Trial Focus

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Salt Index (SI) of Polyhalite

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Abstract

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

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

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Introduction

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

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

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

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

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

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

Adopted from: Murray and Clapp, 2004.

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

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

Materials and methods

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

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

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

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

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

Results

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

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

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

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

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

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

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

Discussion

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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