's resistance to pathogens. Thus, the knowledge of how a balanced fertilization of Ca and K interferes in the distribution of these nutrients at the infection site would contribute to elucidate the resistance of the plant related to its nutrition. This study investigated the effect of calcium and potassium fertilizer application on the content and distribution of these nutrients in the symptomatic leaf area, transition zone and asymptomatic leaf area over time. *Eucalyptus* seedlings were grown in nutrient solution under different Ca and K treatments (6 mmol/L K + 4 mmol/L Ca, 6 mmol/L K + 8 mmol/L Ca and 9 mmol/L K + 12 mmol/L Ca) and inoculated with *C. pteridis*. Leaves were removed at 24, 48 and 72 hr after inoculation (hai) and evaluated by X-ray microanalysis. The highest calcium content among the different leaf areas was observed in the symptomatic area, and the levels in this area increased over time, with the highest mean value observed at 72 hai in the 6K + 8Ca treatment. In the other treatments, the mean calcium content peaked at 48 hai and then decreased. A similar pattern in asymptomatic tissue was observed for potassium in the 6K + 8Ca treatment. Fertilization with calcium and potassium directly affected the demand and availability of nutrients at different times during infection. These results demonstrate that plant defence responses and their continuity over time during infection rely on balanced calcium and potassium fertilization because these nutrients are directly involved in plant resistance to the pathogen.

Effects of Potassium Nutrition and Water Availability on Iron Toxicity of Rice Seedlings

Suriyagoda L.D.B., M. Tränkner, and K. Dittert. 2020. Journal of Plant Nutrition 43(15):2350-2367. DOI: 10.1080/01904167.2020.1771578.

Abstract: The aim of the study was to investigate the influence of potassium (K) nutrition and/or aeration of flooded soil through drainage on iron (Fe) toxicity of rice during the period of establishment. A hydroponic experiment with three Fe (0.1, optimal; 1, high; 2.5 mM, very high) and K levels (0.3, low; 2, optimal; 5 mM, high), and a soil experiment with two moisture levels [continuously flooded; alternate-wetting and drying (AWD)] and three Fe levels (16, low; 163, optimal; 490 mg Fe(II) kg^{-1} soil, high) was conducted. In the hydroponic experiment, high Fe supply increased tissue concentrations of Fe, phosphorus (P) and magnesium (Mg), and reduced manganese (Mn) concentrations. Particularly Fe, K and P were maintained at root surfaces in larger amounts than taken up by the roots. Growth of rice, photosynthesis, maximum quantum yield, effective quantum yield and electron transport rate were decreased at high and very high Fe concentrations while K application had no positive effect. In the soil experiment, growth and nutrient relations under increased Fe supply were similar to those observed in the hydroponic experiment. However, comparing both moisture levels showed that soil solution Fe concentration and plant growth were reduced and tissue P, Mg and Mn concentrations were increased in the AWD system compared to flooding. Therefore, the application of K or aeration of flooded soil cannot be generalized as promising strategies to alleviate Fe toxicity in rice at the initial crop establishment stage.

Nutrients Accumulation, Biometric, Chlorophyll and Potassium Indexes and Production in Minituber Potato as Function of Potassium Doses in Organic and Hydroponic Conditions

Fontes P.C.R., C.B.A. Tufik, C. do Carmo Milagres, M.A. Moreira, and A.M. Milanez. 2020. Communications in Soil Science and Plant Analysis 51(10):1357-1369. DOI: 10.1080/00103624.2020.1781155.

Abstract: Potato is one of the most economically important crops in Brazil. In this crop, potassium (K) is the most accumulated nutrient and has significant and positive effect on potato plant growth and tuber yield. Thus, the aim of this work was to determine the effects of K doses on nutrients accumulation, biometric, chlorophyll, and K indexes in potato plants grown. Two experiments were installed simultaneously in an unheated greenhouse with Agata cultivar. The experiment 1 was carried out in pot with commercial organic substrate with five K doses (0, 0.66, 1.32, 1.98, and 2.64 g dm$^{3-1}$). The experiment 2, nominated hydroponic system, with washed sand above a layer of expanded clay pebbles where the plants received daily nutrient

solution application. The treatments were five K doses (0.0, 2.5, 5.0, 7.5 e 10.0 mmol L^{-1}). The biometrics data were collected 21 days after emergence and at harvest. Both experiments were set at a randomized block design with four replications. In both experiments, no visual symptoms of deficiency or excess were observed but only in plants at 0 mmol L^{-1} of K. In both experiments, K doses interacted with some biometric and chlorophyll indexes measured in the fourth completely expanded leaf with portable SPAD and Dualex devices, commonly used as a guide to in-season fertilizer N management, leading to recommend their use only in plants properly nourished in K. K critical concentration in the fourth fully expanded leaf was 61.7 g kg^{-1}.

Reliance on Biological Nitrogen Fixation Depletes Soil Phosphorus and Potassium Reserves

Reimer M., T.E. Hartmann, M. Oelofse, J. Magid, E.K. Bünemann, and K. Möller. 2020. Nutrient Cycling in Agroecosystems 118:273-291. DOI: 10.1007/s10705-020-10101-w.

Abstract: Limited nutrient availability is one of the major challenges in organic farming. Little is known about nutrient budgets of organic farms, the underlying factors or effects on soil fertility. We therefore assessed farm gate nutrient budgets for nitrogen (N), phosphorus (P), potassium (K), magnesium (Mg) and sulfur (S) of 20 organic farms in Germany and analyzed their soil nutrient status. In average, the budgets showed a surplus of N (19 kg ha^{-1}), K (5 kg ha^{-1}), S (12 kg ha^{-1}), and Mg (7 kg ha^{-1}), and a deficit of P (−3 kg ha^{-1}). There was, however, high variability between farms (e.g. standard deviation up to ± 36 kg N ha^{-1}), which was mainly explained by different degrees of reliance on biological N fixation (BNF) as N source. When farms obtained more than 60% of their N input through BNF, they had deficits of P (mean −8 kg P ha^{-1}) and K (mean −18 kg K ha^{-1}). Nutrient status of most soils was within the advised corridor, but for P, K and Mg, 10-15% of fields were lower and 45-63% were higher than advised. Extractable soil nutrient contents did not correlate with the nutrient budgets, inputs or outputs. Only extractable soil P increased with increasing P inputs and outputs. Furthermore, a decrease in extractable soil P was detected with a prolonged history of organic farming, indicating a risk of soil P mining in organic farming systems. In conclusion, the study revealed nutrient imbalances in organic farming and pointed to P and K scarcity as a major challenge for organic farms with high reliance on BNF in the long term.

Microscopic Analysis Reveals Potential Mode of Action of Foliar-Applied Potassium Silicate against Powdery Mildew Development

Dallagnol L.J., D.A. Magano, and L.E.A Camargo. 2020. European Journal of Plant Pathology 157:815-823. DOI: 10.1007/s10658-020-02041-6.

Abstract: Silicon (Si) efficiently controls *Podosphaera xanthii* in melon by affecting epidemic components related to the infection and colonization processes. Root amendments of Si prime melon defences, but its mode of action when sprayed on the leaves is unknown. The effects of potassium silicate (PS) on the development of the pathogen were observed by scanning electron microscopy. Both forms of PS application reduced conidial germination and delayed colony development. At 120 h after inoculation (hai), differentiation of the conidiophores was inhibited only by the root treatment and at 144 hai visual differences between PS treatments accentuated. Comparison of foliar PS with compounds of contrasting pH and ionic strength (KOH, KCl and PEG) showed that only PS and PEG inhibited conidial germination ruling out these variables as inhibitory factors. Alteration of the leaf surface tension was also excluded since it was affected by all compounds. The results indicate that foliar-applied PS affects *P. xanthii* conidial germination of and colony development by modifying the osmotic potential of the leaf surface.

Read on

Improving Potassium Recommendations for Agricultural Crops

Conference Proceedings. Editors: T. Scott Murrell, Robert L. Mikkelsen, Gavin Sulewski, Robert Norton, Michael L. Thompson.
https://link.springer.com/book/10.1007%2F978-3-030-59197-7

Growing US Population Potassium Deficiency Linked to Crop Removal from Soils

www.fertilizer.org/Public/Media/In_Brief/2020_11_13_Potassium%20Deficiency.aspx

Function and Management of Potassium in Hydroponics

www.hortidaily.com/article/9254989/function-and-management-of-potassium-in-hydroponics/

View on

Soybean School – Think P&K for Pods and Yield

https://youtu.be/8Qd-tpVfrkc

Obituary

Obituary of Abraham Cohen (1927-2020)

We are sorry to announce the death of Abraham Cohen. He was an IPI coordinator for 26 years and a member of the IPI Technical Secretariat. He brought to his research work a huge amount of knowledge and experience from his studies and career in many countries.

Mr. Cohen was born in Mogador, Morocco on 24 December 1927. He studied agricultural engineering at L'Institut Agricole de L'Universite de Toulouse in France and was awarded an engineering diploma on 28 June 1949.

In March 1950, Mr. Cohen emigrated to Israel aboard the ship named 'Negba'. He studied for his MSc in Agriculture at the Hebrew University of Jerusalem (1963), with research at the Agricultural Research Organization (Volcani Center) and the Weizmann Institute.

From 1963 to 1966 he joined an FAO mission in Burkina Faso, at that time known as Upper Volta, and during 1966-1969 he was appointed by FAO to their offices in Peru.

Mr. Cohen joined IPI in 1971. After a few years, he was posted to IPI's mission in Pretoria, South Africa (1982-1986) as an IPI coordinator, before returning to work at the head office in Switzerland (1994-1997).

Mr. Cohen described how most of his professional satisfaction came from the in-country opportunity to assist in developing sound research on K nutrition with local scientists, many of whom he stayed in contact with over the years. He had a significant impact on K soil research, through many university and research centers' projects. Mr. Cohen was an expert on plant nutrition and had vast practical field knowledge which he shared generously.

IPI remembers Abraham Cohen

Above all, Abraham Cohen was respected as a very kind and dear man, much loved by everyone who knew him. He was a pioneer in his field, and his work and character were an inspiration to many which is why his influence lives on in the work of a new generation of agronomists at IPI.

May his memory be blessed.

Written by

Mr. Hillel Magen, IPI Director

Dr. Patricia Imas, IPI Scientific and Communications Coordinator

In the next edition of the *e-ifc*

Research Findings

The Research Findings in the next edition of the *e-ifc* include papers on three field experiments investigating the effect of the use of polyhalite fertilizer on peanuts in China, cabbage in Vietnam, and alfalfa in France.

IPI Photo Competition

The IPI Photo competition is now closed to new entries. We were delighted to receive a record number of crop deficiency photographs. Now the process of shortlisting the best and deciding on the winners begins. We will bring you the results in the next edition.

Impressum *e-ifc*

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