Efficiency of polyhalite as a fertilizer supplying potassium, magnesium, calcium and sulfate

Uri Yermiyahu¹, Isaac Zipori¹, Inna Faingold¹, Ludmila Yusopov¹, Nitay Faust¹ and Asher Bar-Tal²

¹Gilat Research Center, Agricultural Research Organization, M.P. Negev, 85280, ISRAEL (uri4@agri.gov.il)
²Institute of Soil, Water and Environmental Sciences, Agricultural Research Organization, The Volcani Center, Derech HaMaccabim, Rishon LeTsiyon, 75359, ISRAEL (abartal@agri.gov.il)

INTRODUCTION
Polysulphate is a fertilizer produced from the mineral polyhalite – a hydrated sulfate of potassium (K), calcium (Ca) and magnesium (Mg) with the formula: \( K_2Ca_2Mg(SO_4)4\cdot2H_2O \). The main objective of the present study was to investigate and compare the efficiency of polyhalite as a fertilizer supplying K, Ca, Mg and sulfur (S) relative to equivalent soluble salts.

The specific objectives were to investigate the effect of fertilization with different doses of polyhalite relative to equivalent soluble salts on: 1. The release and transport of Ca, Mg, K and S in soil; 2. Uptake of these minerals by wheat plants and 3. Biomass production of wheat plants.

METHODS
Pot experiments were conducted in which the effects of four levels of applied polyhalite (0, 500, 1,500 and 2,500 kg/ha) and one level of Ca, Mg and K sulfate salts (equivalent to the 1500 kg/ha polyhalite dose) were investigated (2015 experiment). In a second experiment, residual effects of the fertilizers were studied using the pots from the first experiment (2015R). A third experiment was conducted with new set of pots with the same treatments as the 2015 experiment. Different leaching fractions (30% and 10%, respectively) were used in the 2015R and 2016 experiments compared to the 2015 experiment, allowing investigation of the effect of water management on mineral transportation in the soil and plant uptake.

RESULTS AND DISCUSSION
At the start of the 2015 and 2016 experiments, the electrical conductivities (EC) and mineral concentrations of the leachate increased with increasing polyhalite application level and they were lower than for the equivalent soluble salt application treatment, indicating the lower solubility of polyhalite. Higher EC and mineral concentration values were obtained in the leachates of the 2015 experiment than the 2016 experiment due to the higher leaching fraction (30% and 10%, respectively). Biomass production was significantly higher under all polyhalite levels than under nil polyhalite for the 2015R and 2016 experiments. The residual concentrations of K, Ca and Mg in soil extract of the top 0-5 cm at the end of each experiment were measured. In general, the residual concentrations of these elements increased with increasing polyhalite application level, however, the residual effect on Ca concentration was much higher than on Mg, K and S. Mineral concentrations and uptake by wheat were effected by treatments with different responses between the elements. In the 2015 and 2016 experiments, shoot K concentration and uptake increased significantly with increasing application of the polyhalite fertilizer. In the same experiments, shoot Ca and Mg concentrations decreased with increasing polyhalite application level, whereas their uptake increased, suggesting that Ca and Mg levels were not limiting factors for biomass production (Figure 1).

CONCLUSIONS
Polyhalite is a more efficient fertilizer for supplying K, Ca, Mg and S relative to equivalent soluble salts. To meet the plant required ratios for Ca, Mg and K, polyhalite should be applied to provide...
sufficient Ca and Mg, and additional fertilizers should be used as a source of K. Transport and leaching of Ca, Mg, K and S in soil following polyhalite application is lower than following the application of the equivalent sulfate salts. The residual effect of polyhalite fertilizer on the subsequently grown crop is higher than the effect of the equivalent sulfate salts, especially regarding Ca, Mg and S. Irrigation management, as determined by the leaching fraction, has a strong impact on the efficiency of polyhalite as a source of K, Ca, Mg and S for plant nutrition.

Figure 1. K, Ca, Mg and S concentrations in the dry matter of the aboveground wheat and the uptake of these nutrients in response to application levels of polyhalite or fertilizer control (equivalent to 1,500 kg/ha). Different letters indicate significant differences between polyhalite dose in each experiment, p<0.05.

ACKNOWLEDGEMENTS
This work was supported by the Center of Fertilization and Plant Nutrition (CFPN).
Leaching rate of selected sulphur fertilizers; understanding selenate - sulphate competition

Jiang L¹, Young S.D.¹, Broadley M.R.¹, Bailey E.H.¹, Graham N.S.¹ and McGrath S.P.²

¹School of Biosciences, College Rd, University of Nottingham, Sutton Bonington Campus, Loughborough, Leicestershire, LE12 5RD, UK (linxi.jiang@nottingham.ac.uk)
²Department of Sustainable Agriculture Sciences, Harpenden, Rothamsted Research, Harpenden, Hertfordshire AI5 2JQ, UK

INTRODUCTION
Deposition of SOx has decreased over recent decades and this trend currently continues. Sulphur deposition is predicted to be c. 0.1 to 0.5 kg ha⁻¹ per month in England by 2020 with net leaching of 1.4 to 4.1 kg ha⁻¹ per year. This will result in an increased requirement for sulphur fertilizer, as an essential element for plant protein composition and formation of chlorophyll, to avoid deficiency and crop failure.

Biofortification with selenium is an effective mean of increasing dietary Se intake and the requirement for Se biofortification is becoming more apparent. More than 0.5 billion people currently experience low selenium dietary intakes that can result in cardiovascular disease, cancer, various oxidative stress-related disorders and reduced fertility. A relatively unknown aspect of Se biofortification is the extent to which sulphur fertiliser application may suppress selenate uptake by plants. This is caused by sulphate (SO₄²⁻) and selenate (HSeO₄⁻, SeO₄²⁻) anions competing for the same transporters on roots. The aim of this study is to investigate this potential conflict between S and Se uptake.

Competition for uptake between SO₄²⁻ and SeO₄²⁻ may be greatest following application prior to the Se being converted to fixed humus-bound forms in soil. There may therefore be some advantage in utilizing sulphate fertilizers that have a slower rate of dissolution in soil. The relative rates of solubilisation of five sulphate based fertilizers: ammonium sulphate, potassium sulphate, magnesium sulphate, anhydrite and polyhalite (Ca₂K₂Mg(SO₄)₄.2H₂O) have been investigated.

METHODS
Triplicate re-packed soil columns (200 g sandy loam (< 4 mm); arable Wick series) were amended with three granules of polyhalite, (NH₄)₂SO₄, K₂SO₄, MgSO₄ or CaSO₄. The granules were covered with 1 cm soil except for a second ‘surface-applied’ polyhalite treatment. The soil columns were leached daily with 1 pore volume of water for 30 days and the leachate collected for analysis by inductively coupled plasma mass spectrometry for sulphur and the constituent cations. Additionally, the rapid dissolution of polyhalite was assessed drop-wise, using a continuous peristaltic pump (0.23 mL min⁻¹) and fraction collector (5 mL fractions), to determine whether the solubility of nutrients it contains was incongruent or congruent.

RESULTS AND DISCUSSION
The soil leaching trial indicated that ammonium, potassium and magnesium sulphate are dissolved readily and > 80% of the S applied was recovered in 10 days. As expected, anhydrite released sulphur much more slowly than the pure sulphate compounds while polyhalite showed an intermediate trend suggesting a more evenly paced dissolution (Fig. 1). The leachate in drop direct leaching on polyhalite shows a congruent dissolution in each cation and anion (Fig. 2).

CONCLUSIONS
Polyhalite releases sulphate at a rate which is intermediate between those of soluble sulphate salts such as NH₄, K and Mg sulphate and that of anhydrous CaSO₄. Polyhalite dissolves by congruent dissolution of a homogeneous isomorphically-substituted crystal (Ca₂K₂Mg(SO₄)₄.2H₂O) but slow dissolution in soil leads to in-situ re-precipitation of CaSO₄.2H₂O. It seems possible that the use of polyhalite as a sulphate fertilizer...
could offset possible suppression of selenium uptake during the limited period of selenate availability in Se biofortification of crops; this is the next phase of work with polyhalite.

![Cumulative Sulphur leached through soil column as a % of total applied](image)

**Fig. 1.** Average (n = 3) cumulative proportion (%) of sulphur leached from soil columns as a function of time (days) and leachate volume (pore volumes) for five alternative sulphate compounds: polyhalite surface-applied (green circles), polyhalite covered (red circles), MgSO₄ (open triangles), (NH₄)₂SO₄ (open diamonds), K₂SO₄ (open squares), , and CaSO₄ (open circles).

![Dissolution of polyhalite: individual trends](image)

**Fig. 2.** Proportion dissolution of each cation and anion in polyhalite singe granule leachate on Mg²⁺ (green), SO₄²⁻ (red), K⁺ (yellow) and Ca²⁺ (blue).

**ACKNOWLEDGEMENTS**

This work was supported by ICL fertilizers and the UoN-China Scholarship scheme. Project participants are named as co-authors. We gratefully thank Rory Hayden and Lolita Wilson for help in setting up the leaching trial.
Comparing polyhalite and KCl in alfalfa fertilization

Alberto C. de Campos Bernardi, Gilberto Batista de Souza, Fabio Valle, Hillel Magen

1Embrapa Pecuaria Sudeste, São Carlos, SP, Brazil (alberto.bernardi@embrapa.br)
2ICL Fertilizers, São Paulo, SP, Brazil (fabio.vale@icl-group.com)
3IPI - International Potash Institute, Zug, Switzerland (h.magen@ipipotash.org)

INTRODUCTION

Supplying nutrients in balanced and adequate levels is a key factor for alfalfa production and is essential to maintain high quality and efficient yields. Potassium fertilization is essential for alfalfa production and is the most common nutrient input for this crop in the high weathered, low-fertile and acids soils of the tropical region (Bernardi et al., 2013).

The minerals commonly explored as sources of K are sylvite (KCl), sylvinite (KCl + NaCl), and carnallite (KMg2Cl3.6H2O). Potassium chloride potash (58 to 62% of K2O) is the most potash fertilizer used in Brazil accounting for over 95% of the market. However, there are other minerals composed of sulfates that may be considered of economic interest owing to their potassium content and easy solubilization, e.g., langbeinite, kainite, and polyhalite (Prud’homme and Krukowski, 2006). Polyhalite (K2MgCa2(SO4)4.2H2O) is a mineral of natural occurrence with large existing deposits and has potential to be a multi-nutrient (ratio of 11.7%-K, 19%-S, 3.6%-Mg, and 12.1%-Ca) fertilizer for forage crop production.

However, little information is available for the response of alfalfa to polyhalite. Acid, low-fertile, high-weathered soils typically benefit from the addition of K, Ca, Mg, and S fertilizers, and polyhalite may provide a slow-release fertilizer source of these nutrients (Barbarick, 1991). The objective of this study was to evaluate the effect of doses and sources of application of potassium fertilizer on the alfalfa dry matter yield, quality, and nutritional status.

METHODS

The greenhouse experiment was conducted at Embrapa Pecuária Sudeste, in São Carlos (22°01’ S and 47°54’ W; 856 m above sea level), State of São Paulo, Brazil. Alfalfa (Medicago sativa) was grown in pots with 3 kg completed with soil samples taken at a 0-0.2 m deep layer of a Typic Hapludox. Soil presented the following chemical properties: pHCaCl2 = 5.2, organic matter = 24 g/dm3, Presine = 2 mg/dm3, K = 1.6 mmol/dm3, Ca = 19 mmol/dm3, Mg = 8 mmol/dm3, CEC = 52 mmol/dm3, basis saturation = 55%; S-SO4 = 12 mg/dm3, B = 0.37 mg/dm3, Cu = 6.3 mg/dm3, Fe = 13 mg/dm3, Mn = 1.5 mg/dm3, Zn = 0.5 mg/dm3; and the physical characteristics: 265 g/kg of sand, 198 g/kg of silt and 537 g/kg of clay. Pots were uniformly limed (until V = 80%) before planting and fertilized at planting with 458 mg/kg of P2O5, and 25 mg/kg of FTE-BR12 (1.8% of B, 0.8% Cu, 3% Fe, 2% Mn, 0.1% Mo, 9% Zn).

Treatments comprised two K sources: polyhalite and KCl (60% K2O), five ratios (polyhalite:KCl) and four K2O levels (0, 50, 100, and 200 kg/ha) combined in a 7x3x4 factorial design with 4 replications, in a total of 88 experimental units. The treatments were: i) Control (no K, S, Mg or Ca); ii) KCl 100%; iii) KCl 87.5% + Polyhalite 12.5%; iv) KCl 50% + Polyhalite 50%; v) KCl 12.5% + Polyhalite 87.5%; vi) Polyhalite 100%; vii) KCl 100% + gypsum (12.5%); viii) KCl 100% + gypsum 50%.

Alfalfa shoot was sampled at the beginning of flowering. A total of 6 cuts were evaluated. Measurements carried out were: dry matter yield, % of leaves, leaf area, quality analysis (crude protein, digestibility) and foliar diagnosis (N, P, K, Ca, Mg, S, Cu, Fe, Mn and Zn).

RESULTS AND DISCUSSION

Alfalfa responded positively to the application of both K and S. Polyhalite was an effective source of both K and S as measured by alfalfa yield and nutrient uptake; and it’s better than KCl alone or...
plus gypsum. Polyhalite and KCl mixture significantly out yielded the control, the highest polyhalite concentration improved alfalfa performance. KCl with gypsum did not get the same performance. Given its relatively low K uptake on control, it is likely that availability of K might have been a limiting factor to alfalfa yield. Based on K and S uptake, there may some synergy between the nutrients in polyhalite that enhances alfalfa performance (Table 1).

Table 1. Alfalfa dry matter yield (g per pot), leaf area (cm$^2$), K and S concentration on shoot (g/kg) due K source and dosis.

<table>
<thead>
<tr>
<th>Dosis (K$\text{O }$kg/ha)</th>
<th>KCl 100%</th>
<th>KCl 87.5% + Polyh 12.5%</th>
<th>KCl 50% + Polyh 50%</th>
<th>KCl 12.5% + Polyh 87.5%</th>
<th>Polyh 100%</th>
<th>KCl 100% + gypsum 12.5%</th>
<th>KCl 100% + gypsum 50%</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>28.2</td>
<td>28.2</td>
<td>28.2</td>
<td>28.2</td>
<td>28.2</td>
<td>28.2</td>
<td>28.2</td>
</tr>
<tr>
<td>50</td>
<td>45.7</td>
<td>52.0</td>
<td>54.2</td>
<td>57.7</td>
<td>61.1</td>
<td>36.4</td>
<td>48.4</td>
</tr>
<tr>
<td>100</td>
<td>56.9</td>
<td>55.1</td>
<td>77.1</td>
<td>53.0</td>
<td>72.3</td>
<td>55.2</td>
<td>57.4</td>
</tr>
<tr>
<td>200</td>
<td>48.6</td>
<td>64.1</td>
<td>63.7</td>
<td>68.1</td>
<td>82.0</td>
<td>62.1</td>
<td>65.4</td>
</tr>
<tr>
<td>Leaf area (cm$^2$)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>0</td>
<td>2406.3</td>
<td>2406.3</td>
<td>2406.3</td>
<td>2406.3</td>
<td>2406.3</td>
<td>2406.3</td>
<td>2406.3</td>
</tr>
<tr>
<td>50</td>
<td>2805.0</td>
<td>3153.8</td>
<td>3159.9</td>
<td>3181.3</td>
<td>3811.5</td>
<td>2060.3</td>
<td>2651.3</td>
</tr>
<tr>
<td>100</td>
<td>3616.8</td>
<td>3227.7</td>
<td>3333.1</td>
<td>2644.1</td>
<td>2813.1</td>
<td>3212.6</td>
<td>2636.9</td>
</tr>
<tr>
<td>200</td>
<td>3323.1</td>
<td>3098.5</td>
<td>3631.1</td>
<td>2654.0</td>
<td>3702.3</td>
<td>2976.1</td>
<td>4081.1</td>
</tr>
<tr>
<td>K (g/kg)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>0</td>
<td>4.8</td>
<td>4.8</td>
<td>4.8</td>
<td>4.8</td>
<td>4.8</td>
<td>4.8</td>
<td>4.8</td>
</tr>
<tr>
<td>50</td>
<td>11.3</td>
<td>8.2</td>
<td>9.9</td>
<td>7.2</td>
<td>5.3</td>
<td>9.2</td>
<td>10.1</td>
</tr>
<tr>
<td>100</td>
<td>10.9</td>
<td>11.5</td>
<td>10.2</td>
<td>13.4</td>
<td>9.9</td>
<td>10.2</td>
<td>11.3</td>
</tr>
<tr>
<td>200</td>
<td>15.0</td>
<td>13.2</td>
<td>13.4</td>
<td>16.2</td>
<td>15.1</td>
<td>13.0</td>
<td>7.2</td>
</tr>
<tr>
<td>S (g/kg)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>0</td>
<td>1.32</td>
<td>1.32</td>
<td>1.32</td>
<td>1.32</td>
<td>1.32</td>
<td>1.32</td>
<td>1.32</td>
</tr>
<tr>
<td>50</td>
<td>1.64</td>
<td>1.37</td>
<td>1.68</td>
<td>1.56</td>
<td>1.30</td>
<td>1.30</td>
<td>1.69</td>
</tr>
<tr>
<td>100</td>
<td>1.35</td>
<td>1.45</td>
<td>1.69</td>
<td>1.59</td>
<td>1.71</td>
<td>1.47</td>
<td>1.48</td>
</tr>
<tr>
<td>200</td>
<td>0.97</td>
<td>1.52</td>
<td>1.70</td>
<td>1.94</td>
<td>1.94</td>
<td>1.58</td>
<td>1.25</td>
</tr>
</tbody>
</table>

CONCLUSIONS
This study demonstrated that polyhalite is an alternative source of K and S and can meet the nutritional requirements of alfalfa for healthy growth and production.

ACKNOWLEDGEMENTS
To the International Potash Institute - IPI, for the financial support for this research.

REFERENCES
Efficiency of Polyhalite as a sulfur source on wheat in Argentina

Magen, H.1, Melgar, J.R.2, Ventimiglia, L.3, Torrens, L.3, Vale, F.4

1International Potash Institute (IPI), Zug, Switzerland (ipi@ipipotash.org)
2INTA Pergamino, Av. Frondizi (Ruta 32) Km 4,5, Pergamino, Buenos Aires, Argentina (melgar.ricardo@inta.gob.ar)
3INTA 9 de Julio, Av. Bme. Mitre 857, 9 de Julio - Buenos Aires, Argentina (ventimiglia.luis@inta.gob.ar ; torrens.lisandro@inta.gob.ar).
4International Potash Institute (IPI), Latin American Coordinator, Piracicaba, Brazil (fabio.vale@ipipotash.org)

INTRODUCTION

Polyhalite is one of a number of evaporate minerals containing potassium (K). The content of impurities is low consisting almost entirely of sodium chloride at a maximum inclusion of 5%. Polyhalite (dehydrate) is a single crystal complex with two molecules of water of crystallization. It is not a mixture of salts. The chemical formula is: \( K_2Ca_2Mg(SO_4)_4 \cdot 2(H_2O) \).

Continuous cropping of sorghum Sudan grass under greenhouse conditions showed that Polyhalite was at least as effective, if not superior, to equivalent rates of soluble sources (sulphate of potash treatments) of K, calcium (Ca), magnesium (Mg) and sulphate (SO4-S) (Barbarick, 1989). One important characteristic of Polyhalite is the slow release and availability of nutrients, especially in relation to sulfur (S). Evaluation in soil columns at the University of Nottingham, UK, showed that 50-60% of S from Polyhalite was immediately available after application, with the other 40-50% released more slowly over time. (Jiang et al., 2016).

The objective of this research was to compare the agronomic efficiency of fertilizer bulk blends that include Polyhalite, on wheat production in Argentina, under field conditions.

METHODS

The site cropped to wheat was sown under no-till on June 16, 2016, with a Klein variety at a density of 278 seeds m\(^{-2}\). The main characteristic of the arable layer (0-20 cm) of the trial soils were: pH = 5.9; organic matter = 29 g kg\(^{-1}\); P-Bray = 9.8 mg kg\(^{-1}\); S-SO\(_4\) = 7.1 mg kg\(^{-1}\); K = 1.23 cmolc kg\(^{-1}\); Ca = 6.5 cmolc kg\(^{-1}\); Mg = 1.36 cmolc kg\(^{-1}\). The soil is of sandy loam texture, and organic matter and available S-SO\(_4\) levels indicates a potential for improved nutrient response.

The experiment was conducted in a randomized complete block design with four replications, and comprised six treatments based on different blends of monoammonium phosphate (MAP) plus sources of sulfur, in order to apply a single rate of P\(_2\)O\(_5\) (30 kg ha\(^{-1}\)) and variable rates of S (0 to 57 kg ha\(^{-1}\)) at sowing, according to Table 1. Fertilizers were applied in the seed line with a planter. At sowing, 167 kg of urea was applied broadcast. Nitrogen at 75 kg N ha\(^{-1}\) rate was applied as urea, prior to emergence on June 29, 2016.

Table 1. Different blends of monoammonium phosphate (MAP) plus sources of sulfur

<table>
<thead>
<tr>
<th>#</th>
<th>Treatments</th>
<th>Fertilizer N</th>
<th>P(_2)O(_5)</th>
<th>S</th>
<th>K(_2)O</th>
<th>CaO</th>
<th>MgO</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Check – MAP (No S)</td>
<td>58</td>
<td>6</td>
<td>30</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>2</td>
<td>Single Superphosphate (SSP)</td>
<td>158</td>
<td>0</td>
<td>30</td>
<td>19</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>3</td>
<td>MAP + Gypsum (34%/66%)</td>
<td>167</td>
<td>6</td>
<td>30</td>
<td>19</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>4</td>
<td>MAP+ Polyhalite (37%/63%)</td>
<td>158</td>
<td>6</td>
<td>30</td>
<td>19</td>
<td>14</td>
<td>17</td>
</tr>
<tr>
<td>5</td>
<td>MAP+ Polyhalite (22%/78%)</td>
<td>258</td>
<td>6</td>
<td>30</td>
<td>38</td>
<td>28</td>
<td>34</td>
</tr>
<tr>
<td>6</td>
<td>MAP+ Polyhalite (16%/84%)</td>
<td>358</td>
<td>6</td>
<td>30</td>
<td>57</td>
<td>42</td>
<td>51</td>
</tr>
</tbody>
</table>

Note: MAP: Monoammonium phosphate (11-52-0-0S); SSP: Single superphosphate (0-19-0-12S). Treatments 3-5 are bulk blends of MAP and granular gypsum (0-0-0-17S) and Polyhalite (0-0-14-19S -17CaO - 6MgO).
Grain was harvested mechanically on December 10, 2016, and samples of grains were taken for testing for commercial quality, which included hectoliter weight, protein and gluten content.

RESULTS AND DISCUSSION

Results of grain yield and quality parameters as hectoliter weight, protein and gluten content are shown in Table 2. The experiment was conducted in a typical field of the area, presenting very low nutritional values, especially in S which was shown to be deficient in soil tests before planting. Since all treatments had the same amount of N and P, the differences between treatments was attributed to S, K and/or Mg. The response to S was conclusive, as the soil test diagnosed prior to sowing, giving the statistical difference between the control and other treatments.

Regarding the protein level, which was positively correlated with gluten content, low values were obtained. The only treatment that reached the commercial standard was the control (11% protein), while the other treatments resulted in below 10%, which would lead to penalties. It is speculated that the applied N was not sufficient resulting in these poor protein content values. The reason for this situation was that the N level supplied was insufficient to produce yields near to 6 t/ha and achieve high protein values.

The hectoliter weight values are consistent with flour yield. The commercial standards to achieve the best grade is a value of 79 or higher. Although all treatments presented higher values than the commercial standard, treatments with gypsum and polyhalite as the sulfur source were better than single superphosphate (SSP).

Table 2. Grain yield and quality parameters in function of sources and rates of sulfur

<table>
<thead>
<tr>
<th>#</th>
<th>Treatments</th>
<th>Grain yield</th>
<th>Protein %</th>
<th>Hect. Wgt.</th>
<th>Gluten</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Check – MAP (No S)</td>
<td>4719 b</td>
<td>11,0 a</td>
<td>84,5 ab</td>
<td>26,7 a</td>
</tr>
<tr>
<td>2</td>
<td>Single Superphosphate (SSP)</td>
<td>5934 a</td>
<td>9,1 c</td>
<td>82,4 b</td>
<td>22,0 c</td>
</tr>
<tr>
<td>3</td>
<td>MAP + Gypsum (34%/66%)</td>
<td>6165 a</td>
<td>9,3 b</td>
<td>86,6 a</td>
<td>22,9 b</td>
</tr>
<tr>
<td>4</td>
<td>MAP+ Polyhalite (37%/63%)</td>
<td>5919 a</td>
<td>9,3 b</td>
<td>86,4 a</td>
<td>22,9 b</td>
</tr>
<tr>
<td>5</td>
<td>MAP+ Polyhalite (22%/78%)</td>
<td>6089 a</td>
<td>9,2 b</td>
<td>85,8 ab</td>
<td>22,5 bc</td>
</tr>
<tr>
<td>6</td>
<td>MAP+ Polyhalite (16%/84%)</td>
<td>6345 a</td>
<td>9,2 bc</td>
<td>87,6 a</td>
<td>22,1 c</td>
</tr>
</tbody>
</table>

p>F Treatment < 0.001 < 0.001 < 0.08 < 0.001
DLS% 474 0,15 3,58 0,73
CV % 5,4 1,1 2,8 2,1

CONCLUSIONS

The results highlight the importance of S in improving wheat yields. This nutrient should not be lacking in the productive approaches used in the region. According to the trial rates, 19 kg S /ha was sufficient to achieve a good response. Polyhalite is an efficient source for supplying sulfur for wheat fertilization in Argentina.

ACKNOWLEDGEMENTS

International Potash Institute for financing the project.

REFERENCES

Effects of Polysulphate application on the yield, quality and shelf life of green pepper in Hainan province, China

Guohua Li¹, Ming He¹, Eldad Sokolowski², Patricia Ima², Hillel Magen²

¹ ICL Fertilizers China, Rm. 908, Shanghai Times Square, No 93 Middle Huaihai Road, Shanghai, 2000021, China (Guohua.li@icl-group.com)
² ICL Fertilizers, Potash house, P.O.B 75, Beer Sheva, 8410001, Israel

INTRODUCTION
Green pepper is one of the most important cash crops in Hainan province, representing the prominence that China has gained in the tropical crop industry (Zu et al., 2014). The soil pH in approximately 50% of the typical pepper fields in Hainan province is below 5.5, falling below the suitable green pepper soil pH range of 5.5-7.0 (Yang et al., 2009). Green pepper grown on low pH soil often results in poor growth, nutrient deficiencies (K, Ca and Mg), low yield and poor quality (Zu et al., 2012).

Polyhalite, $K_2Ca_2Mg(SO_4)_4-2H_2O$ (George, 1931; Douglas, 1980; Luca, 2005), marketed as PolysulphateR by ICL Fertilizers, is a naturally occurring mineral which is certified as a organic fertilizer, containing 48% SO₃, 14% K₂O, 6% MgO and 17% CaO of which all are fully soluble. This new 4 in 1 fertilizer is abundant in Ca and Mg which makes it the ideal fertilizer for the tropical agricultural regions of China.

The objective of this study was to quantify the effects of Polysulphate on green pepper production in Hainan province including: yield, quality, and shelf life.

METHODS

Properties of Soil
The soil is a sandy loam with a pH value of 5.0. The basic physical properties of the soil were as follows: organic matter 14.12 g kg⁻¹, alkali-hydrolyzed nitrogen 96.45 mg/kg, available phosphorus ($P_2O_5$) 13.21 mg kg⁻¹, available potassium ($K_2O$) 65.12 mg kg⁻¹, exchangeable calcium 763.25 mg kg⁻¹, exchangeable magnesium 115.36 mg kg⁻¹.

Experimental Design
The field experiment was conducted on location at a farm in Wenchang city, Dongyang county, Hainan province. The experiment was laid out in a complete randomized block design with three replications. (1) Treatment 1: Farmer traditional practice (Control): 1125 kg ha⁻¹ of compound fertilizer (15-15-15) applied as base-fertilizer; topdressing of 375 kg ha⁻¹ of compound fertilizer at fruit stage; (2) Treatment 2: Farmer practice + 375 kg ha⁻¹ Polysulphate (T1); (3) Treatment 3: Farmer practice + 750 kg ha⁻¹ Polysulphate (T2); (4) Treatment 4: Farmer practice + 1125 kg ha⁻¹ Polysulphate (T3); (5) Treatment 5: Farmer practice + 1500 kg ha⁻¹ Polysulphate (T4).

The area of each plot was 20.0 m² (1.43 m × 14 m); plant and row spacing: 25 cm × 40 cm. Control of weeds, insects, and diseases were done according to the standard practice of the local prevention recommendations.

RESULTS AND DISCUSSION
The results showed that a high dose of Polysulphate (T2, T3 and T4) had significantly increased the weight and length per green pepper as well as the concentration of vitamin C. There was no significant difference in pepper diameter between the different treatments. Table 1 shows that there was no significant difference in the percentage of marketable pepper among all treatments after storage of 9 days. However, with the increase of storage time from 9 days to 15 or 20 days, a significant higher percentage of marketable pepper was achieved in treatments with application of Polysulphate as compared with the control. It is therefore concluded that the application of Polysulphate can improve the shelf life of green pepper.
Table 1. Comparison of marketable pepper percentage after harvest in different treatments

<table>
<thead>
<tr>
<th>Treatment</th>
<th>9 days of storage (%)</th>
<th>15 days of storage (%)</th>
<th>20 days of storage (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Control</td>
<td>96.28 a</td>
<td>65.67 a</td>
<td>34.61 a</td>
</tr>
<tr>
<td>T1</td>
<td>96.55 a</td>
<td>71.03 a</td>
<td>44.73 b</td>
</tr>
<tr>
<td>T2</td>
<td>97.25 a</td>
<td>73.12 b</td>
<td>43.26 b</td>
</tr>
<tr>
<td>T3</td>
<td>95.69 a</td>
<td>72.28 b</td>
<td>43.83 b</td>
</tr>
<tr>
<td>T4</td>
<td>98.12 a</td>
<td>74.56 b</td>
<td>44.16 b</td>
</tr>
</tbody>
</table>

The results shows that there was no significant difference in average yield per plot between control and T1 treatment, however, higher doses of Polysulphate (T2, T3 and T4) had significantly increased the yields of pepper. Comparing with control, the yields of green pepper with the application of Polysulphate had been increased by 9.12%, 15.87%, 23.75%, 23.95% in treatments of T2, T3 and T4, respectively.

Application of Polysulphate had increased the soil available K, Ca and Mg compared with control. Low pH in the soils of Hainan province may have directly inhibited pepper roots’ development and function, which resulted in a limited absorption of K, Ca and Mg from soil (Zu et al., 2014). The abundant and prolonged availability of nutrients in Polysulphate, especially for Ca and Mg, had played a key role in improving soil available nutrients to the pepper plant, consequently increasing the yields and quality of green pepper. Furthermore the sufficient uptake of Ca by pepper in treatments with the application of Polysulphate may have increased the skin thickness of the peppers, leading to a higher marketable percentage and a longer shelf life.

CONCLUSIONS
1. Application of Polysulphate in Hainan province can improve the yields and quality of green pepper.
2. Application of Polysulphate can significantly increase the shelf life of green pepper.
3. Application of Polysulphate can improve the availability of nutrients in the soil, especially for K, Ca and Mg, that in turn improves the fertility of acidic soil.

REFERENCES
George, F.R., (1931) Recovery of potassium sulphate from polyhalite. US Patent 1,812,497
Luca Bindi. (2005) Reinvestigation of polyhalite, K₃Ca₂Mg(SO₄)₄·2H₂O. Acta Cryst, E61, i135–i136