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Editorial

Dear readers,

The world looks East for excellence this year when the very greatest of human physical endeavour is displayed at the postponed Tokyo 2020 Olympic games. There may not be crowds to look on and cheer, but nevertheless the excellence on show is measured and appreciated. Much like the quiet excellence in science to be seen if we look East not for sport but for science and the papers featured in this edition of the *e-ifc*.

First, we turn to Malaysia, to turn the spotlight on the ever-popular durian fruit. The paper we share is from a team that assesses how the fruit's firmness and sweetness was affected when polyhalite was applied instead of the usual fertilizer.

For more excellence, we shift the focus to China, the world's largest producer of peanuts, and from where we have a paper on the effects on yield, nutrient content and partitioning from combining nutrition of NPK compound fertilizer with polyhalite.

Finally, and still speaking of excellence, most of you will be aware that, after 17 years with us, Hillel Magen is retiring from his role as IPI Director. We know how much Hillel will be touched by the outpouring of international good wishes, thanks and appreciation for his work from our IPI network. Now, just as in a running relay, Shay Mey-Tal takes on the baton as our new IPI Director and with it the responsibility to continue the excellent track record. I am sure you will join me in giving Shay a warm welcome and wishing him well in his new role in our team.

I hope this edition's selection of excellent science provides you with some essential and enjoyable reading.

Stay safe!

Dr. Patricia Imas
IPI Scientific and Communications Coordinator

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Photo cover page: Lysimeter oil palm trial, Malaysia.

Research Findings

Photo 1. Durian fruit. Photo by the authors.

Polyhalite Improves Physiochemical and Organoleptic Properties of Durian When Applied After Flowering and During Fruit Development

Mei Kying Ong[(1)*], Cong Rong Cheng[(2)], and Choon Cheak Sim[(3)]

Abstract

Secondary macronutrients play a major role in durian fruit yield and quality. The treatment in this study withdrew nitrogen (N) and phosphorus (P) input, increased the rate of magnesium (Mg), calcium (Ca) and sulfur (S) input, whilst maintaining potassium (K) input through the application of polyhalite during D101 durian fruit development stage. There was a significant increase in thickness of the distal portion of durian husk (1.47 cm vs 1.63 cm) in the polyhalite treatment. However, there were no significant changes observed in durian fruit weight and other physical characteristics. Several characteristics of the arils were significantly increased in the treatment group, such as pH (6.15 vs 6.92) and firmness (0.088 N vs 0.169 N). In terms of nutritional quality, protein content in the polyhalite-treated arils increased from 6.36% to 7.52% whereas fat content increased significantly from 7.68% to 10.64%. Sensory attribute mean scores obtained from a consumer panel showed

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significant improvements in terms of flavor and sweetness of the arils in the polyhalite treatment group. However, a decrease in total soluble solids (°Brix) was recorded. In short, application of polyhalite resulted in improved quality of durian fruits. The results of the research did not discount the importance of primary macronutrients but rather emphasized the requirement to balance primary and secondary macronutrient input during fruit development.

Introduction

The Durio genus consists of almost 30 recognized species, including the internationally traded *Durio zibethinus* L., and is now widely cultivated in Thailand, Malaysia, and Indonesia due to the favorable climate (Brown, 1997). In Malaysia, many different planting materials exist, and their fruits differ in characteristics including the taste and aroma of the arils (Idris *et al.*, 2018). The D101 cultivar is fairly popular in Malaysia due to its more affordable price, while the D197 cultivar (*Musang* King) remains unrivaled in terms of demand, both locally and from China. The arils of D101 are yellow to yellowish-orange, taste fairly sweet, are creamy, and have a fair strength of aroma (Idris *et al.*, 2018).

One metric tonne of durian fruit removes 2.4 kg of nitrogen (N), 0.4 kg of phosphorus (P), 4.0 kg of potassium (K), 0.3 kg of calcium (Ca), and 0.5 kg of magnesium (Mg) (Jamil, 1968; Ng and Thamboo, 1967). The high potassium removal leads growers to apply high levels of K fertilizer, before and after anthesis. Potassium foliar spray has been shown to result in a higher flesh to fruit weight ratio and improved yellowness of arils (Punnachit *et al.*, 1992).

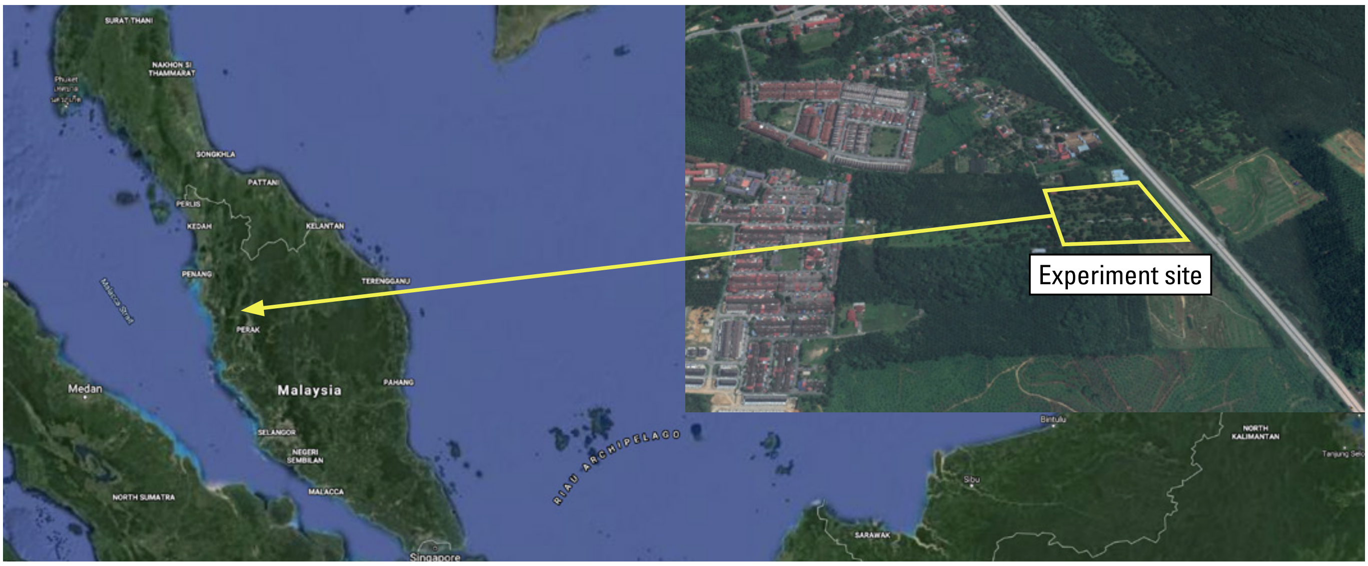
Although yield response is highly desirable, improvements in fruit quality are also crucial to secure higher profitability for farmers. Poor quality characteristics include uneven ripening which has always been associated with genetics, poor weather, and imbalanced nutrition. Uneven ripening tends to occur in D24 clones or under poor weather conditions. In terms of nutrients, lack of calcium input leads to an imbalanced Ca:Mg or Ca:K ratios, leading to poor ripening in durian. Although it is commonly believed that imbalanced nutrition, such as high application of N but lower secondary macronutrient applications, during the fruit development phase leads to poor fruit quality, scientific evidence is scarce.

Organically-grown durian is currently in high demand but production is difficult due to durian's high potassium requirement and the rarity of organic potassium fertilizers. Polyhalite ($K_2Ca_2Mg(SO_4)_4 \cdot 2(H_2O)$) is a mineral containing K, Mg, Ca and S (14% K_2O, 6% MgO, 17% CaO, and 45% SO_3). The mineral can be applied in its natural state directly to the field, without going through any industrial processing, hence it is certified for use in organic farming systems. The prolonged release of the nutrients, and its supply of four out of six macronutrients, were recently shown to improve crop yields in legumes and cereal crops (Melgar *et al.*, 2017; Liu, 2019; Li and Lu, 2019).

The effect of fertilizer on the yield of durian trees is always difficult to determine due to the influence of climate, flowering and the farmers pruning practices. The current study aims to evaluate the effect on the quality of durian fruit of application of polyhalite as a replacement for conventional high-K NPK 15-5-20 + 2MgO + 10S + TE applied after anthesis and during fruit development.

Materials and methods

The study was conducted from January 2020 to January 2021 at a durian farm in Tapah, Perak. Six durian trees of the D101 cultivar were selected for the study. The trees were planted in 2012-2013 on



Map 1. Location of the trial carried out at a durian farm in Tapah, Perak, Malaysia. *Source:* Google Maps.

Table 1. Nutrient input per durian tree after anthesis until harvest.

	Fertilizer	Rate	N	P_2O_5	K_2O	MgO	CaO	SO_3
		--*kg^{-1} tree*--						
Control	NPK 15-5-20-2	3.5	0.53	0.18	0.70	0.07	Foliar	0.88
Treatment	Polyhalite	5.0	0.00	0.00	0.70	0.30	0.85	2.25

recent alluvium with excellent drainage and were selected based on uniformity of growth and size.

An NPK 15-5-20-2 + 10S + TE fertilizer was applied at a rate of 3.5 kg $tree^{-1}$ divided into two applications, after fruit set and during fruit development, as a control (farmer's practice). This was in combination with a calcium and boron foliar spray during fruit development. In the treatment plot, polyhalite was applied as an alternative at a rate of 5 kg $tree^{-1}$ as shown in Table 1.

Anthesis and fruit drop occurred mid-August 2020 and 10 January 2021, respectively. The number of fruits produced per tree ranged from 30 to 40 for the December 2020-February 2021 harvest season, with no pruning conducted. Flowering and fruit set remained low due to higher-than-average rainfall from August to December 2020. Fruits were allowed to ripen on the tree and drop naturally. Six durians free from physiological defects and pest damage, ranging from 1.65-2.05 kg, were selected randomly from treatment and control trees (three each). The durians were collected on the morning of 10 January 2021.

Total soluble solids

Total soluble solids of samples were determined using a hand-held digital refractometer (PAL-3, ATAGO, Japan). Calibration of the refractometer was done by dripping distilled water onto the prism. The distilled water was wiped off before the samples were analyzed. Durian pulp was blended and diluted with distilled water (1:10). Approximately 2 to 3 drops of the sample were placed onto the prism of the refractometer (Onyekwelu, 2017). The Brix value (% Brix) of the sample was shown on the digital screen. Total soluble solids of samples were expressed as % Brix multiplied by the dilution factor, and triplicates for each sample were obtained.

Measurement of moisture content

The moisture content of each durian sample was measured by using a moisture analyzer (MX-50, A&D, Japan). "Quick mode" operation was selected as the measurement method, and the drying temperature for the program was set at 160°C.

pH determination

pH was determined using a pH meter (FP20, Mettler Toledo, USA). Calibration was conducted using buffer solutions of pH 4.0, 7.0, and 10.0. Next, the electrode of the pH meter was dipped into the sample to obtain the pH reading. When the pH meter beeped, the finalized pH of the sample was shown on the digital screen. All samples in both treatments were run in triplicate and the results were presented as mean ± standard deviation.

Photo 2. Six durian trees of the D101 cultivar were selected for the study on a durian farm in Tapah, Perak, Malaysia. Photo by the authors.

Photo 3. Flowering durian tree. Photo by the authors.

Photo 4. Durian aril color was recorded. Photo by the authors.

Titratable acidity (TA)

According to the Association of Official Analytical Chemists method (AOAC, 2010), titratable acidity was determined using titration. NaOH (0.1 N) was used as a titrant. To prepare 0.1 N of sodium hydroxide, 4 g of NaOH was dissolved in 1 L of distilled water. The solution was then filled into the burette. Ten grams of sample was poured into a volumetric flask and diluted to 250 mL with the purpose of allowing the endpoint of titration to be easily detected. One hundred mL of the diluted sample was transferred into a conical flask and titration was conducted by titrating NaOH into the sample until the endpoint was reached, whereby a distinct color change of the sample was observed. The titratable acidity of the samples was expressed as % malic acid, since malic acid is the major compound in durian. The titratable acidity was calculated using the formula shown below.

$$\text{TA (\%)} = \frac{Normality\ of\ base \times volume\ of\ base\ (mL) \times miliequivalent\ of\ malic\ acid \times 100}{volume\ of\ sample\ (mL)}$$

$$= \frac{0.1\ N\ NaOH \times volume\ of\ base \times 0.067 \times 100}{10\ g\ sample}$$

Color analysis

Evaluation of color of durian arils was measured using a colorimeter (CM-600D, Konica Minolta, Japan) according to Niu *et al.*, 2008. The black and white plates were used to calibrate the colorimeter, followed by zero calibration. After the standard calibration of the colorimeter, the color of each sample was measured. Color measurement was obtained, and CIE-Lab parameters were expressed as L* (lightness intensity), a* (+ redness, – greenness), and b* (+ yellowness, – blueness) values. All samples in both treatments were run in triplicate and the results were presented as mean ± standard deviation.

Texture analysis

The texture of each sample was analyzed by subjecting the sample to a puncture test performed by a texture analyzer (TA.XT Plus, Stable Micro Systems, UK). The firmness of the durians was analyzed freshly, right after the fruits were opened. The durian sample was placed in a plastic tube with a diameter of 2 cm and height of 4 cm. A cylindrical probe with a diameter of 5 mm was used. The equipment was set for a puncture test performed at a constant velocity of 100 mm min^{-1} until the probe reached 25 mm of the sample's depth according to Holzwarth *et al.*, 2013. The sample texture was recorded as the maximum force (N) at the breaking point of the sample and expressed as firmness.

Protein determination

Protein content determination was carried out using Kjeldahl and titration method which referred to AOAC 984.13 (AOAC, 2010) that involved three steps: digestion, distillation, and titration. The protein content of all samples was determined in triplicate. First, 2 g of powdered sample was added into the cleaned Kjeldahl flask with 0.8 g of $CuSO_4$ and 7 g of K_2SO_4, followed by 25 mL of 98% concentrated sulfuric acid (H_2SO_4), then all six flasks were transferred to the speed digester for digestion. During digestion, the flasks were heated for one hour until clear green mixtures were obtained, then the flasks were cooled to room temperature. The cooled digested mixtures were then transferred to the distillation unit and digestion was conducted for five minutes, with the end tube of the distillation unit connected to a conical flask with 50 mL of boric acid and three drops of methyl orange indicator. When distillation was completed, the boric acid mixture was then titrated with 0.25 M of H_2SO_4 until the mixture turned from blue to pink (Maisarah *et al.*, 2014). The volume of acid used was recorded and used in the protein content calculation, by using the formula shown:

$$\%N = ([V(1)-V(B1)] \times F \times c \times f \times M(N))/(m \times 1000) \times 100\%$$

$$\%\ Protein = \%N \times PF$$

Where:

V (1) = volume of acid (H_2SO_4) used (mL)

V (B1) = volume of blank (mL)

F = molar reaction factor (1 = HCl, 2 = H_2SO_4)

c = concentration of acid (mol L^{-1})

f = factor of titrant (acid)

M(N) = molecular weight of N (14.007 g mol^{-1})

m = sample weight (g)

PF = protein factor (6.25)

%N = % weight of N

%P = % weight of protein

Fat determination

Fat content determination using Soxtherm method was performed for all samples according to AOAC standard as per Bagchi *et al.* (2016). Soxtherm fat analyzer (Gerhardt, SOX 6-place) was used

Table 2. Weight characteristics of the durian samples.

Sample	Weight of husk	Weight of aril and seed	Weight of aril	Weight of seed
	----------%----------			
Control	66.30 ± 3.16[a]	33.70 ± 3.16[a]	22.88 ± 1.53[a]	10.81 ± 1.64[a]
Polyhalite	65.70 ± 3.57[a]	34.30 ± 3.57[a]	24.70 ± 1.88[a]	9.61 ± 2.05[a]

Values in the table represent the mean ± standard deviation of three biological replications. Means within each column with different letters are significantly ($p < 0.05$) different.

in this analysis. Firstly, the extraction beakers with three pieces of boiling stones were dried at 105˚C for one hour, then cooled in the desiccator for one hour, the weight of each cooled extraction beaker with boiling stones was then determined and recorded as M1. Then 5 g of powdered samples were weighed and recorded as M0, then wrapped with filter paper. The wrapped samples were inserted into thimbles and covered with cotton wool, and placed into the labelled extraction. Hence, 90 mL of petroleum ether was added into each extraction beaker, then the beakers were connected to the fat analyzer and the analysis program was conducted. When the extraction was completed, the extraction beakers were dried at 105˚C for one hour, and the weight after drying was recorded as M2. The fat content was determined using the formula shown below:

$$\% \text{ Fat} = (M2 - M1)/M0 \times 100\%$$

Where:

M0 = weight of samples (g)

M1 = weight of extraction beakers and boiling stones before extraction (g)

M2 = weight of extraction beakers and boiling stones after extraction (g)

All the measurements were performed in triplicate. The data was analyzed with independent samples T-test and generated by software IBM SPSS Statistics 25 (SPSS Inc., Chicago, Illinois, USA). The significance level was pre-set at $\alpha = 0.10$ and $\alpha = 0.05$.

Sensory evaluation

Sensory evaluation was conducted in accordance with the procedure described by Olivera and Salvadori (2006). A panel of eight semi-trained individuals from Universiti Tunku Abdul Rahman were recruited and required to evaluate the acceptability of each durian sample in terms of yellowness, attractiveness of aril in terms of color and shape, flavor, sweetness, aroma, less watery pulp and texture on a typical 9-point hedonic scale. The 9-point hedonic scale was used by having 9 scaling tests ranging from 9 = like extremely, 5 = neither like nor dislike and 1= dislike extremely.

Results and discussion

Higher than average rainfall was recorded from September 2020 to January 2021 directly resulting in poorer yields of durian. Approximately two weeks before anthesis, irrigation was withheld but heavy rainfall continued. High rainfall after anthesis causes flowers to drop, resulting in poor pollination, and subsequently in poorer fruit set. Accompanied by strong winds, higher fruit abscission could occur. The trees in this experiment yielded approximately 30 fruits tree^{-1} only, and no fruit pruning was conducted.

Polyhalite application and the withdrawal of N and P input after anthesis showed an increase in weight percentage of arils and decreases in husk and seed weight (Table 2). The same treatment also non-significantly increased the average fruit roundness and sphericity, while significantly increasing shell thickness in the distal portion of the fruit (Table 3). Reductions of N applications during the fruit development stage is generally associated with higher yields, improved quality and good fruit shape (Datepumee *et al.*, 2019).

Characteristics of the arils (Total soluble solid, moisture content, pH, and titratable acidity)

TSS gives an estimate of sugar content which included other components such as organic acids, amino acids, or pectin (Martínez *et al.*, 2013). Sucrose was the predominant sugar in durian. Durian also contains glucose, fructose, and maltose (Aziz and Jalil, 2019). This study recorded that both control and polyhalite-treated

Table 3. Physical characteristics of the durian samples.

Sample	Roundness	Sphericity	Shell thickness	
			Distal	Middle
			------cm------	
Control	0.86 ± 0.26[a]	0.87 ± 0.29[a]	1.47 ± 0.07[a]	1.18 ± 0.13[a]
Polyhalite	0.86 ± 0.31[a]	0.88 ± 0.49[a]	1.63 ± 0.06[b*]	1.17 ± 0.10[a]

Values in the table represent the mean ± standard deviation of three biological replications. Means within each column with different letters are significantly different.
(*) denotes $p < 0.05$.

Table 4. Characteristics of the arils (Part 1).

Sample	TSS	Moisture content	pH	Titratable acidity
	°*Brix*	*%*		*%*
Control	29.0 ± 1.0^{a}	49.75 ± 0.69^{a}	6.15 ± 0.52^{a}	0.256 ± 0.13^{a}
Polyhalite	27.0 ± 1.7^{a}	48.43 ± 1.56^{a}	6.92 ± 0.15^{b}	0.256 ± 0.00^{a}

Values in the table represent the mean ± standard deviation of three biological replications. Means within each column with different letters are significantly ($p < 0.10$) different.

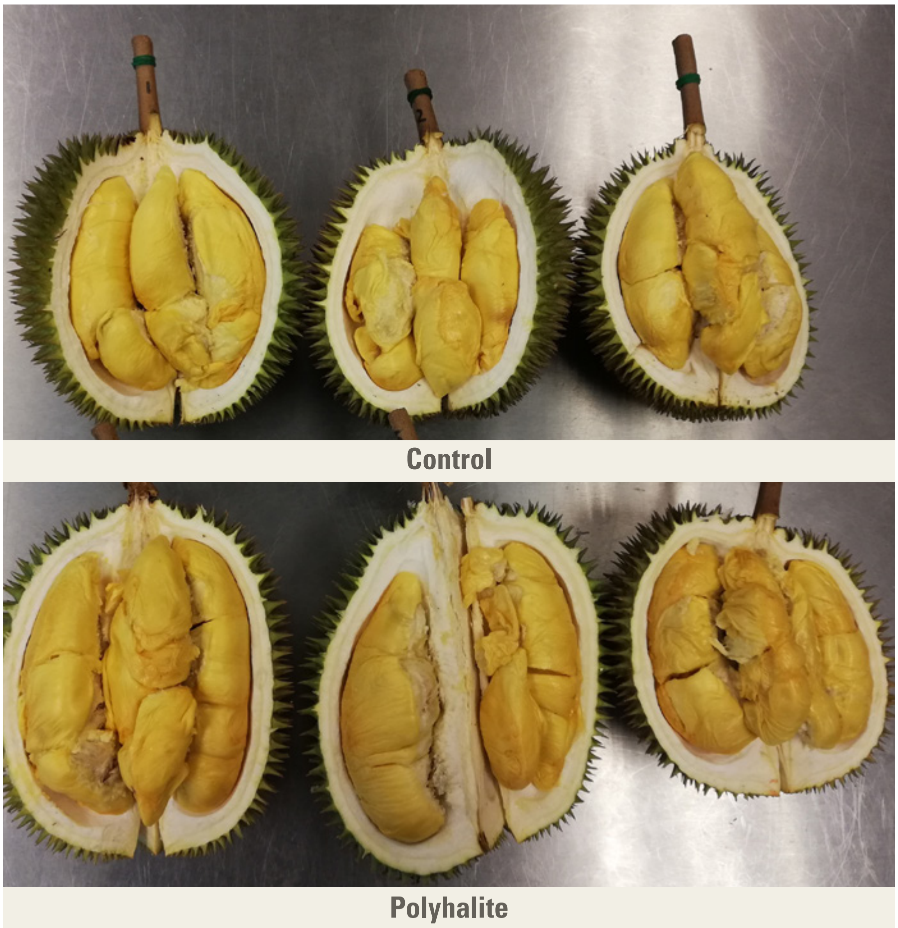


Photo 5. Arils from the durian fruit from the control plots (top) were yellower than those from fruit taken from the polyhalite treated plots. Photo by the authors.

(27.0-29.0 °Brix), with no significant ($p > 0.05$) difference among the samples (Table 4). The moisture content of both samples ranged from 48.43 to 49.75% and showed no significant difference. Moreover, the titratable acidity of both samples showed no significant differences (~0.256%). However, the durian pulp pH of the control and the polyhalite-treatment showed a significant difference at $p < 0.10$. This demonstrated that polyhalite-treated durian pulp has a higher pH, nearer to neutral and less acidic, compared to control durian pulp. The pH is commonly used to determine the quality and freshness of durian. Durian with a low pH can be categorized as acidic and might not be appropriate for consumption. However, durian with a high pH, or alkaline, might promote the growth of spoilage microorganisms (Tan *et al.*, 2018).

Characteristics of the arils (color and firmness)

Based on the results shown in Table 5, durian pulp, either control or polyhalite-treated, was lighter in color, indicated by a high L* value (79.05-80.52) and a low a* value (redness 11.42-12.49). There were no significant differences ($p > 0.05$) among the samples, either in the control or treated durian. However, the control has higher yellowness b* value (45.60) which is significantly different ($p < 0.10$) compared to the treated sample (42.91). Although the yellowness of the polyhalite-treated arils was a slightly lower intensity when measured by the colorimeter, the sensory evaluation panel determined the yellowness to be higher in the polyhalite-treated durian compared to the control (Table 7).

Table 5. Characteristics of the arils (Part 2).

Sample	Color			Firmness (N)
	L*	a*	b*	
Control	80.52 ± 1.72^{a}	11.42 ± 2.41^{a}	45.60 ± 0.67^{b}	0.088 ± 0.008^{a}
Polyhalite	79.05 ± 0.18^{a}	12.49 ± 0.69^{a}	42.91 ± 1.93^{a}	0.169 ± 0.041^{b*}

Color measurements expressed using CIE-Lab color space: L* (lightness intensity), a* (+ redness, – greenness), and b* (+ yellowness, – blueness). All values represent the mean ± standard deviation of three biological replications. Means within each column with different letters are significantly ($p < 0.10$) different. (*) denotes $p < 0.05$.

Table 6. Nutritional composition of the durian arils.

Sample	Protein	Fat content
	------------------------------%------------------------------	
Control	6.36 ± 1.31^a	7.68 ± 1.03^a
Polyhalite	7.52 ± 0.70^a	$10.64 \pm 0.53^{b*}$

Values in the table represent the mean ± standard deviation (n = 6). Means within each column with different letters are significantly ($p < 0.10$) different. (*) denotes $p < 0.05$.

The firmness test showed the polyhalite-treated durian arils were significantly firmer (p < 0.05) than the control durians. According to Szczesniak (2002), texture is a multifaceted sensory property consisting of a combination of multiple sensory characteristics and perceptions linked to mechanical properties (hardness, chewiness, crunchiness, etc.), geometric properties (shape, size, etc.), and product composition (fat and water contents).

Nutritional composition of the durian arils

Based on the result of this study (Table 6), polyhalite-treated durians were found to be significantly richer (p < 0.05) in fat content than the control (10.64% vs 7.68%). However, all durians contained a moderate amount of protein (6.36-7.52%) with no significant differences.

Sensory quality of the arils

The results of the hedonic scaling test for durian arils are listed in Table 7 and Table 8. Polyhalite application non-significantly increased the attractiveness (color) score, attractiveness (shape) score, aroma score, texture score, and reduced the watery pulp texture according to consumers. However, there were significant differences for flavor (p < 0.10) and sweetness (p < 0.10) between the control and polyhalite-treated durian pulps. Sweet and fruity aromas correlate strongly with most esters and an aldehyde compound respectively (Voon *et al.*, 2007). However, flavor compounds were not quantified in this study.

Most of the panelists commented that the polyhalite-treated durian pulps had a stronger onion-sulphur aroma and flavor compared to the control. There could be close correlations between the mean scores of liking for the flavor and aroma characteristics of the polyhalite-treated durians. The mean score of liking for texture of the polyhalite-treated durian pulps was higher compared to the control, which was correlated to the enhanced firmness exhibited by the treated durian pulps. However, there were no significant differences between these two samples for the texture attribute.

Conclusion

Polyhalite application at the rate of 5 kg tree^{-1} to the D101 cultivar on the durian farm in Tapah, Perak, could potentially increase weight percentage of arils and decreases in husk and seed weight. Furthermore, it showed better physicochemical and organoleptic properties of the durian arils in terms of color, flavor, sweetness, aroma and texture. Therefore, polyhalite has shown positive and promising results on the overall quality of durian and can be a possible alternative to conventional high potassium NPK 15-5-20-2 + 10S +TE applied after flowering and during fruit development.

Table 7. Sensory attribute mean scores of the arils (Part 1).

Sample	Sensory attributes		
	Attractiveness		Flavor
	Color	Shape	
Control	7.14 ± 1.07^a	6.86 ± 1.21^a	6.29 ± 1.98^a
Polyhalite	7.50 ± 1.07^a	7.00 ± 1.60^a	8.00 ± 0.76^b

Values in the table represent the mean ± standard deviation (n = 6). Means within each column with different letters are significantly ($p < 0.10$) different.

Table 8. Sensory attribute mean scores of the arils (Part 2).

Sample	Sensory attributes			
	Sweetness	Aroma	Watery pulp	Texture
Control	6.14 ± 1.77^a	7.00 ± 1.15^a	6.14 ± 1.77^a	6.14 ± 1.07^a
Polyhalite	7.38 ± 0.74^b	7.25 ± 1.16^a	6.38 ± 1.51^a	7.00 ± 1.31^a

Values in the table represent the mean ± standard deviation (n = 8). Means within each column with different letters are significantly ($p < 0.10$) different.

Acknowledgements

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Research Findings

Photo 1. Peanut (*Arachis hypogaea* L.) at 111 days after emergence. Photo by the authors.
Left to right: T4 NPK+525 kg ha^{-1} polyhalite; T2 NPK+225 kg ha^{-1} polyhalite; T5 NPK+375 kg ha^{-1} Sofipoly; and T1 Control NPK.

Effects of Combined Application of NPK Compound Fertilizer with Polyhalite Fertilizers on Peanut Yield, Nutrient Content and Partitioning in Henan Province, China

Li Xue[(1)], Jiao Nianyuan[(1)*], and Guohua Li[(2)]

Abstract

China is the world-leading peanut (*Arachis hypogaea* L.) producer accounting for 35.93% of overall world production (in 2019), followed by India (13.80%) and Nigeria (9.13%). Within China, Henan is the leading peanut producing province producing 5.767 million metric tons in 2019, followed by Shandong and Guangdong regions with 2.848 and 1.087 million metric tons, respectively. Peanut is therefore an economically important crops in this province. The common fertilizer application practice in Henan province is dominated by NPK, which has been contributing to yield increments. However, the continuous application of the same nutrients over many years has resulted in unbalanced nutrient supply, and stagnant yield. Peanut, being a legume, meets most of its nitrogen requirement through nitrogen fixation. While it only requires a small rate of nitrogen (N) as a starter, an adequate supply of phosphorus (P), potassium (K),

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calcium (Ca), and sulfur (S) are essential to obtain higher yields and quality. Polyhalite is a sedimentary marine evaporate which consists of a hydrated sulfate of K, Ca and Mg with the formula: $K_2Ca_2Mg(SO_4)_4 \cdot 2(H_2O)$. Polyhalite contains 48% S and is being used in China as a source of K, S and other nutrients. The objective of this study in Henan, China, was to evaluate the effects of different polyhalite application rates on yield and nutrient content of different peanut plant parts at different growth stages. Eight fertilization treatments were tested: current practice (NPK) as the control, and seven combinations of NPK and polyhalite fertilizers. Results indicated that application of polyhalite in addition to the current practice produced higher leaf, stem and nut yields, and relatively higher nutrient contents at different growth stages. Highest leaf dry weight was obtained at 67 days after emergence (DAE) while highest stem and nut dry weight was obtained at 111 DAE. Different plant parts responded differently to different treatment combinations. Total leaf dry weight was the highest in T2 (NPK + 225 kg ha^{-1} polyhalite) and lowest in T1 (control), the increase being 43%. Stem weight was the highest in T3 (NPK + 375 kg ha^{-1} polyhalite) and lowest in T5 (NPK + 375 kg ha^{-1} Sofipoly). T3 gave 37.8% more stem total dry weight yield over T5 and 20% more over the control (T1). Similarly, total nut yield was highest in T6 (90% NPK + 375 kg ha^{-1} polyhalite) and lowest in T7 (80% NPK + 375 kg ha^{-1} polyhalite). T6 yielded 28.9% more yield over T7 and 27% more yield over the control (T1). Application of NPK with 375 kg ha^{-1} polyhalite gave higher stem dry weight while application of 70% NPK with 375 kg ha^{-1} polyhalite gave the lowest dry matter yield indicating that optimum application of NPK is required to benefit from nutrients from polyhalite application. However, further multi-location and multi-year experiments are required to make optimum rate recommendations. Economic analysis of the fertilizer combinations is also required.

Keywords: Peanut; Fertilizer; Polyhalite; Growth stage; Plant parts.

Introduction

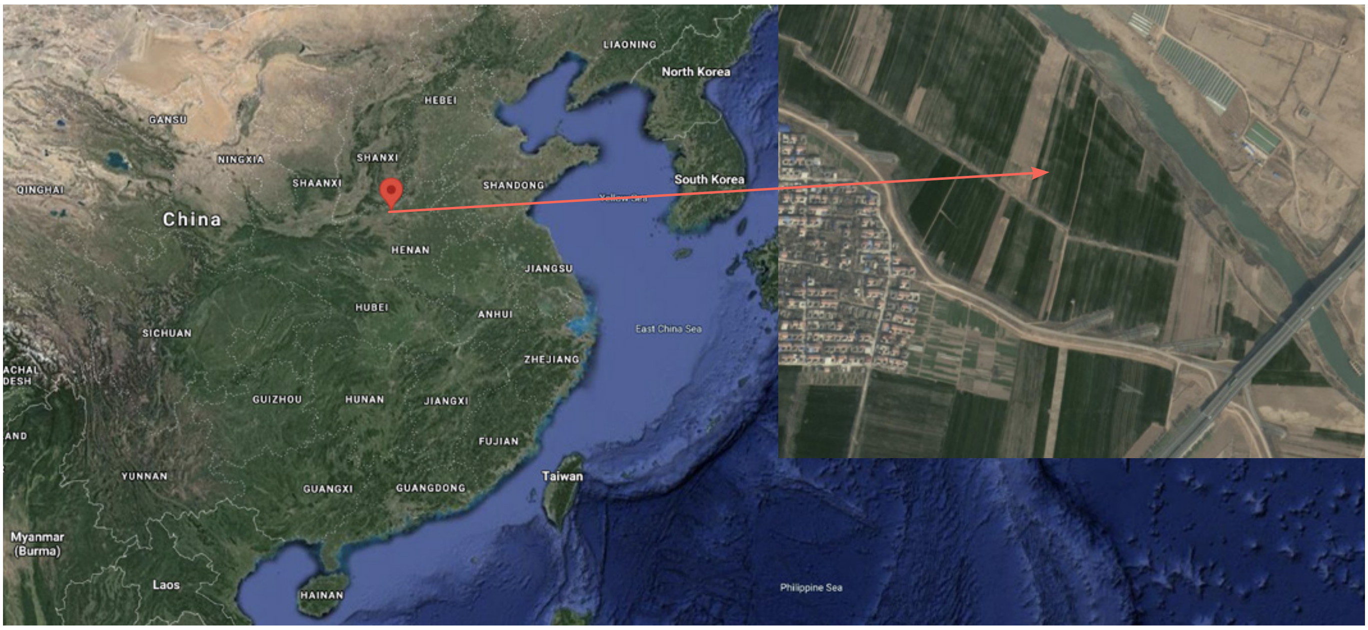
Peanuts (*Arachis hypogaea*), also referred to as groundnuts, are an annual herbaceous legume with an indeterminate growth habit. As these alternate names imply, this unique plant produces its fruit (peanut) below ground. Peanut is an economically important oilseed, feed, and food crop and widely cultivated in tropical and subtropical regions of the world. Although a legume; it is generally included amongst the oilseeds due to its high oil content. Peanuts are rich in protein, oil, and fibers (Suchoszek-Lukaniuk *et al.*, 2011). For human consumption, the crop is cultivated primarily as whole seeds or as a processed product. Peanuts are key oilseed and food-legume crops for both humans and livestock in tropical and subtropical regions, and globally they are the fourth largest source of edible oil (Mondal *et al.*, 2020). China leads in the production of peanuts, 35.93% of world production, followed by India (13.80%) and Nigeria (9.13%) in 2019 (FAOSTAT, 2019). According to Statista report, Henan is the leading producer of peanut in China with production of 5.767 million metric tons in 2019 (Statista.com, 2020) followed by Shandong and Guangdong regions.

Balanced fertilization is one of the most critical groundnut production management strategies to improve crop yield and quality. Assessing pod yield and plant nutrient demand can provide theoretical guidance for fertilization management of high-yielding peanut. Being a legume, peanut gets most of its N from nitrogen-fixing bacteria (*Bradyrhizobium*) colonizing the plant's roots, however, peanut does require a small rate of N as a starter fertilizer. Adequate rates of P, K and S application are essential to obtain considerable yields and quality. Sulfur is now recognized as the fourth major plant nutrient after N, P and K, and an integral part of balanced fertilization and nutrition for oilseed crops including groundnut. Calcium is another critical nutrient in groundnut production (Baughman and Dotray, 2015). Various research results indicated that peanut responds to P (Dzomeku *et al.*, 2019), K (Pradyut *et al.*, 2006; Reddy *et al.*, 2011; Sharma *et al.*, 2011; Lobo *et al.*, 2012), Ca (Xiao-long *et al.*, 2018), S (Ariraman and Kalaichelvi, 2020) and B (Singh *et al.*, 2009) especially when these nutrients are deficient in the soil where peanut is grown and where there is sufficient supply of other nutrients.

Polyhalite is a sedimentary marine evaporate fertilizer that supplies multiple essential primary, secondary and micronutrients. Mined in the UK by ICL Fertilizers, and marketed under the trademark Polysulphate®, polyhalite consists of a hydrated sulfate of K, Ca and Mg with the formula: $K_2Ca_2Mg(SO_4)_4 \cdot 2(H_2O)$, which contains 48% S. Sofipoly on the other hand is a granulated fertilizer produced from polyhalite and SOP (sulphate of potash) and consists of 30% K_2O, 15.7% S, 5.8% CaO, 10.2% MgO and 0.3% B. Both fertilizers have attracted strong interest in China as they can provide the nutrients needed to help farmers increase yields and become more productive.

Currently, the practice of blanket fertilization in peanut production is widespread, especially in rural areas of China. This continuous and higher dose use of nitrogen and phosphate fertilizers, and lower use of other essential nutrients like potassium would result in unbalanced nutrient input and low fertilizer efficiency (Swarup, 1998; Mahajan and Gupta, 2009). In peanut, N, P and K compound fertilizers have been widely used in production and have greatly boosted peanut yield in the past. However, recently the yield of peanuts has not increased much, even with an increased use of N, P and K compound fertilizers indicating that other essential nutrients are becoming limiting. Use of fertilizers containing Ca, Mg and S is rare in the study area.

Previous studies have shown that NPK combined with calcium and magnesium sulfate fertilizers significantly increased the yield of rape (Tian *et al.*, 2019), rice (Zhao *et al.*, 2014), pakchoi, tea, and watermelon (Lin *et al.*, 2005). In Jinzhou, Fujian and other places, experiments applying calcium, magnesium and sulfur containing fertilizers to peanut have shown that peanut yield has increased significantly (Huang *et al.*, 2014). However, there is limited information on the effect of NPK combined with Ca, Mg and S nutrients on yield, nutrient content and partitioning of peanut in Henan province of China. The objective of this experiment is therefore to



Map 1. Location of the experiment site in Henan, China. Source: Google Earth.

study the effects of combined application of conventional NPK fertilizer with polyhalite and Sofipoly fertilizers on peanut yield, nutrient content and partitioning, and quality in Henan province of China.

Materials and methods

The field experiment was conducted at the experimental farm of Henan University of Science and Technology (33°35'-35°05'N, 111°8'-112°59'E), Henan, China in 2019. Combinations of conventional NPK and polyhalite fertilizer treatments, and conventional NPK fertilizer as the control treatment, were tested. Details of the treatment combinations used in the experiment are presented in Table 1.

The test site is in a temperate zone, with a semi-humid and semi-arid continental monsoon climate. The site has a mean annual temperature between 12.1-14.6°C, mean annual rainfall of 600 mm, annual average evaporation 2,113.7 mm, and annual average radiation 491.5 kJ cm^{-2}. The annual sunshine hours are 2,300-2,600 hours, and the frost-free period is 215-219 days. Monthly mean temperature and precipitation from 2010 to 2020 are displayed in Table 2. The soil of the test site is characterized as yellow fluvo-aquic, the main soil type in the North China Plain which produces almost 60-80% of China's wheat and 35-40% of China's maize every year (Kong *et al.*, 2014). Preplant soil samples were collected at 0-20 cm depth to determine selected physicochemical properties. The soil samples were air dried, ground to pass 2 mm, and analyzed for soil alkaline N using alkaline diffusion method (Mulvaney and Khan, 2001), available P using $NaHCO_3$ method (Olsen *et al.*, 1954), available (exchangeable) Ca, Mg and Fe using EDTA extraction-ICP method (Barrows and Simpson, 1962), available S using calcium chloride solution extraction-ICP method (Houba *et al.*, 2000) and available potassium using 1N ammonium acetate extraction-ICP method (Johnson and Goulding, 1990; Normandin *et al.*, 1998). The physicochemical properties of the experiment soil are displayed in Table 3.

Table 1. Treatment descriptions on combined application of polyhalite and NPK on peanut experiment in Henan China.

Treatments		Fertilizer			Nutrients						
Code	Description	NPK	Polyhalite	Sofipoly	N	P_2O_5	K_2O	S	Ca	Mg	B
		----------	----------	----------	----------	----------	*kg ha^{-1}*	----------	----------	----------	----------
T1	Control (NPK)	600	0	0	108	108	108	0	0	0	0
T2	NPK + 225 kg ha^{-1} polyhalite	600	225	0	108	108	140	43	8	27	0
T3	NPK + 375 kg ha^{-1} polyhalite	600	375	0	108	108	161	72	14	46	0
T4	NPK + 525 kg ha^{-1} polyhalite	600	525	0	108	108	182	101	19	64	0
T5	NPK + 375 kg ha^{-1} Sofipoly	480	0	375	86	86	199	59	23	15	1.2
T6	90% NPK + 375 kg ha^{-1} polyhalite	540	375	0	97	97	150	72	14	46	0
T7	80% NPK + 375 kg ha^{-1} polyhalite	480	375	0	86	86	139	72	14	46	0
T8	70% NPK + 375 kg ha^{-1} polyhalite	420	375	0	76	76	129	72	14	46	0

Table 2. Monthly mean temperature and precipitation from 2010 to 2020.

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Precipitation (mm)	10.7	13.5	17.3	47.1	54.0	71.6	108.3	99.9	101.9	49.1	33.0	4.5
Temperature (°C)	0.8	3.6	10.4	16.1	21.7	25.8	27.1	25.7	21.2	15.6	9.0	3.0

Table 3. Physicochemical properties of the experiment soil in Henan, China.

Soil property	Value	Rating
Sand (%)	12.5	Loam texture
Silt (%)	64.2	Loam texture
Clay (%)	23.3	Loam texture
pH	7.56	Alkaline
Bulk density (g cm^{-3})	1.31	Low (Hunt and Gilkes, 1992)
Alkali hydrolyzable nitrogen (mg kg^{-1})	33.86	Low
Available phosphorus (mg kg^{-1})	18.46	Low (Marx *et al.*, 1999)
Available iron (mg kg^{-1})	5.98	Low
Organic matter (g kg^{-1})	10.72	Very high: https://njaes.rutgers.edu/soil-testing-lab/organic-matter-levels.php

Peanut variety Huayu 16 was used as the test material for the experiment. The experiment plot size was 3.5 × 5 m. Seeds were planted at a row spacing of 35 cm with 20 cm between planting holes and two seeds were planted in each hole. Ridge planting was adopted with bottom and top ridge width of 70 cm and 45 cm, respectively. The experiment had 8 treatments arranged in a randomized complete block design with three replications. Fertilizers for each treatment were broadcast applied before ploughing. The peanut planting and harvesting dates were 16 June 2019 and 22 October 2019, respectively.

Plant samples were collected at four different growth stages (32, 50, 67 and 111 DAE) for leaves and stems, and at 67 and 111 DAE for nuts, to determine plant fresh weight, dry weight and concentration of N, P, K, Ca, Mg and S following standard procedures for each. Four randomly selected plants from two holes were sampled from each plot at each stage. The concentration of phosphorus, potassium, calcium, magnesium, and sulfur in the plants were determined by inductively coupled plasma (ICP) after digestion in a mixture of concentrated HNO_3 and H_2O_2 in a microwave oven. Nitrogen was determined by Kjeldahl after digestion in a mixture of concentrated H_2SO_4 and H_2O_2.

The effects of different combinations of the applied NPK and polyhalite fertilizers on the biomass accumulation and partitioning were statistically analyzed using ANOVA.

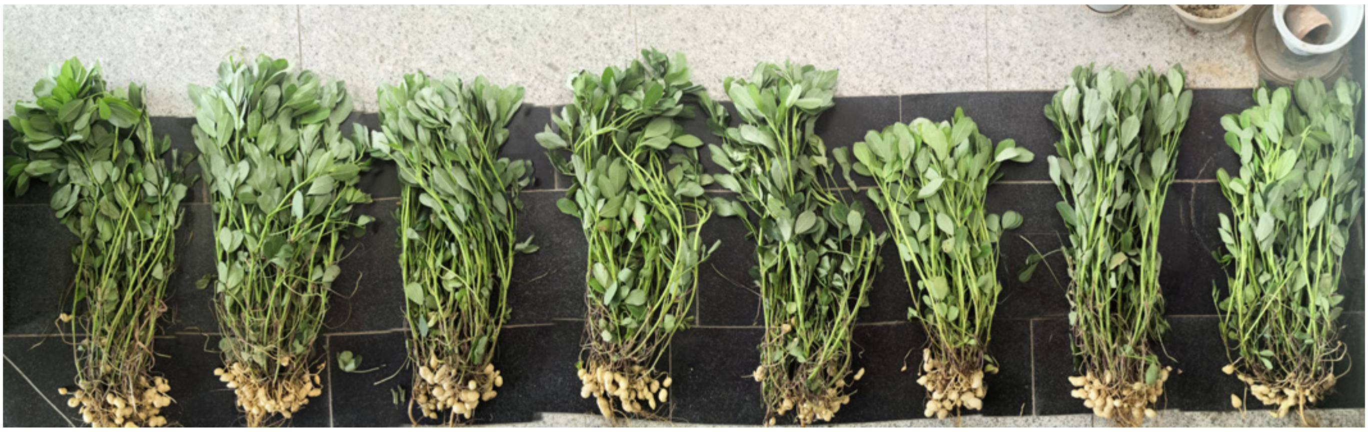


Photo 2. Peanut (*Arachis hypogaea* L.) samples taken at 67 days after emergence. Left to right: Treatment T3, T6, T7, T8, T4, T2, T5, and T1 (Control). See Table 1 for details. Photo by the authors.

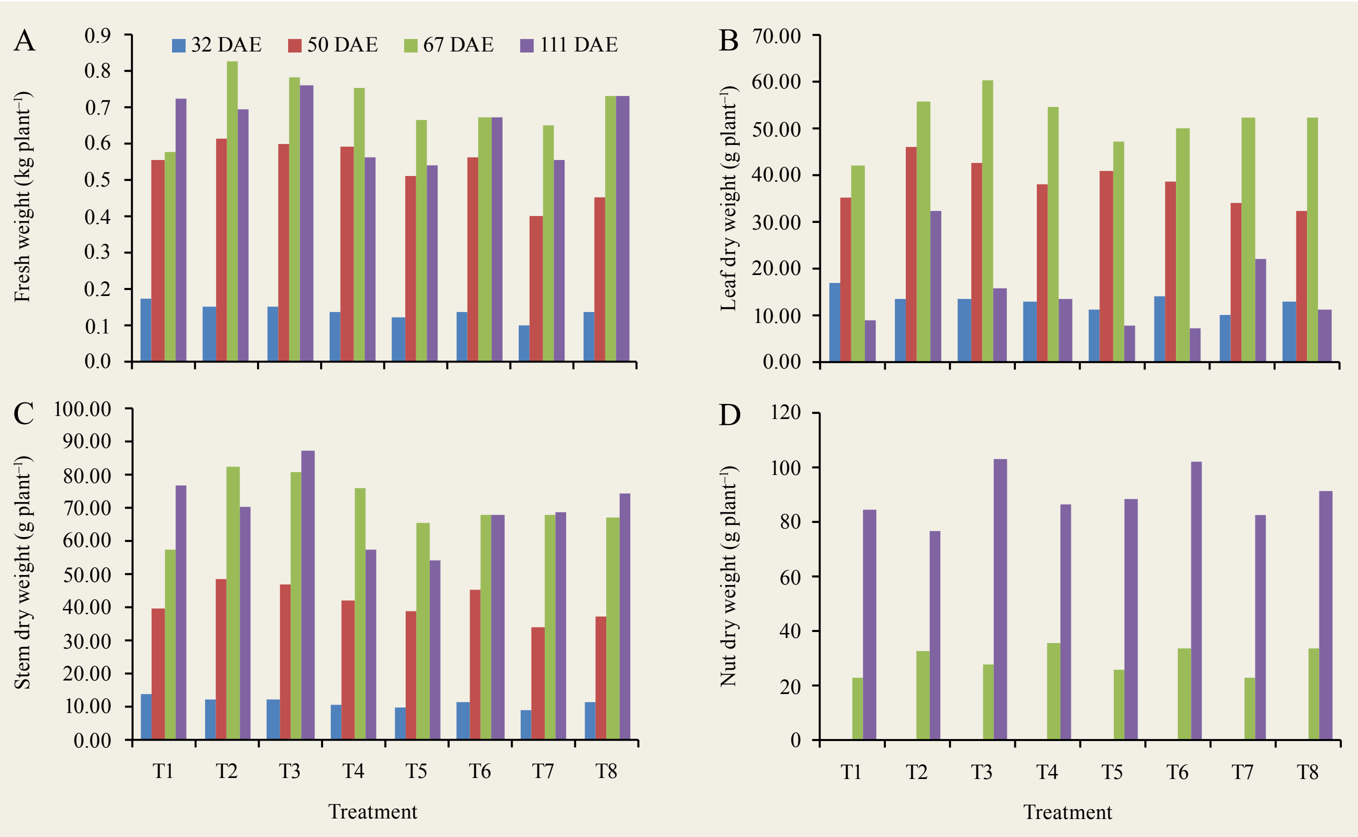


Fig. 1. Effects of fertilizer treatments on total fresh weight (A), leaf dry weight (B), stem dry weight (C) and nut dry weight (D) at four growth stages (32, 50, 67 and 111 DAE) of peanut in Henan, China in 2019. Refer to Table 1 for detailed description of the fertilizer treatments.

Results

The experiment soil was loamy in texture and alkaline in reaction with very high organic matter content, low available P and low alkali hydrolyzable nitrogen. The bulk density was low, indicating that it is not compacted and is suitable for plant growth (Table 3).

Combined application of NPK fertilizer with polyhalite affected the fresh and dry weight of peanut plant parts at different growth stages. The fresh weight of peanut showed an increasing trend up to 67 DAE and decreased afterwards in most of the treatments except the control where the fresh weight increased with increasing age (111 DAE). Treatment T2 gave the highest fresh weight at all stages of growth compared to other treatments, followed by T3, while the lowest was T7 (Fig. 1A). Peanuts' fresh biomass

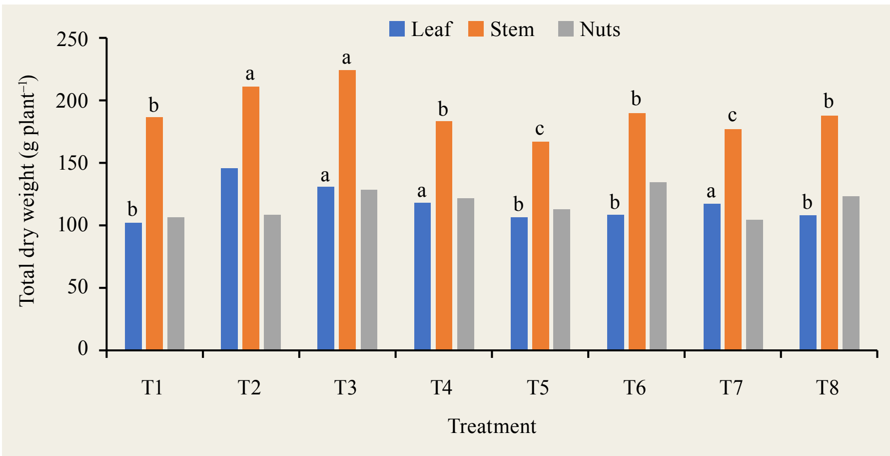


Fig. 2. Effects of combined application of NPK with polyhalite on total leaf dry weight, total stem dry weight and total nut dry weight summed from four peanut growth stages (32, 50, 67 and 111 DAE) in Henan, China in 2019. Refer to Table 1 for detailed description of the fertilizer treatments.

yield ranged from 0.54 to 0.76 kg plant^{-1} at 111 DAE. The highest yield was obtained from T3 and the lowest from T5. Combined application of NPK with polyhalite gave the highest yield, followed by NPK only. The effect of polyhalite reduced as the amount of NPK decreased.

Table 4. ANOVA table showing the effect of treatments on various yield and nutrient contents of nuts.

Treatments	Total dry weight			Nutrient contents in nuts at 111 DAE					
	Leaf	Stem	Nut	N	P	K	Ca	Mg	S
	---g $plant^{-1}$---			---g kg^{-1}---					
T1	103.00b	188.67bc	107.33	41.17bc	11.97b	5.50ab	1.00ab	1.70ab	1.40b
T2	147.00a	213.33ab	109.33	44.10a	11.20b	4.93b	0.93b	1.60b	1.27b
T3	132.00ab	226.33a	130.33	36.27de	12.23ab	5.67ab	1.10ab	1.90ab	1.40b
T4	119.00ab	185.33bc	122.67	36.23de	11.83b	5.20ab	1.03ab	1.73ab	1.33b
T5	107.33b	168.67c	114.00	42.13ab	16.47a	7.17a	1.10ab	2.33a	2.03a
T6	109.67b	192.00bc	136.00	33.27f	14.23ab	6.63ab	1.17a	2.10ab	1.77ab
T7	119.00ab	178.67c	105.33	33.87ef	13.37ab	6.27ab	1.10ab	2.03ab	1.60ab
T8	109.00b	189.33bc	124.33	38.43cd	11.73b	5.73ab	0.97b	1.80ab	1.43ab
Significance level	**	***	ns	***	ns	ns	ns	ns	ns
LSD	29.27	31.04	56.52	2.78	4.43	2.00	0.18	0.65	0.61
CV	8.76	5.69	16.85	4.17	19.87	19.66	9.72	19.69	22.97

Significance level: *** 0.001 and ** 0.01. ns = non-significant. Values with the same letter within each column are not significantly different from each other.

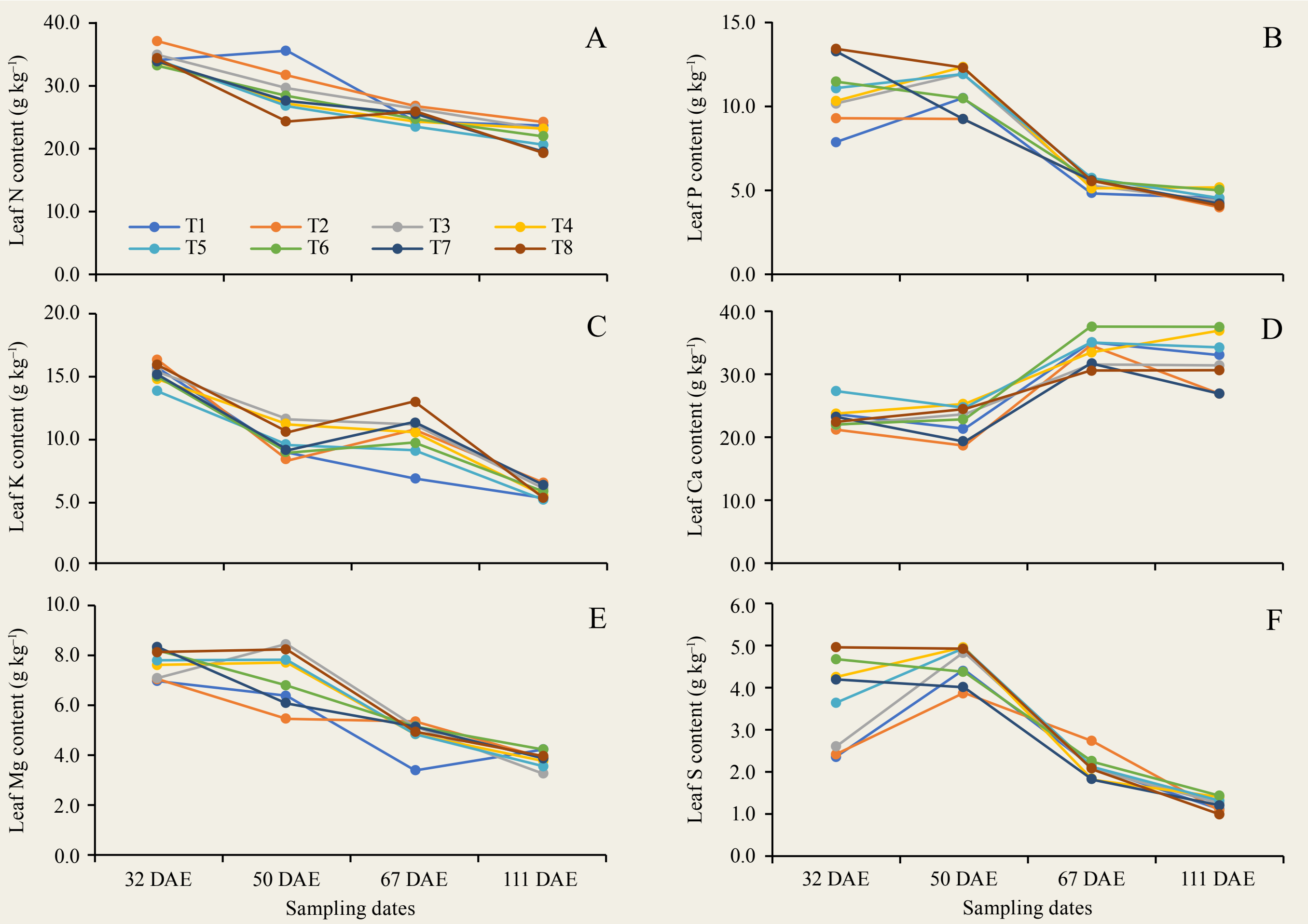


Fig. 3. Effects of NPK and polyhalite fertilizer combinations on N, P, K, Ca, Mg, and S concentrations in leaves at four growth stages in Henan, China.

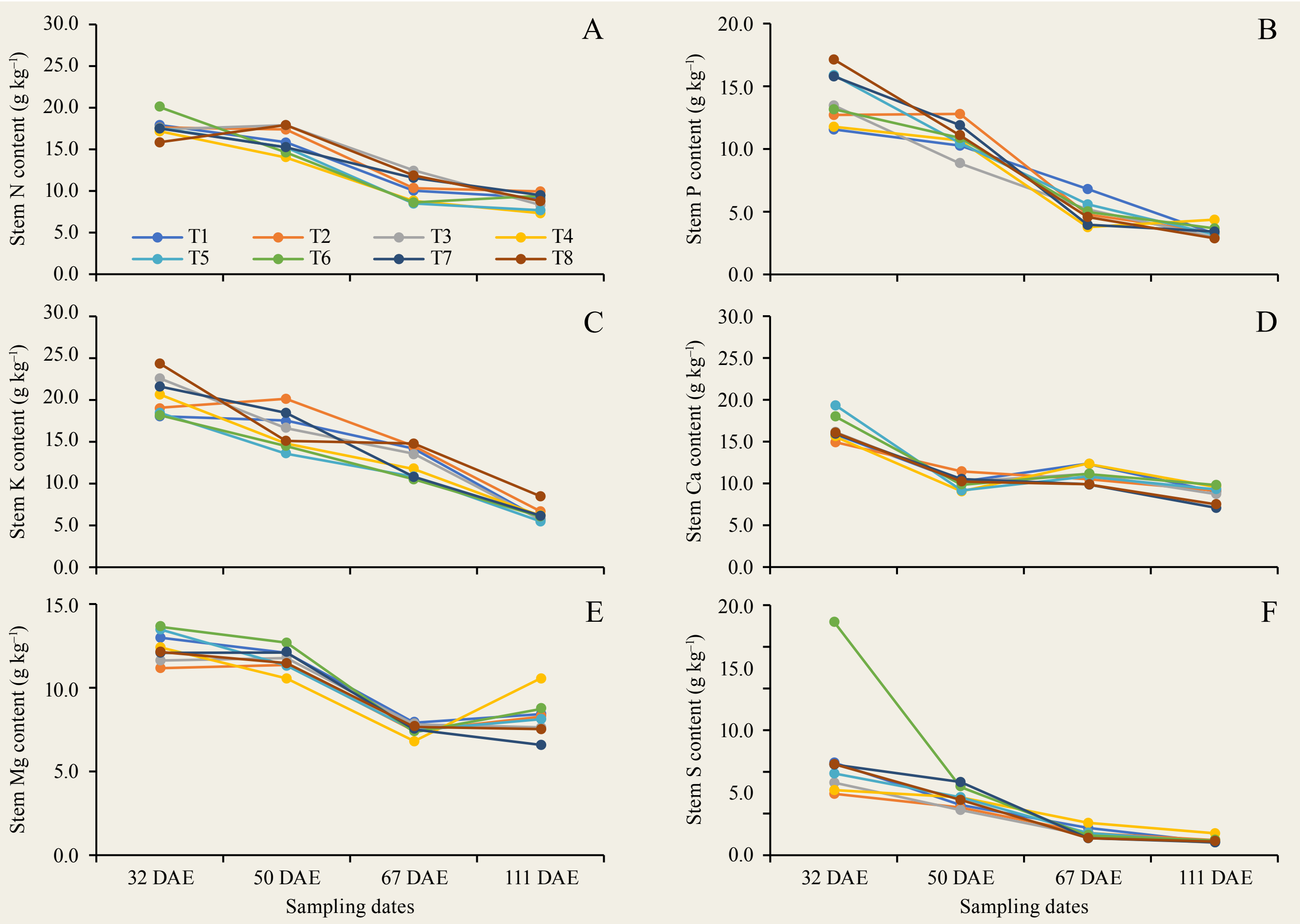


Fig. 4. Effects of NPK and polyhalite fertilizer combinations on N, P, K, Ca, Mg, and S concentrations in stems at four growth stages in Henan, China.

Similarly, leaf dry weight showed an increasing trend until 67 DAE and decreased at later stages in all treatments. On the contrary, stem dry weight and nut dry weight increased as the plant gets to maturity (111 DAE). The highest stem and nut dry weight were obtained from T2, and the lowest was from T7 (Fig. 1B, 1C, 1D). Highest leaf dry weight was obtained at 67 DAE from T2 and the lowest from the control at the same stage. Highest stem dry weight was obtained at 111 DAE in most treatments, except that of T2, T4 and T5 treatments where higher stem dry weight was obtained at 67 DAE. T3 gave the highest stem dry weight followed by the control at 111 DAE. Lowest stem dry weight was obtained from T5 followed by T7 where the lowest amount of NPK (70%) was applied with the same amount of polyhalite, indicating that optimum application of NPK is required to benefit from the additional nutrients supplied by polyhalite.

The effect of combined application of NPK with polyhalite fertilizers on total dry weight yields of leaf, stem, and nut collected at four different growth stages is presented in Fig. 2. Total leaf dry weight was the highest in T2 and lowest in T1, the increase being 43%. Stem weight was the highest in T3 and lowest in T5. T3 gave 37.8% more stem total dry weight yield over T5 and 20% more over the control (T1). Similarly total nut yield was highest in T6 and lowest in T7. T6 produced 28.9% more yield over T7 and 27% more yield over the control (T1).

Combined application of NPK with polyhalite also affected the concentration of plant nutrients in peanut plant parts at different growth stages. Accordingly, leaf concentrations of N, P, K, Mg and S decreased while leaf Ca increased with plant age. Stem N, P, K, Ca, Mg and S showed a decreasing trend with plant age. Nut N, P and S contents increased while K, Ca, Mg contents decreased with plant age (Fig. 3, 4, 5).

Leaf P content was highest at 50 DAE and decreased afterwards. The trend was similar for most treatments except T3 and T4 treatments where higher P was obtained from 32 DAE. Leaf K content was highest in early stage (32 DAE) followed by 67 DAE. The highest leaf K was obtained from T4 and the lowest from T1 (control), and

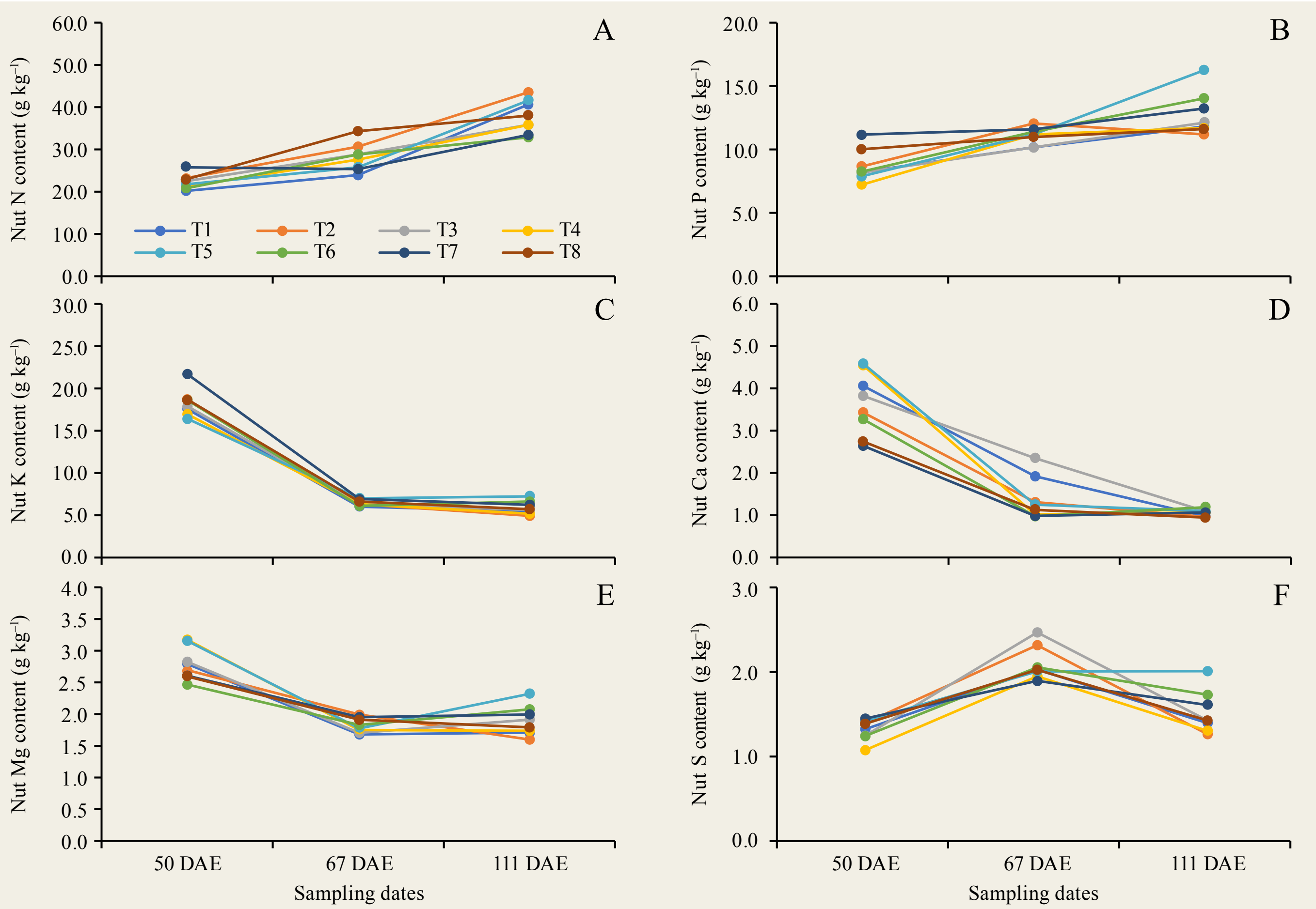


Fig. 5. Effects of NPK and polyhalite fertilizer combinations on N, P, K, Ca, Mg, and S concentrations in nuts at three growth stages in Henan, China.

there was significant difference between the two treatments. Leaf S content was highest at 50 DAE and decreased afterwards. The trend was similar for all treatments and there was no significant difference among treatments on leaf S content.

Nut N and P concentration showed an increasing trend with plant age; the highest N and P concentrations were at 111 DAE. Nut K, Ca and Mg content showed a general decrease with plant age. The nut S content was highest at 67 DAE followed by 111 DAE (Fig. 5). Nutrient contents of nuts do not vary greatly among treatments at 111 DAE, with the exception of N where a significant difference among treatments was observed (Table 4). All treatments resulted in a similar trend in nutrient concentrations in nuts, with no significant difference in nut nutrient content among treatments at all stages of growth.

Discussion

Appropriate crop nutrition management through balanced fertilization is crucial for sustainably achieving higher yield and quality of produce. Like other crops, peanut also requires a sufficient supply of essential nutrients other than N and P. In this experiment, application of polyhalite fertilizers in addition to the conventional NPK practice resulted in better yield and nutrient content in different parts of the peanut crop, and at different growth stages. This could be due to the effect of additional nutrients such as S, or Ca, and their interaction with other nutrients.

In line with this, previous studies indicated that exogenous calcium application had significant positive effects on absorption and accumulation of nitrogen, phosphorous, calcium and magnesium in different organs of peanut under salt stress (Xiao-long *et al.*, 2018; Yadav *et al.*, 2015). In their 2-year study, Abdel-Motagally *et al.* (2016) showed that sulfur application had a significant influence on yield and quality parameters in both seasons. Similarly, Patel and Zinzala (2018) have also reported that application of S and B improved yield and nutrient contents of peanut. Kabir *et al.* (2013) also reported that P, Ca and B application significantly increased plant height, number of branches plant^{-1}, and total dry weight of peanut.

In summary, basic NPK containing fertilizers are commonly used in China, however the result from this experiment is an indication that application of additional nutrients is required to improve crop performance. Besides yield and quality of peanut, understanding the effect of these fertilizers on soil properties after harvest and their role in nodulation needs further investigation. Dry matter yield and nutrient concentrations in different plant parts were affected differently. Application of NPK with 375 kg ha^{-1} polyhalite gave higher stem dry weight, which could be due to the addition of 72 kg ha^{-1} S and 43 kg ha^{-1} of K. On the other hand, application of 70% NPK with 375 kg ha^{-1} polyhalite gave the lowest dry matter yield indicating that optimum application of NPK is required to benefit from the applied nutrients from polyhalite. Potash and S responses will be visible when there are sufficient amounts of N and P, which are the most limiting elements. The results indicated that application of K and S contributed to improvements in yield and nutrient content. But adding higher contents of these two nutrients (beyond 161 kg ha^{-1} K_2O and 72 kg ha^{-1} S) do not continue improving yield and nutrient content in peanut. It is therefore recommended that determining the optimum rates of K and S under balanced application of other nutrients is required. Further multi-location and multi-year experiments are required to make optimum rate recommendations for S and K. Economic analysis of the fertilizer combinations is also required.

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The paper "Effects of Combined Application of NPK Compound Fertilizer with Polyhalite Fertilizers on Peanut Yield, Nutrient Content and Partitioning in Henan Province, China" also appears on the IPI website.

The IPI welcomes new Director

After 17 years, Hillel Magen has retired as Director of the International Potash Institute (IPI) and an international welcome is being given to the new Director, Shay Mey-Tal.

"It is an honor for me to take on the role of IPI Director" explained Shay Mey-Tal. "You only have to look at IPI's global achievements since 1952 to understand the responsibility and great potential of this role."

Handing on the privilege of leading IPI

Hillel Magen was one of the first to join in the congratulations. "I am happy that Shay Mey-Tal takes the helm. Shay's proven abilities in ag-tech, plant nutrition and irrigation are a perfect match for the IPI. Besides continuing with solid soil and plant science agronomy, it is high time now to bring in innovation and new digital tools to serve farmers and improve sustainable agricultural production. I am sure Shay will lead the institute to successes and ambitious collaborations with the many researchers and institutions we work with."

Before his appointment to IPI, Shay Mey-Tal had more than twenty years of agronomy experience working first as a seed breeding farm manager, five years work with ICL Speciality Fertilizers, then ten years as owner and CEO of an Israeli specialist agronomy company followed by almost five years as chief agronomist for an irrigation company before joining ICL as VP Agronomy early in 2021.

Forging a future with ag-tech and on-the-ground best practice

Looking ahead to the potential of IPI to continue to contribute to global agriculture, Shay Mey-Tal is optimistic. "We'll need to find ways to produce much more food, while taking into account environmental

Shay Mey-Tal, the new Director of the International Potash Institute (IPI).

effects. This is a huge challenge for all who are involved in agriculture and our organization, of course, will play its part. Previously, I have worked in agronomy at the field level and in Ag-tech entrepreneurship. I'll use this experience to steer our organization to develop technology-based solutions and relevant fertilizing methods for the farmer's level globally."

Hillel Magen believes Shay's proven abilities in ag-tech, plant nutrition and irrigation are a perfect match for the IPI.

Valuing IPI's strong foundations

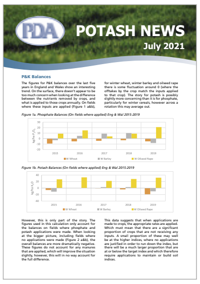
Facilitating positive change on a global scale requires strong partnerships and positive collaboration. Just before he handed over to the new Director, Hillel Magen wanted to shine a light on what he sees as one of the IPI's greatest strengths. "On this occasion, I wish to thank all our partners around the world: without the fertile cooperation we always shared, it would have been impossible to conduct research and disseminate the results that farmers so appreciate. It was so rewarding to work with you all. Good luck to you, Shay: IPI has a young spirit, even though it will be celebrating reaching the age of 70 next year!"

In response, the new IPI Director Shay Mey-Tal wanted to express his own thanks. "I want to thank the board members of IPI who nominated me, and especially Hillel Magen, the previous IPI director who held the wheel and navigated IPI so wisely since 2004." He concluded with a rallying call to all current and future collaborators. "I encourage you all to join us on this next part of our great journey and to be involved in the IPI's activities. I think we are living in an exciting time for agriculture."

Publications

Publications by the PDA

The Situation Regarding P&K Balances
POTASH News, June 2021



When looking at P&K balances in detail over the last five years, including fields where no applications were made, the overall balances are dramatically negative. Maintaining soils at the target index is the safest way to ensure these crops are able to access the required quantities at the appropriate times to optimize growth, yield and therefore financial returns. Read more on the PDA website.

Maize Nutrition
PDA Blog, April 2021

To produce a good crop, maize plants need to grow very rapidly once they have germinated. To achieve this, a good soil structure, adequate soil moisture and warm soil temperatures (8-12°C) are essential. Maize can easily produce 50 t ha^{-1} in a period of four months and therefore has a large demand for nutrients. Any shortage will restrict early growth and final yield. Read more on the PDA website.

Sugar Beet Nutrition
PDA Blog, April 2021

Sugar beet has a large requirement for potassium, with the majority taken up during the early months of growth. For maximum sugar yield it is essential to optimise the interception of sunlight to provide the energy to convert carbon dioxide to sugars. This requires a rapidly expanding leaf canopy. Nitrogen drives the rapid production and expansion of cells whilst potassium is required to obtain water and maintain their turgor, and to transfer sugars produced in the leaves to the storage root. 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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Reliance on Biological Nitrogen Fixation Depletes Soil Phosphorus and Potassium Reserves

Reimer, M., T.E. Hartmann, M. Oelofse, J. Magid, E.K. Bünemann, and Kurt 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 nutri-ent 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 ad-vised 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.

Potassium Deficiency Significantly Affected Plant Growth and Development as Well as microRNA-Mediated Mechanism in Wheat (*Triticum aestivum* L.)

Thornburg T.E., J. Liu, Q. Li, H. Xue, G. Wang, L. Li, J.E. Fontana, K.E. Davis, W. Liu, B. Zhang, Z. Zhang, M. Liu and X. Pan. 2020. Front. Plant Sci. 11:1219. DOI: 10.3389/fpls.2020.01219.

Abstract: It is well studied that potassium (K^+) deficiency induced aberrant growth and development of plant and altered the expression of protein-coding genes. However, there are not too many systematic investigations on root development affected by K^+ deficiency,

and there is no report on miRNA expression during K^+ deficiency in wheat. In this study, we found that K^+ deficiency significantly affected wheat seedling growth and development, evidenced by reduced plant biomass and small plant size. In wheat cultivar AK-58, up-ground shoots were more sensitive to K^+ deficiency than roots. K^+ deficiency did not significantly affect root vitality but affected root development, including root branching, root area, and root size. K^+ deficiency delayed seminal root emergence but enhanced seminal root elongation, total root length, and correspondingly total root surface area. K^+ deficiency also affected root and leaf respiration at the early exposure stage, but these effects were not observed at the later stage. One potential mechanism causing K^+ deficiency impacts is microRNAs (miRNAs), one important class of small regulatory RNAs. K^+ deficiency induced the aberrant expression of miRNAs and their targets, which further affected plant growth, development, and response to abiotic stresses, including K^+ deficiency. Thereby, this positive root adaption to K^+ deficiency is likely associated with the miRNA-involved regulation of root development.

Effect of the Application Date of Fertilizer Containing Silicon and Potassium on the Yield and Technological Quality of Sugar Beet Roots

Artyszak, A., D. Gozdowski, and A. Siuda. 2021. Plants 10(2):370. DOI: 10.3390/plants10020370.

Abstract: Water shortage and drought are a growing problem in Europe. Therefore, effective methods for limiting its effects are necessary. At the same time, the “field to fork” strategy adopted by the European Commission aims to achieve a significant reduction in the use of plant protection products and fertilizers in the European Union. In an experiment conducted in 2018-2020, the effect of the method of foliar fertilization containing silicon and potassium on the yield and technological quality of sugar beet roots was assessed. The fertilizer was used in seven combinations, differing in the number and time of application. The best results were obtained by treating plants during drought stress. The better soil moisture for the plants, the smaller the pure sugar yield increase was observed. It is difficult to clearly state which combination of silicon and potassium foliar application is optimal, as their effects do not differ greatly.

Ammonium Nutrition Modulates K^+ and N Uptake, Transport and Accumulation during Salt Stress Acclimation of Sorghum Plants

Coelho, D.G., R. de Souza Miranda, S. de Oliveira Paula-Marinho, H.H. de Carvalho, J.T. Prisco, and E. Gomes-Filho. 2020. Archives of Agronomy and Soil Science 66(14):1991-2004. DOI: 10.1080/03650340.2019.1704736.

Abstract: NH_4^+ nutrition has emerged as an effective approach to generate salt tolerance in sorghum plants. Our hypothesis was that salt-tolerance mechanisms in NH_4^+-grown sorghum are related to rapid absorption and assimilation of NH_4^+ as well as favorable K^+ uptake. Sorghum plants were grown in nutrient solutions containing NO_3^- or NH_4^+ and subjected to NaCl at 75 mM. Under control conditions, K^+ uptake was more pronounced in NO_3^- than that of NH_4^+-fed plants. Under salinity, NH_4^+-grown plants showed lower Na^+ and higher K^+ contents than NO_3^--grown plants at 1 and 10 days after salt exposure, and thereby increased K^+/Na^+ ratio. The data indicate that NH_4^+ does not increase K^+ uptake under salt stress conditions, but decrease the K^+ efflux and maintain an elevated K^+/Na^+ ratio in tissues. In parallel, sorghum plants displayed elevated NH_4^+ uptake, evidenced by higher V_{max} for NH_4^+, assimilating a higher amount of NH_4^+ into amino acids in roots; whereas NO_3^--fed plants accumulated NH_4^+ in the shoot. In conclusion, NH_4^+-fed salt-stressed sorghum plants maintain favorable K^+/Na^+ homeostasis due to greater retention of K^+ in tissues together with restricting control of Na^+ accumulation and transport. *S. bicolor* face to NH_4^+ toxicity by activating mechanisms for rapid inorganic N-assimilation.

K Fertilizers Reduce the Accumulation of Cd in *Panax notoginseng* (Burk.) F.H. by Improving the Quality of the Microbial Community

Shi, Y., L. Qiu, L. Guo, J. Man, B. Shang, R. Pu, X. Ou, C. Dai, P. Liu, Y. Yang, and X. Cui. 2020. Frontiers in Plant Science 11:888. DOI: 10.3389/fpls.2020.00888.

Abstract: The high background value of cadmium (Cd) in the *Panax notoginseng* planting soil is the main reason for the Cd content in *P. notoginseng* exceeding the limit standards. The main goal of this study was to reveal the mechanism by which potassium (K) reduces Cd accumulation in *P. notoginseng* from the perspective of the influences of soil microbial communities on soil pH, total organic matter (TOM) and cation exchange capacity (CEC). Pot experiments were conducted to study the effects of different types and amounts of applied K on the Cd content in *P. notoginseng*, and on the soil pH, TOM, CEC, and bioavailable Cd (bio-Cd) content in soil. Field experiments were conducted to study the effects of K_2SO_4 fertilizer on the microbial community, and its correlations with the soil pH, TOM and CEC were analyzed. A moderate application of K_2SO_4 (0.6 $g•kg^{-1}$) was found to be the most optimal treatment for the reduction of Cd in the pot experiments. The field experiments proved that K fertilizer (K_2SO_4) alleviated the decreases in pH, TOM and CEC, and reduced the content of bio-Cd in the soil. The application of K fertilizer inhibited the growth of Acidobacteria, but the abundances of Mortierellomycota, Proteobacteria and Bacteroidetes were promoted. The relative abundances of Acidobacteria and Proteobacteria in the soil bacteria exhibited significant negative and positive correlations with pH and CEC, respectively. In contrast, the relative abundance of Mortierellomycota was found to be positively correlated with the pH, TOM and CEC. The bio-Cd content was also found to be positively correlated with the relative abundance of Acidobacteriia but negatively correlated with the relative abundances of Proteobacteria and Mortierellomycota. The application of K fertilizer inhibited the abundance of Acidobacteria, which alleviated

the acidification of the soil pH and CEC, and promoted increase in the abundances of Mortierellomycota, Proteobacteria and Bacteroidetes, which ultimately increased the soil TOM and CEC. Soil microorganisms were found to mitigated decreases in the soil pH, TOM, and CEC and reduced the bio-Cd content in the soil, which significantly reduced the accumulation of Cd in *P. notoginseng*.

Deep Learning for Non-Invasive Diagnosis of Nutrient Deficiencies in Sugar Beet Using RGB Images

Yi, J., L. Krusenbaum, P. Unger, H. Hüging, S.J. Seidel, G. Schaaf, J. Gall. 2020. Sensors 20:5893. DOI: 10.3390/s20205893.

Abstract: In order to enable timely actions to prevent major losses of crops caused by lack of nutrients and, hence, increase the potential yield throughout the growing season while at the same time prevent excess fertilization with detrimental environmental consequences, early, non-invasive, and on-site detection of nutrient deficiency is required. Current non-invasive methods for assessing the nutrient status of crops deal in most cases with nitrogen (N) deficiency only and optical sensors to diagnose N deficiency, such as chlorophyll meters or canopy reflectance sensors, do not monitor N, but instead measure changes in leaf spectral properties that may or may not be caused by N deficiency. In this work, we study how well nutrient deficiency symptoms can be recognized in RGB images of sugar beets. To this end, we collected the Deep Nutrient Deficiency for Sugar Beet (DND-SB) dataset, which contains 5648 images of sugar beets growing on a long-term fertilizer experiment with nutrient deficiency plots comprising N, phosphorous (P), and potassium (K) deficiency, as well as the omission of liming (Ca), full fertilization, and no fertilization at all. We use the dataset to analyse the performance of five convolutional neural networks for recognizing nutrient deficiency symptoms and discuss their limitations.

Potassium Control of Plant Functions: Ecological and Agricultural Implications

Sardans, J., and J. Peñuelas. 2021. Plants 10(2):419. DOI: 10.3390/plants10020419.

Abstract: Potassium, mostly as a cation (K^+), together with calcium (Ca^{2+}) are the most abundant inorganic chemicals in plant cellular media, but they are rarely discussed. K^+ is not a component of molecular or macromolecular plant structures, thus it is more difficult to link it to concrete metabolic pathways than nitrogen or phosphorus. Over the last two decades, many studies have reported on the role of K^+ in several physiological functions, including controlling cellular growth and wood formation, xylem–phloem water content and movement, nutrient and metabolite transport, and stress responses. In this paper, we present an overview of contemporary findings associating K^+ with various plant functions, emphasizing plant-mediated responses to environmental abiotic and biotic shifts and stresses by controlling transmembrane potentials and water, nutrient, and metabolite transport. These essential roles of K^+ account for its high concentrations in the most active plant organs, such as leaves, and are consistent with the increasing number of ecological and agricultural studies that report K^+ as a key element in the function and structure of terrestrial ecosystems, crop production, and global food security. We synthesized these roles from an integrated perspective, considering the metabolic and physiological functions of individual plants and their complex roles in terrestrial ecosystem functions and food security within the current context of ongoing global change. Thus, we provide a bridge between studies of K^+ at the plant and ecological levels to ultimately claim that K^+ should be considered at least at a level similar to N and P in terrestrial ecological studies.

Foliar Spray of Amino Acids and Potassic Fertilizer Improves the Nutritional Quality of Rice

Mirtaleb, S.H., Y. Niknejad, and H. Fallah. 2021. Journal of Plant Nutrition 44(14):2029-2041. DOI: 10.1080/01904167.2021.1889588.

Abstract: The effect of amino acid (AA) fertilizers on the quality and nutritional value of rice have rarely been studied. A field trial to determine the effect of foliar application of amino acids (AA) and potassium (K) on mineral nutrients (Fe, Cu, Mn, Zn, Ca and Mg), the contents of protein, amylose and amino acids (non-essential and essential) of two rice varieties (Tarom mahali and Neda), comprising of four treatments (control, AA, K and AA+K) using randomized complete block design with three replications was conducted at the Rice Research Institute of Iran (Amol). The two years data during 2018 and 2019 showed that the foliar spray of AA and AA+K improved the concentrations of mineral nutrients, protein and amylose contents of brown and milled rice in both rice varieties compared to the control treatment. The foliar application of AA+K also significantly increased the contents of essential and non-essential amino acids of brown and milled rice in both rice varieties. In all similar treatments, the concentrations of element nutrients and the contents of protein, amylose, and amino acids of T. mahali variety were higher than Neda. Therefore, it can be concluded that the combined spray of AA and K can be a suitable practice for improving the quality of rice.

Nitrogen and Potassium Fertilization on Cabbage Biometrics and Foliar Nutritional Levels

Silva, A.C.M.M., H.C. de O. Charlo, P.F. Vargas, J.L.R. Torres, O.F. da Silva Neto, and E.M. Lemes. 2021. Scientia Plena 17(1): Janeiro/January 2021 DOI: 10.14808/sci.plena.2021.010201.

Abstract: Among the most absorbed nutrients by cabbage, nitrogen (N) and potassium (K) are the most extracted; thus, the objective of this study was to evaluate the responses of N and K fertilization on the cabbage biometrics and foliar levels of macro and micronutrients.

Four N doses (0, 75, 150, 300 kg ha^{-1} of N) and four K doses (0, 75, 150, 300 kg ha^{-1} of K_2O). Biometrics of cabbage head (height, circumference and diameter) and productivity were evaluated. The cabbage levels of macro and micronutrients were also evaluated in leaves of plants at the phenological stage of head-formation. Nitrogen fertilization did not significantly affect the variables evaluated mostly due to the great natural fertility of the experimental soil area. This lack of response highlights the importance of constant monitoring of the nutritional status of the productive area to avoid non-necessary N fertilization. The lowest Mg leaf content was observed at 88 kg ha^{-1} of K_2O, after which the Mg leaf content increased. The foliar Zn was reduced in doses after 133 kg ha^{-1} of K_2O. The cabbage head diameter and circumference decreased with the increase of the K_2O doses. The cabbage head height increased up to 128 kg ha^{-1} of K_2O. The decreasing sequence of the macro and micronutrient levels in cabbage leaves followed the sequence K>Ca>N>S>Mg>P and Mn>Fe>B>Zn>Cu regardless of the level of the factors applied.

Nutrient Storage in the Perennial Organs of Deciduous Trees and Remobilization in Spring – A Study in Almond (*Prunus dulcis*) (Mill.) D. A. Webb

Muhammad, S., B.L. Sanden, B.D. Lampinen, D.R. Smart, S. Saa, K.A. Shackel, and P.H. Brown. 2020. Front. Plant Sci. 11:658. DOI: 10.3389/fpls.2020.00658.

Abstract: The annual dynamics of whole mature almond tree nutrient remobilization in spring and the accumulation of nutrients in perennial tissues during the year were determined by sequential coring, tissue sampling, nutrient analysis, whole tree excavation and biomass estimation for trees grown under four nitrogen rate treatments 140 kg ha^{-1} N (N140), 224 kg ha^{-1} N (N224), 309 kg ha^{-1} N (N309), and 392 kg ha^{-1} N (N392) over 2 years. Whole tree perennial organ N content was greatest in dormancy then declined through bud swell, flowering and fruit set, achieving the lowest total whole tree nutrient content of perennial organs by March 12 [12-14 days after full bloom (DAFB)] coincident with 60-70% leaf expansion. During this period no net increment in whole tree N content (annual plus perennial N) was observed indicating that tree demand for N for bud break, flowering, fruit set and leaf out was met by remobilized stored N and that there was no net N uptake from soil. Remobilizable N increased with increasing N application up to N309 and was maximal at 44.4 ± 4 kg ha^{-1} and 37.5 ± 5.7 kg ha^{-1} for the optimally fertilized N309 in 2012 and 2013 respectively. Net increases in perennial organ N (stored N) commenced 41 DAFB and continued through full leaf abscission at 249 DAFB. Total annual N increment in perennial organs varied from 25 to 60 kg ha^{-1} and was strongly influenced by N rate and tree yield. N remobilized from senescing leaves contributed from 11 to 15.5 ± 0.6 kg ha^{-1} to perennial stored N. Similar patterns of nutrient remobilization and storage were observed for P, K, and S with maximal whole tree perennial storage occurring during dormancy and remobilization of that stored P, K, S to support annual tree demands through to fruit set and 70-100% leaf development. Net annual increment in perennial organ P, K, S commenced 98 DAFB and continued through full leaf abscission at 249 DAFB. Organ specific contribution to remobilizable and stored nutrients changes over the growing season are presented. Details of the pattern of perennial organ nutrient allocation, storage, and remobilization provides a framework for the optimal management of nutrients in almond with relevance for other deciduous tree species.

Combined Application of Nitrogen and Potassium Reduces Seed Yield Loss of Oilseed Rape caused by Sclerotinia Stem Rot Disease

Zhang, J., J. Li, G. Geng, W. Hu, T. Ren, R. Cong, X. Li, J. Lu. 2020. Agronomy Journal 112:5143-5157. DOI: 10.1002/agj2.20410.

Abstract: Sclerotinia stem rot (SSR) is a major fungal disease of oilseed rape (*Brassica napus* L.) that causes severe yield losses. Nutrient management is crucial for protecting crops against SSR. Two-yr field trials combined four levels of N application (0, 90, 180, and 270 kg N ha^{-1}) and four levels of K application (0, 60, 120, and 180 kg ha^{-1} K_2O) to investigate their interaction effects on SSR disease incidence and seed yield loss caused by SSR. Compared to the sole application of N, the combined application of N and K decreased the SSR disease incidence by 9.9-24.4 and 17.4-37.9% in 2016-2017 and 2018-2019, respectively. N application increased the severity of SSR only at lower K application rates (0 and 60 kg ha^{-1} K_2O). Additionally, compared to the sole application of N, the co-application of N and K dramatically decreased the total yield loss rate (TYLR), by 31.1-60.9 and 19.2-60.3% in 2016-2017 and 2018-2019, respectively. The seed yield response to N uptake was dependent on the level of K application. However, SSR disease dramatically decreased the nutrients use efficiency. Nitrogen and K supply showed synergistic interaction effects on N and K recovery efficiency. These results emphasized the importance of N and K co-application on reducing the yield loss caused by SSR infection. For a stabilized seed yield, an adequate N (180 kg ha^{-1}) application rate combined with a slightly high K application rate (120-180 kg ha^{-1}) represents a feasible nutrient management strategy for oilseed rape against SSR disease.

Estimating *Fritillaria thunbergii* Miq. Yield, Quality, and Potassium Use Efficiency in Response to Potassium Application Rate

Sui, N., L. Wang, J. Sun, J. Wu, M. Chen, S. Zhang, Q. Yuan, and G. Kai. 2021. Industrial Crops and Products 164:113409. DOI: 10.1016/j.indcrop.2021.113409.

Abstract: There is a high market demand for the dried bulb of *Fritillaria thunbergii* Miq. because of its use to treat airway inflammatory and endocrine system diseases. Although *F. thunbergii* requires more potassium than nitrogen and phosphorus during development, the response of *F. thunbergii* to potassium has rarely been studied. Field experiments were conducted in 2016/2017 and 2017/2018 with two *F. thunbergii* cultivars under six levels of potassium fertilization (0, 40, 80, 120, 160 and 200 kg K_2O ha^{-1}) to investigate the effects of potassium application on *F. thunbergii* yield, quality, and potassium utilization efficiency. Results showed that potassium fertilization increased the bulb yield, bulb quality (peimine and peiminine content), and net income by 6.4-23.8%, 2.1-26.6% and 47.7-205.4%, respectively. More biomass and potassium were partitioned to underground parts when potassium application increased. The yield and quality of the bulb were positively correlated with potassium accumulation in the underground part. The economic benefit of *F. thunbergii* is stable at 120-160 kg K_2O ha^{-1}, while the potassium utilization efficiency was reasonable at 80-120 kg K_2O ha^{-1}. In summary, potassium application is an effective strategy to simultaneously improve bulb yield and quality in *F. thunbergii*. Considering the economic and environmental benefits, a potassium application rate of 120 kg K_2O ha^{-1} is optimal for *F. thunbergii* cultivation.

Exogenous Potassium (K^+) Positively Regulates Na^+/H^+ Antiport System, Carbohydrate Metabolism, and Ascorbate–Glutathione Cycle in H_2S-Dependent Manner in NaCl-Stressed Tomato Seedling Roots

Khan M.N., S. Mukherjee, A.A. Al-Huqail, R.A. Basahi, H.M. Ali, B.M.A. Al-Munqedhi, M.H. Siddiqui, and H.M. Kalaji. 2021. Plants 10(5):948. DOI: 10.3390/plants10050948.

Abstract: Potassium (K^+) is one of the vital macronutrients required by plants for proper growth and blossoming harvest. In addition, K^+ also plays a decisive role in promoting tolerance to various stresses. Under stressful conditions, plants deploy their defense system through various signaling molecules, including hydrogen sulfide (H_2S). The present investigation was carried out to unravel the role of K^+ and H_2S in plants under NaCl stress. The results of the study show that NaCl stress caused a reduction in K^+ and an increase in Na^+ content in the tomato seedling roots which coincided with a lower H^+-ATPase activity and K^+/Na^+ ratio. However, application of 5 mM K^+, in association with endogenous H_2S, positively regulated the Na^+/H^+ antiport system that accelerated K^+ influx and Na^+ efflux, resulting in the maintenance of a higher K^+/Na^+ ratio. The role of K^+ and H_2S in the regulation of the Na^+/H^+ antiport system was validated by applying sodium orthovanadate (plasma membrane H^+-ATPase inhibitor), tetraethylammonium chloride (K^+ channel blocker), amiloride (Na^+/H^+ antiporter inhibitor), and hypotaurine (HT, H_2S scavenger). Application of 5 mM K^+ positively regulated the ascorbate–glutathione cycle and activity of antioxidant enzymes that resulted in a reduction in reactive oxygen species generation and associated damage. Under NaCl stress, K^+ also activated carbohydrate metabolism and proline accumulation that caused improvement in osmotic tolerance and enhanced the hydration level of the stressed seedlings. However, inclusion of the H_2S scavenger HT reversed the effect of K^+, suggesting H_2S-dependent functioning of K^+ under NaCl stress. Therefore, the present findings report that K^+, in association with H_2S, alleviates NaCl-induced impairments by regulating the Na^+/H^+ antiport system, carbohydrate metabolism, and antioxidative defense system.

Rice Yield Response to Potassium: An Economic Analysis

Popp, M.P., N.A. Slaton, J.S. Norsworthy, and B. Dixon. 2021. Agronomy Journal 113:287-297. DOI: 10.1002/agj2.20471.

Abstract: Potassium fertilizer represents a non-trivial input cost in rice (*Oryza sativa* L.) production and its rate recommendation is often based on yield and K deficiency observations alone. However, profit-maximizing fertilizer-K rate not only hinges on the yield response to both initial available soil K and applied fertilizer K, but also the crop value and fertilizer cost. To that end, K application rate studies for rice, performed across 91 site-years from 2001 to 2018, allowed estimation of a generic yield response curve to calculate profit-maximizing K rates for producers in the mid-southern United States. To determine whether those calculation efforts are justified, we compared profit-maximizing fertilizer-K rates to those currently recommended. Using rice prices and yields, fertilizer-K cost, and a range of initial soil-test K values, as observed over the last 10 yr, we find that current fertilizer-K rate recommendations are too high. Profit-maximizing rates added from US$0.88 ha^{-1} at initial Mehlich-3 K availability values of 75 mg K kg^{-1} to $28.19 ha^{-1} at 105 mg K kg^{-1} on average. The corresponding fertilizer-K reductions were 0.35 and 56 kg K ha^{-1}, respectively, resulting in attendant yield penalties of only 4 kg ha^{-1} and 105 kg ha^{-1}. Hence, performing soil tests and using decision support software to obtain profit-maximizing fertilizer-K rates is expected to enhance producer profit at rice yield penalties that are smaller than fertilizer cost savings. While profit-maximizing rate recommendations do vary in a field with varying available soil K, using the mid-range estimate rather than variable-rate technology was deemed most feasible.

Effect of Different Nutrient Sources on Yield and Biochemical Properties of Soil Under Rice–Wheat Cropping Sequence in Middle Gangetic Alluvial Plain

Kumar, M., S.K. Singh, and A. Patra. 2021. Journal of Plant Nutrition 44(15):2310-2330. DOI: 10.1080/01904167.2021.1899206.

Abstract: In the present agricultural scenario, balanced nutrients application is a key to improved crop production without deteriorating soil health. Therefore, from environmental concern, there is need to supplement a part of chemical fertilizers with locally available organics. To attain this objective, field experiments were conducted to study the effect of sewage sludge (SS), vermicompost (VC) and *Sesbania* (SB) using them by 75% recommended dose of inorganic fertilizers (RDF) and combination of customized fertilizers (CF) for

rice and wheat separately and also sulfur (S), zinc (Zn) and boron (B) with RDF. Among the nutrient sources, the maximum grain yield in rice (4.92 t ha^{-1}) recorded with 100% RDF applied along with S, Zn and B whereas in wheat (4.64 t ha^{-1}), it was with CF. Total removal of nitrogen (N), phosphorus (P), potassium (K), S and B were higher by rice crop than that of wheat. The treatment with 75% RDF along with VC had significantly higher water holding capacity and lower bulk density of post-harvest soil (PHS) during both years. Organic carbon, available N, P, K content in PHS increased significantly by application of 100% RDF along with S, Zn, B and CF for both years. Application of S, Zn and B resulted a significant increase in available S and B content in soil over 100% RDF. Application of VC significantly increased the bacterial, fungal and actinomycetes population in PHS.

The Molecular–Physiological Functions of Mineral Macronutrients and their Consequences for Deficiency Symptoms in Plants

de Bang, T.C., S. Husted, K.H. Laursen, D.P. Persson, and J.K. Schjoerring. 2021. New Phytol 229:2446-2469. DOI: 10.1111/nph.17074.

Abstract: The visual deficiency symptoms developing on plants constitute the ultimate manifestation of suboptimal nutrient supply. In classical plant nutrition, these symptoms have been extensively used as a tool to characterise the nutritional status of plants and to optimise fertilisation. Here we expand this concept by bridging the typical deficiency symptoms for each of the six essential macronutrients to their molecular and physiological functionalities in higher plants. We focus on the most recent insights obtained during the last decade, which now allow us to better understand the links between symptom and function for each element. A deep understanding of the mechanisms underlying the visual deficiency symptoms enables us to thoroughly understand how plants react to nutrient limitations and how these disturbances may affect the productivity and biodiversity of terrestrial ecosystems. A proper interpretation of visual deficiency symptoms will support the potential for sustainable crop intensification through the development of new technologies that facilitate automatised management practices based on imaging technologies, remote sensing and in-field sensors, thereby providing the basis for timely application of nutrients via smart and more efficient fertilisation.

ZMK1 Is Involved in K^+ Uptake and Regulated by Protein Kinase ZmCIPK23 in *Zea mays*

Han, W., Y. Ji, W. Wu, J-K Cheng, H-Q Feng, and Y. Wang. 2021. Front. Plant Sci. 12 517742. DOI: 10.3389/fpls.2021.517742.

Abstract: Potassium (K^+) is one of essential mineral elements for plant growth and development. K^+ channels, especially AKT1-like channels, play crucial roles in K^+ uptake in plant roots. Maize is one of important crops; however, the K^+ uptake mechanism in maize is little known. Here, we report the physiological functions of K^+ channel ZMK1 in K^+ uptake and homeostasis in maize. *ZMK1* is a homolog of *Arabidopsis* AKT1 channel in maize, and mainly expressed in maize root. Yeast complementation experiments and electrophysiological characterization in Xenopus oocytes indicated that ZMK1 could mediate K^+ uptake. *ZMK1* rescued the low-K^+-sensitive phenotype of akt1 mutant and enhanced K^+ uptake in *Arabidopsis*. Overexpression of *ZMK1* also significantly increased K^+ uptake activity in maize, but led to an oversensitive phenotype. Similar to AKT1 regulation, the protein kinase ZmCIPK23 interacted with ZMK1 and phosphorylated the cytosolic region of ZMK1, activating ZMK1-mediated K^+ uptake. ZmCIPK23 could also complement the low-K^+-sensitive phenotype of *Arabidopsis* cipk23/lks1 mutant. These findings demonstrate that ZMK1 together with ZmCIPK23 plays important roles in K^+ uptake and homeostasis in maize.

Foliar-Applied Potassium Silicate Coupled with Plant Growth-Promoting Rhizobacteria Improves Growth, Physiology, Nutrient Uptake and Productivity of Faba Bean (*Vicia faba* L.) Irrigated with Saline Water in Salt-Affected Soil

Hafez E.M., H.S. Osman, U.A.A. El-Razek, M. Elbagory, A.E.-D. Omara, M.A. Eid, and S.M. Gowayed. 2021. Plants 10(5):894. DOI: 10.3390/plants10050894.

Abstract: The continuity of traditional planting systems in the last few decades has encountered its most significant challenge in the harsh changes in the global climate, leading to frustration in the plant growth and productivity, especially in the arid and semi-arid regions cultivated with moderate or sensitive crops to abiotic stresses. Faba bean, like most legume crops, is considered a moderately sensitive crop to saline soil and/or saline water. In this connection, a field experiment was conducted during the successive winter seasons 2018/2019 and 2019/2020 in a salt-affected soil to explore the combined effects of plant growth-promoting rhizobacteria (PGPR) and potassium (K) silicate on maintaining the soil quality, performance, and productivity of faba bean plants irrigated with either fresh water or saline water. Our findings indicated that the coupled use of PGPR and K silicate under the saline water irrigation treatment had the capability to reduce the levels of exchangeable sodium percentage (ESP) in the soil and to promote the activity of some soil enzymes (urease and dehydrogenase), which recorded nearly non-significant differences compared with fresh water (control) treatment, leading to reinstating the soil quality. Consequently, under salinity stress, the combined application motivated the faba bean vegetative growth, e.g., root length and nodulation, which reinstated the K^+/Na^+ ions homeostasis, leading to the lessening or equalizing of the activity level of enzymatic antioxidants (CAT, POD, and SOD) compared with the controls of both saline water and fresh water treatments, respectively. Although the irrigation with saline water significantly increased the osmolytes concentration (free amino acids and proline)

in faba bean plants compared with fresh water treatment, application of PGPR or K-silicate notably reduced the osmolyte levels below the control treatment, either under stress or non-stress conditions. On the contrary, the concentrations of soluble assimilates (total soluble proteins and total soluble sugars) recorded pronounced increases under tested treatments, which enriched the plant growth, the nutrients (N, P, and K) uptake and translocation to the sink organs, which lastly improved the yield attributes (number of pods plant^{-1}, number of seeds pod^{-1}, 100-seed weight). It was concluded that the combined application of PGPR and K-silicate is considered a profitable strategy that is able to alleviate the harmful impact of salt stress alongside increasing plant growth and productivity.

A Potassium-Sensing Niche in Arabidopsis Roots Orchestrates Signaling and Adaptation Responses to Maintain Nutrient Homeostasis

Wang, F.-L., Y.-L.Tan, L. Wallrad, X.-Q. Du, A. Eickelkamp, Z.-F. Wang, G.-F. He, F. Rehms, Z. Li, J.-P. Han, I. Schmitz-Thom, W.-H. Wu, J. Kudla, and Y. Wang. 2021. Developmental Cell 56(6):781-794.e6. DOI: 10.1016/j.devcel.2021.02.027.

Abstract: Organismal homeostasis of the essential ion K^+ requires sensing of its availability, efficient uptake, and defined distribution. Understanding plant K^+ nutrition is essential to advance sustainable agriculture, but the mechanisms underlying K^+ sensing and the orchestration of downstream responses have remained largely elusive. Here, we report where plants sense K^+ deprivation and how this translates into spatially defined ROS signals to govern specific downstream responses. We define the organ-scale K^+ pattern of roots and identify a postmeristematic K^+-sensing niche (KSN) where rapid K^+ decline and Ca^{2+} signals coincide. Moreover, we outline a bifurcating low-K^+-signaling axis of CIF peptide-activated SGN3-LKS4/SGN1 receptor complexes that convey low-K^+-triggered phosphorylation of the NADPH oxidases RBOHC, RBOHD, and RBOHF. The resulting ROS signals simultaneously convey HAK5 K^+ uptake-transporter induction and accelerated Casparian strip maturation. Collectively, these mechanisms synchronize developmental differentiation and transcriptome reprogramming for maintaining K^+ homeostasis and optimizing nutrient foraging by roots.

Effects of Potassium Levels on Plant Growth, Accumulation and Distribution of Carbon, and Nitrate Metabolism in Apple Dwarf Rootstock Seedlings

Xu, X., X. Du, F. Wang, J. Sha, Q. Chen, G. Tian, Z. Zhu, S. Ge, and Y. Jiang. 2020. Front. Plant Sci. 11:904. DOI: 10.3389/fpls.2020.00904.

Abstract: Nitrogen (N) is one of the most required mineral elements for plant growth, and potassium (K) plays a vital role in nitrogen metabolism, both elements being widely applied as fertilizers in agricultural production. However, the exact relationship between K and nitrogen use efficiency (NUE) remains unclear. Apple dwarf rootstock seedlings (M9T337) were used to study the impacts of different K levels on plant growth, nitrogen metabolism, and carbon (C) assimilation in water culture experiments for 2 years. The results showed that both deficiency and excess K inhibited the growth and root development of M9T337 seedlings. When the K supply concentration was 0 mM and 12 mM, the biomass of each organ, root-shoot ratio, root activity and NO_3^- ion flow rate decreased significantly, net photosynthetic rate (Pn) and photochemical efficiency (Fv/Fm) being lower. Meanwhile, seedlings treated with 6 mM K^+ had higher N and C metabolizing enzyme activities and higher nitrate transporter gene expression levels (NRT1.1; NRT2.1). 13C and 15N labeling results showed that deficiency and excess K could not only reduce 15N absorption and 13C assimilation accumulation of M9T337 seedlings, but also reduced the 15N distribution ratio in leaves and 13C distribution ratio in roots. These results suggest that appropriate K supply (6 mM) was optimal as it enhanced photoassimilate transport from leaves to roots and increased NUE by influencing photosynthesis, C and N metabolizing enzyme activities, nitrate assimilation gene activities, and nitrate transport.

Seasonal Nutrient Cycling and Enrichment of Nutrient-Related Soil Microbes Aid in the Adaptation of Ramie (*Boehmeria nivea* L.) to Nutrient-Deficient Conditions

Wu, S., S. Xue, Y. Iqbal, H. Xing, and Y. Jie. 2021. Front. Plant Sci. 12:644904. DOI: 10.3389/fpls.2021.644904.

Abstract: The breeding for varieties tolerant of adverse growing conditions is critical for sustainable agriculture, especially for ramie (*Boehmeria nivea* L.). However, a lack of information on the tolerance of ramie to nutrient-deficient conditions has hindered efforts to breed ramie varieties tolerant of such conditions. The main objective of this study was to explore the tolerance strategies of ramie plants under poor soil conditions using long-term (8-9 years) field trials. Genotypes of Duobeiti 1 and Xiangzhu XB were highly tolerant of poor soil conditions. The contributions of seasonal nutrient cycling and rhizobacteria to the ability of ramie to tolerate poor soil were tested. Nitrogen and phosphorus retranslocation to the root at the end of the growing season helped ramie adapt to poor soil conditions. The contribution of the microbial community was analyzed using high-throughput Illumina MiSeq sequencing technology. The enrichment of beneficial bacteria (mainly *Bradyrhizobium*, *Gaiella*, and *norank_o_Gaiellales*) and the reduction of harmful fungi (mainly *Cladosporium* and *Aspergillus*) also contributed to the ability of ramie to tolerate poor soils. The results of this study provide new insight into the ability of ramie to tolerate adverse conditions and aid future efforts to breed and cultivate ramie tolerant of adverse conditions.

Interaction Between Macro- and Micro-Nutrients in Plants
Kumar S., S. Kumar, and T. Mohapatra. 2021. Front. Plant Sci. 12:665583. DOI: 10.3389/fpls.2021.665583.

Abstract: Nitrogen (N), phosphorus (P), sulfur (S), zinc (Zn), and iron (Fe) are some of the vital nutrients required for optimum growth, development, and productivity of plants. The deficiency of any of these nutrients may lead to defects in plant growth and decreased productivity. Plant responses to the deficiency of N, P, S, Fe, or Zn have been studied mainly as a separate event, and only a few reports discuss the molecular basis of biological interaction among the nutrients. Macro-nutrients like N, P, and/or S not only show the interacting pathways for each other but also affect micro-nutrient pathways. Limited reports are available on the investigation of two-by-two or multi-level nutrient interactions in plants. Such studies on the nutrient interaction pathways suggest that an MYB-like transcription factor, phosphate starvation response 1 (PHR1), acts as a master regulator of N, P, S, Fe, and Zn homeostasis. Similarly, light-responsive transcription factors were identified to be involved in modulating nutrient responses in *Arabidopsis*. This review focuses on the recent advances in our understanding of how plants coordinate the acquisition, transport, signaling, and interacting pathways for N, P, S, Fe, and Zn nutrition at the molecular level. Identification of the important candidate genes for interactions between N, P, S, Fe, and/or Zn metabolic pathways might be useful for the breeders to improve nutrient use efficiency and yield/quality of crop plants. Integrated studies on pathways interactions/cross-talks between macro- and micro-nutrients in the agronomically important crop plants would be essential for sustainable agriculture around the globe, particularly under the changing climatic conditions.

Read on

Managing Phosphorus and Potassium is Key in Conservation Tillage Systems
Sever, M. 2021. Crops & Soils 54(2)1:14-17.
DOI: 10.1002/crso.20101.

Abstract: More and more, North American farms are moving toward conservation tillage practices, including no-till and strip-till. With this trend has come a lot of questions about how best to apply fertilizers, especially phosphorus and potassium, in conservation tillage. In a recent study, researchers examined how yield and root growth in corn and soybean crops are affected by tillage, fertilizer application rates, and fertilizer placement. The team also looked at nutrient use efficiencies and soil phosphorus and potassium levels. The findings echo the results of previous studies and provide a baseline for best practice recommendations. Earn 0.5 CEUs in Nutrient Management by reading the article and taking the quiz at www.certifiedcropadviser.org/education/classroom/classes/946.

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The Benefits of Fertigation
Hillel Magen, Director at the International Potash institute (IPI) and Munir Rusan, Professor at Jordan University of Science and Technology (JUST) sit down with IFA Deputy Director-General, Patrick Heffer, to discuss the benefits and potential of fertigation for improving nutrient and water use efficiency, increasing farmers' incomes, growing crops on marginal land and improving yields.

28 June 2021. International Fertilizer Association (IFA) Podcast.

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