Research Findings

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Polyhalite - A Multi-Nutrient Fertilizer Preventing Ca and Mg Deficiencies in Greenhouse Tomatoes under Desalinized Irrigation Water

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Abstract

Greenhouse tomatoes (*Lycopersicon esculentum* Mill.) represent a highly sophisticated agriculture in which all plant requirements are accurately fulfilled and optimized in order to maximize yields and benefits to farmers. This includes balanced mineral nutrition applied through fertigation. Desalinated irrigation water lacks essential nutrients such as sulfur (S), calcium (Ca) and magnesium (Mg), and the incorporation of these to composite fertilizers used for fertigation is costly and, in some cases, impractical. Excess nitrogen (N) application, which often occurs as a result of organic manure supplementation, might reduce produce quality and is known to have serious ecological consequences. Polyhalite, a new mineral fertilizer consisting of S, potassium (K), Mg and Ca, offers an opportunity for pre-planting soil amendment and provides prolonged availability of these nutrients during the whole season. A case study was conducted to examine the effect of polyhalite

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at four levels: 0, 1, 1.5, and 2 Mg ha^{-1}, on the performance of on-farm greenhouse tomatoes. Polyhalite prevented Ca and Mg deficiency symptoms that occurred in the control, boosted plant vigor and increased the warm-season's marketable yield by 5-7%. Polyhalite can fully replace all other Ca and Mg liquid fertilizers. It can also provide 33% of the K dose, as well as N-free Mg, thus reducing K-Mg competition and avoiding surplus N nutrition. Given the primality of the present case study and the advantages observed, polyhalite appears as a considerable alternative to other fertilizers. Further research is required in order to combine an optimized polyhalite application with other fertilizer inputs in greenhouse tomatoes.

Keywords: Blossom-end rot; excess nitrogen; fertigation; *Lycopersicon esculentum* Mill.; polyhalite; potassium; sulfur.

Introduction

In recent decades, the trend to produce fresh table tomatoes in greenhouses has steadily increased, resulting in greenhouse tomatoes becoming dominant in many vegetable markets around the world. Greenhouse tomato production has many advantages: it enables out-of-season production, thus extending supplier presence on the market shelves; it provides efficient plant protection, where open-field tomatoes are prone to harmful virus diseases distributed by insects; and productivity can be very high, reaching 18, 35, and even 50 kg m^{-2} $year^{-1}$, in China (Qiu *et al.*, 2013), Israel, and in the Netherlands (FAO, 2014), respectively.

However, these high productivity levels necessitate corresponding fertilizer inputs (Jiang *et al.*, 2015). Thus, the application of high doses of chemical fertilizers, particularly nitrogen (N), is quite common practice among farmers to ensure high yields. For example, the seasonal average N input from chemical fertilizer increased during 1994-2004 in Shouguang, China, from 817 to 1,178 kg N ha^{-1}, three to five times more than plant requirements (Song *et al.*, 2012). Consequently, N recovery efficiency in such systems drops to below 15%, indicating that most applied chemical fertilizer is either washed out of the root zone or lost to the atmosphere and groundwater by different pathways (Min *et al.*, 2012).

Soil organic matter is one of the important soil components, and has a significant role in greenhouse vegetable production. It is widely believed that soil quality declines when soil organic carbon (OC) is below 20% (Loveland and Webb, 2003). Intensive use, high temperature and humidity accelerate the mineralization of soil organic matter, reducing soil OC (Grandy and Robertson, 2007). Composted animal manure is widely used for soil amendment. On loose soils, it significantly improves soil structure and water retention and assists the build-up of soil nutrient reserves (Xin *et al.*, 2016). Manure application can restore soil microbial community diversity and improve the rhizosphere microenvironment (Zhen *et al.*, 2014). Furthermore, poultry manure has shown significant ability to decrease parasitic nematode problems (Thoden *et al.*, 2011).

Appropriate irrigation management is essential for maximizing crop yield, fertilizer and water use efficiency for vegetable production. Drip irrigation combined with optimized fertilization can accurately control the timing and amount of irrigation and reduce fertilizer losses (Tanaskovik *et al.*, 2011; Fan *et al.*, 2014). The use of composite liquid fertilizers enables, in most cases, the matching of temporal application to current demands of most mineral nutrients. Nevertheless, reliance on fertigation requires special consideration of the irrigation water quality in terms of electrical conductivity (EC) as a measure of salinity, water pH, and the presence of essential mineral nutrients. In recent years, desalinated sea water has been a primary source for irrigation water in many regions in Israel. This water lacks mineral nutrients, particularly calcium (Ca), magnesium (Mg), and sulfur (S) that are essential for plant growth and development.

Magnesium deficiency impairs plant hormonal balance, interrupting signal transduction and causing sugar accumulation in productive leaves that consequently reduces photosynthesis through a negative feedback inhibition (Gransee and Führs, 2013; Verbruggen and Hermans, 2013). Sulfur (S) is recognized as the fourth major plant nutrient after N, phosphorus (P), and potassium (K) (Khan *et al.*, 2005) and has been associated with high productivity (Zhao *et al.*, 1999; Saito, 2004; Kovar and Grant, 2011). Sulfur is essential for protein synthesis so often interacts with N to significantly enhance crop productivity (Jamal *et al.*, 2010). *Solanaceae* crop species, including sensitive tomato cultivars, may express typical Ca deficiency symptoms such as yellowish leaves and increasing rates of fruit blossom-end rot (BER) (Fig. 1) with a consequent reduction in marketable yields (Gleason and Edmunds, 2005; Ho and White, 2005; Mestre *et al.*, 2012). Due to considerable differences in solubility, interactions with other solutes or high cost, application methods other than fertigation may be considered for Ca, Mg, and S.

Polyhalite, a new mineral fertilizer (Polysulphate™), mined in the UK from deep underground. It contains four important plant nutrients: S (SO_3, 48%), K (K_2O, 14%), Mg (MgO, 6%), and Ca (CaO, 17%), marketed in powder or granular form. It is suitable for a broad range of crops including open-field and greenhouse vegetables. Polyhalite has a low environmental impact as its production processes involve only mining, grinding, screening and packaging. Polyhalite, as Polysulphate, has been authorized for organic agriculture and is available in an increasing number of countries such as Brazil, Canada, China, France, Germany, Italy, the Netherlands, UK and the USA. Polyhalite gains special importance where Ca, Mg, and S are available at levels lower than the minimum threshold securing normal crop development. The

Fig. 1. Blossom-end rot (BER) in tomato - a typical physiological disorder resulting from Ca deficiency. Photo by A. Bustan. 2009.

fertilizer is available to plant roots as it is easily, though steadily, dissolved into the soil solution upon irrigation. Polyhalite provides S in the form of sulphate, which is available to plants without any need for breakdown by microorganisms. However, the fertilizer is not suitable for fertigation, so in this case study it is applied as a pre-planting fertilizer.

Modern intensive agriculture offers farmers a wide range of practices and opportunities to increase production and benefits. Nevertheless, employing this arsenal is often quite complex and requires flexibility/responsiveness to changing circumstances. The optimization of mineral nutrition during the cropping season is particularly sensitive to local soil fertility, fertilizer choice and application regime, as well as irrigation water quality. In the case study presented, the potency of polyhalite applied as a pre-planting fertilizer to prevent typical Ca and Mg deficiencies and to ensure considerable yield and produce quality was examined in the context of farmer's practice in winter season (September to June) greenhouse tomatoes in Israel.

Materials and methods

The observation was carried out in a farmer's greenhouse on light to medium sandy loam soil (cation exchange capacity [CEC] - 15 meq 100 g^{-1} soil) in Beit-Ezra, located in the coastal plain of Israel. The greenhouse size was 0.8 ha with 0.25 ha used for the trial. The soil was solarized before and during eight weeks after a chemical disinfection (Dichloropropene and Metam sodium, 200 and 400 L ha^{-1}, respectively, with 40 mm of irrigated water) took place. A pre-planting organic fertilizer (40 m^3 ha^{-1} chicken manure [250 kg m^{-3}, 85% dry weight] containing 3.0, 1.4, 2.1, 1.2, 0.3, and 0.3% of N [organic form], P, K, Ca, Mg, and S, respectively) was applied to the entire area to prevent nematodes. Before planting, the soil was irrigated with 70 mm water. Polyhalite fertilizer was spread and embedded along the planting rows according to treatments (Table 1).

Cluster tomato (cv. Ikram, Zeraim Gedera Syngenta, Ltd., grafted on Arnold rootstock) seedlings were planted on 11 Sep 2016, at a density of 22,000 branches ha^{-1}. Desalinated water (650 mm during the season, with an EC_w range of 0.35-0.45 dS m^{-1}, and with Ca, Mg, and Cl concentrations of 35-40, 1-5, and 45 ppm, respectively) was used for irrigation. Liquid fertilizer Sarit Super 5-2-7+0.5+6 (N-P-K + microelements) were applied through fertigation at about 1.5 L m^{-3}.

The observation included four treatments: control - where no additional polyhalite was applied; PS_1, PS_2, and PS_3, where 1,000, 1,500, and 2,000 kg polyhalite ha^{-1}, respectively, was applied pre-planting (Table 1).

The plants were monitored visually. Plant vigor was evaluated by measurements of stem diameter below the uppermost inflorescence. Soil and diagnostic leaves were sampled and analyzed for nutrient content every two months. Marketable fruit yield was weighed and summarized weekly.

Results

Plant establishment and growth were normal. However, symptoms of Mg

Table 1. Nutrient supply vs. anticipated requirements of greenhouse tomatoes under four polyhalite treatments: PS_0 (Control), PS_1, PS_2, and PS_3.

Treatment		Nutrient				
		N	P_2O_5	K_2O	CaO	MgO
		kg ha^{-1}				
	Fertigated nutrients	580	100	720	350	70
	Basal application (chicken manure)	255	119	178.5	102	25.5
PS_0 (Control)	Polyhalite 0 kg ha^{-1}	835	219	898.5	452	95.5
PS_1	Polyhalite 1,000 kg ha^{-1}	835	219	1,038.5	622	155.5
PS_2	Polyhalite 1,500 kg ha^{-1}	835	219	1,108.5	707	185.5
PS_3	Polyhalite 2,000 kg ha^{-1}	835	219	1,178.5	792	215.5
	Calculated crop nutrient requirements	550	110	660	350	110
	Primary excess nutrient supply (in PS_0)	285	109	238.5	102	-14.5

deficiency, expressed as typical yellowing of lower leaves, occurred in the control plants as early as mid-November, two months after planting. Plants applied with polyhalite remained green, healthy, and properly functioning (Fig. 2). Minor Mg deficiency symptoms were also observed among plants fertilized with polyhalite at the beginning of harvest in mid-December 2016. In February, after the regular practice of intensive removal of old leaves had taken place, the symptoms disappeared completely among polyhalite treatments, while only slight signs could be observed in control plants. Clear Mg deficiency symptoms returned in the lower leaves of control plants as the weather warmed up during the spring, whereas similar signs were absent among the polyhalite plants.

At the end of May, the polyhalite plants seemed more vigorous than the control plants. Measurements of the stem diameter below the uppermost inflorescence showed that control stems were significantly thinner than those of polyhalite plants (Fig. 3).

Harvest began on 5 Dec 2016 when early fruit clusters were ripe. During the winter months, no differences between treatments were observed, and the accumulating yields averaged 130 Mg ha^{-1} at the end of March 2017. Nevertheless, from April to the end of the season on 18 June 2017, the marketable control yield was consistently lower than those of the polyhalite treatments (Fig. 4). At the end of the season, the marketable yields of the polyhalite treatments were higher than the control yield by 5-7% (Table 2). This advantage was obtained due to the reduced rates of fruit malformation and BER in the polyhalite treatments.

Soil analyses conducted during the season showed a considerable increase in Ca, Mg, K, and S, in accordance with polyhalite applications (Fig. 5). High soil sulphate levels did not affect soil pH, which was stable at 7.4 throughout the experiment in all treatments. While Ca levels remained at the optimum range, Mg and K concentrations were too high. Also, the proportions of Mg and K in the CEC were higher than the optimum (data not shown). Potassium availability was high among all treatments throughout the growing season. Soil levels of all nutrients were

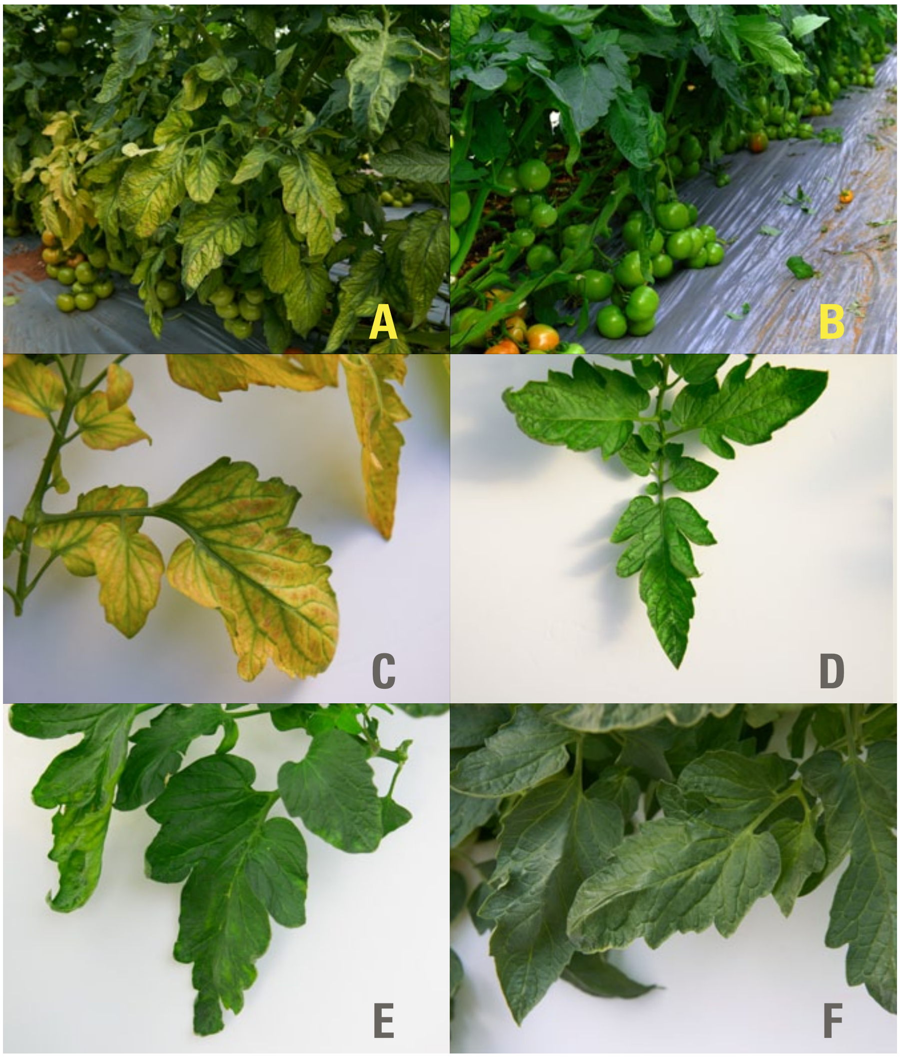

Fig. 2. Magnesium deficiency symptoms in tomato leaves, as noticed on 11 Jan 2017. A, Control plants; B, PS_2 (polyhalite at 1,500 kg ha^{-1}) plants; C, D, E, and F, representative leaves sampled from Control (PS_0), PS_1, PS_2, and PS_3 plants, respectively.

Table 2. Effects of pre-planting polyhalite application on yield distribution between winter and spring periods.

	Pre-planting polyhalite rate (kg ha^{-1})			
	0	1,000	1,500	2,000
Harvest period	Accumulating marketable yield (Mg ha^{-1})			
December - March	129	133	128	133
April - June	88	97	103	95
December - June (total)	217	230	231	228

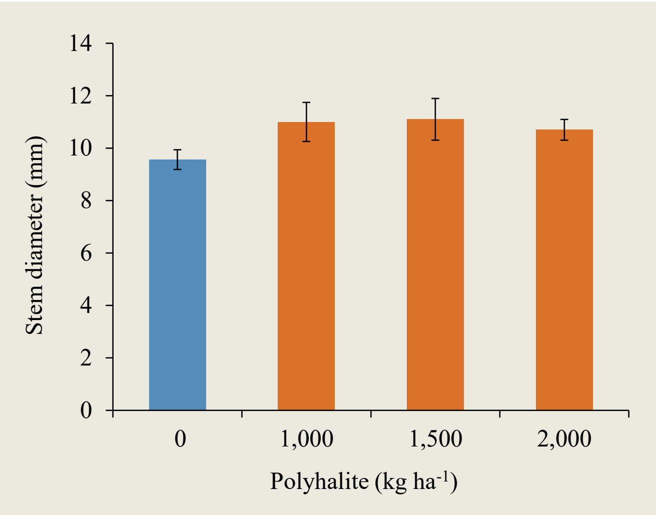

Fig. 3. Tomato stem diameter below the uppermost inflorescence on 23 May 2017 as influenced by pre-planting application of polyhalite.

high in September, decreased in November, rose again during January, and steeply declined in June (excluding P), manifesting the seasonal dynamics of crop nutrient uptake. Interestingly, Mg leaf content was lower than the optimum among all treatments throughout the growing season, while all other nutrients were within the sufficiency range.

Discussion

When optimum mineral nutrition is considered, two goals should be reached: 1. supplying adequate levels of available nutrients throughout the growing season; and, 2. maintenance of balanced cation saturation ratios in the soil solution. Winter greenhouse tomatoes require no less than 550, 110, 660, 350, and 110 kg ha^{-1} of N, P, K_2O, CaO, and MgO, respectively, in order to produce a yield of about 350 Mg ha^{-1}. In the present study, the crop was sufficiently supplied with N, P, K, and Ca through fertigation alone throughout the growing season (Table 1). The basal application of chicken manure, which aimed to reduce nematode problems, significantly increased all nutrient doses far beyond requirements, however, its real contribution to crop nutrition was unclear. Even though, pre-planting polyhalite application prevented visually determined Mg deficiencies that usually occur during rapid growth periods of greenhouse Ikram cluster tomatoes. Polyhalite application promoted plant vigor, as expressed in stem diameter (Fig. 3), and brought about a 5-7% increase in marketable yield (Fig. 4). On the other hand, the excess soil nutrient levels, particularly of K, might have interrupted Mg uptake due to the imbalanced ratio between those cations in the CEC fraction (data not shown).

Excluding the waste of resources associated with excess N supply, it has additional significant adverse consequences. Excess N supply interrupts the C/N balance in the plant, promoting excess vegetative growth at the expense of reproductive organs. Excess N also reduces fruit firmness, Brix, nutritional value, and storability (Bénard *et al.*, 2009). Furthermore, tomato plants grown under excess N levels are more susceptible to physiological disorders such as BER (Gleason and Edmunds, 2005) and to leaf-miner pests (Han *et al.*, 2014). Much effort is being made in Israel and worldwide to halt and prevent the harmful ecological consequences of excess fertilization on water and soil resources (Min *et al.*, 2012; Jiang *et al.*, 2015).

Potassium availability is essential throughout the season, particularly for greenhouse tomatoes, where indeterminate cultivars are employed and the reproductive phase prevails during most of the crop cycle. High K availability may reinforce crop

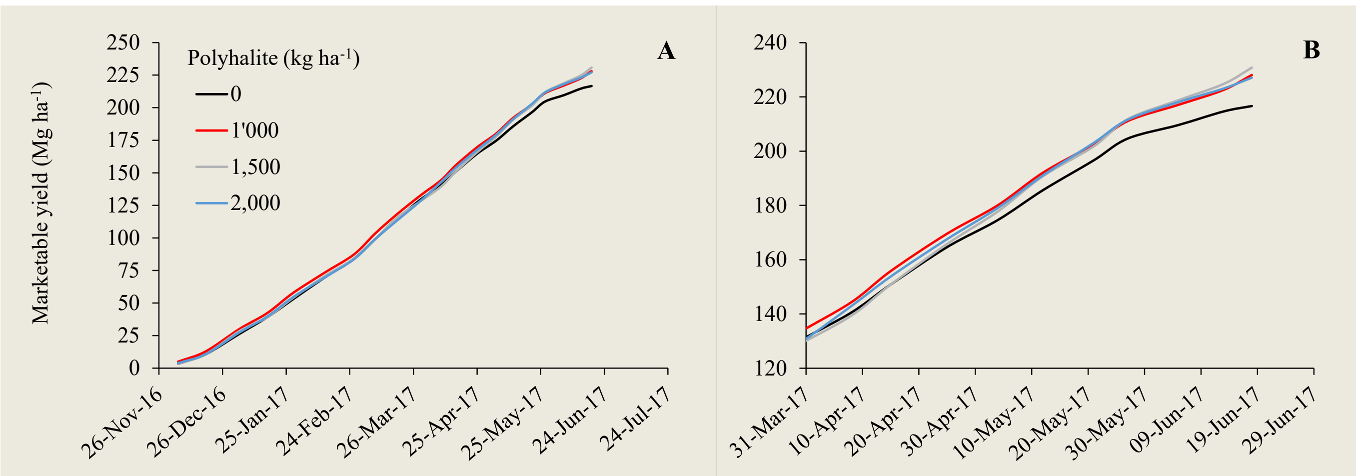

Fig. 4. Effects of pre-planting polyhalite application on the accumulating marketable yield of Ikram greenhouse tomatoes throughout the season (A), and during spring (B) (from April to June).

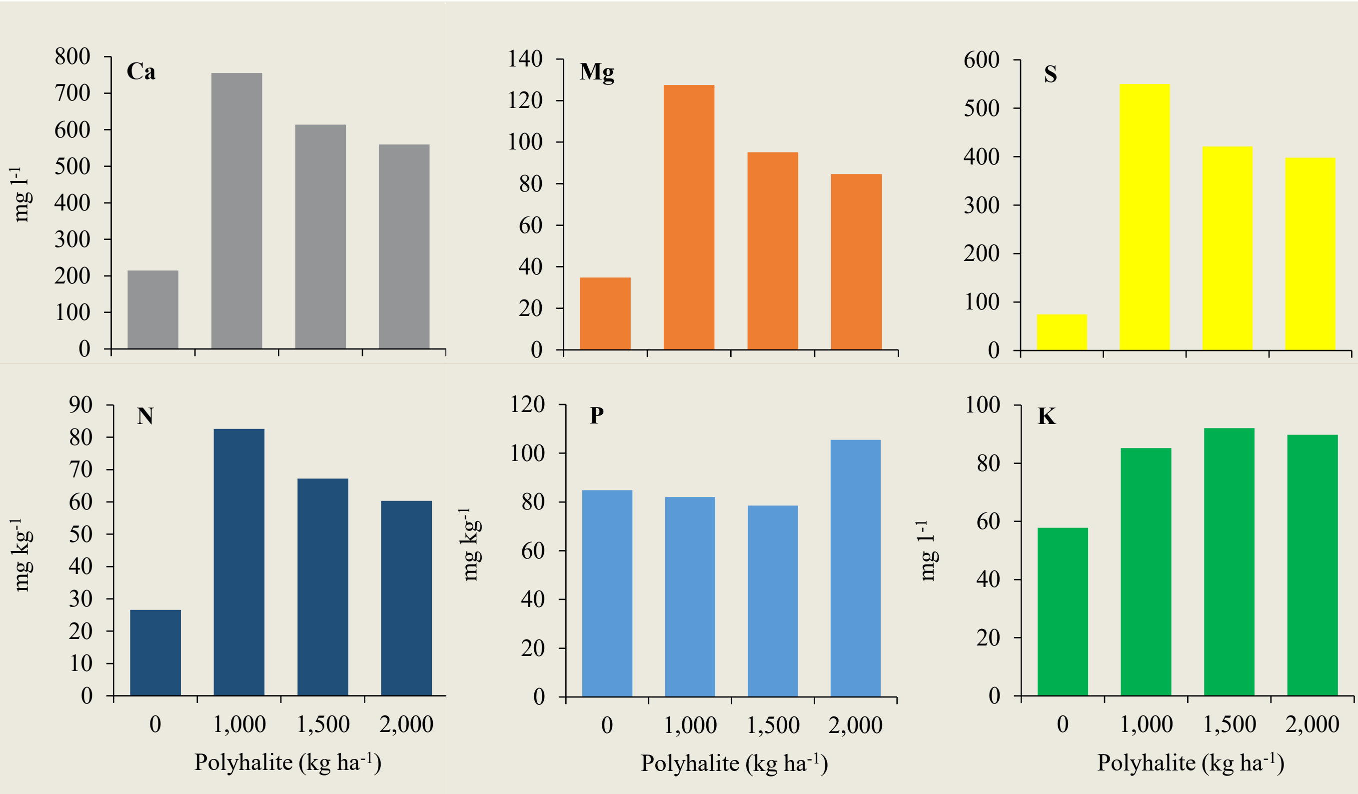

Fig. 5. Soil content of N, P (mg kg^{-1}), and K, Ca, Mg, and S (mg 1^{-1}) on 16 Feb 2017; five months after planting.

resistance to high temperature and drought stresses (Wang *et al.*, 2013) that often occur during the transition seasons in the Middle East. However, K is commonly accompanied by chloride (KCl), which above a certain low optimum range, might have adverse effects on tomato yield and quality (Komosa and Górniak, 2015). Alternatively, K can be applied with nitrate, avoiding excess chloride uptake, although this solution is less useful when reduced N uptake is desired. Thus, a constant in-soil source of prolonged release K would be an ideal choice. In fact, applying the required Ca and Mg via fertigation is costly, hence, these two nutrients should preferably be applied directly to the soil.

The opportunity of replacing large amounts of costly liquid fertilizer with a basal application of polyhalite is very promising. It enables the application of Ca and Mg at the pre-planting stage, with no need for additional application during the growing season. This is especially important where the irrigation water lacks these essential nutrients. Polyhalite can provide 33% of the K dose, as well as N-free Mg, thus reducing K-Mg competition and avoiding surplus N nutrition. Given the primality of the present case study and the advantages observed in yield and produce quality during the warmer phase of the growing season, polyhalite appears as a considerable alternative to other fertilizers. Further research is required in order to combine an optimized polyhalite application with other fertilizer inputs in greenhouse tomatoes and hence enhance the benefits to the grower.

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