Research Findings

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Effect of Different Potassium and Sulfur Fertilizers on Onion (*Allium cepa* L.) Yield and Quality

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Abstract

Onion (*Allium cepa* L.) is the most widely cultivated species of the genus Allium. It is rich in many essential nutrients and sulfur (S)-containing compounds considered important for human health. While potassium's (K) role in plant nutrition is well established, K fertilization practices still suffer from low agronomic efficiency. Recently, crop S requirements have gained special attention, particularly in Allium species. Polyhalite is a sedimentary marine mineral, consisting of a hydrated sulfate of K, calcium (Ca) and magnesium (Mg) at rates of 14, 48, 6, and 17% of K_2O, SO_3, MgO, and CaO, respectively. The objective of this study was to compare the effects of polyhalite, potassium sulphate (SOP), and potassium chloride (MOP) fertilizers on onion bulb yield, nutrient uptake, and on bulb quality properties. An equal dose of 270 kg K_2O ha^{-1} was applied as MOP, SOP, polyhalite, and a mixture of polyhalite and SOP, and these were compared against a control which applied nitrogen (N) and phosphorus (P) fertilizers.

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While MOP increased bulb size and yield by 28%, S fertilizers contributed additional yield increases ranging from 12 to 22% compared to the control. The major effect of all of the fertilizers was that they improved K availability during the onion crop cycle. Polyhalite application resulted in the highest yield, probably due to its slow-release character, providing constant soil K availability throughout the crop cycle. High rates of S application did not correlate with high yield or quality. While polyhalite's advantageous agronomic efficiency was obvious, suitable rates of application remain subject to economic considerations.

Keywords: Allium cepa L.; bioactive compounds; MOP; nutrient uptake; organosulfur compounds; polyhalite; SOP.

Introduction

Onion (*Allium cepa* L.), the most widely cultivated vegetable species of the genus Allium, is pivotal to many cuisines worldwide. About 170 countries cultivate onions for domestic use or trade. In 2016, the global area cultivated with onion was about 5 million ha, which produced 93 million Mg, with a calculated average yield of 18 Mg ha^{-1} (FAOSTAT, 2016). Among the world's greatest onion producers, China, India, and the US are the leading countries, while Turkey is the sixth with production of 2.1 million Mg and an average yield of 32 Mg ha^{-1}.

Onion is often consumed raw, but it is predominantly used to add a unique and highly appreciated flavor to cooked food, as well as its closely related species – garlic and leek (Block, 1995). Onion bulbs contain 89% water but are rich in many essential nutrients and compounds like biotin, vitamin C, quercetin, and antioxidants (Koca *et al.*, 2015; Insani *et al.*, 2016; Lisanti *et al.*, 2016). Nevertheless, sulfur (S)-containing compounds found in the Allium family have been the focus of much research interest during the last few decades (Randle *et al.*, 1995; Ramirez *et al.*, 2017). Recently, more attention has been given to the health attributes associated with onion consumption, which include diabetes prevention, skin health, an improved immune system, lowering of blood pressure and cholesterols, anti-inflammatory disease activity, stress relief, and anti-cancer properties (Nicastro *et al.*, 2015; Suleria *et al.*, 2015; Fujiwara *et al.*, 2016; Insani *et al.*, 2016; Chu *et al.*, 2017).

While the pivotal role of potassium (K) in plant nutrition and crop development and yield is well-established (Marschner, 1995), the agronomic efficiency of K fertilizer application is very low in many crops and countries (Zörb *et al.*, 2014). To resolve this problem, the ability of farmers to accurately select the appropriate fertilizer and deliver the required K dose at the proper time during the crop cycle, must be improved. Excess K application at an early crop developmental stage followed by K deficiency at later stages is a recurrent problem worldwide, due to the common practice of full-dose pre-planting application.

Plant sulfur requirements have gained special attention in the last few decades due to the dramatic reduction in atmospheric S-pollutants that caused S deficiency symptoms in many crop species (Haneklaus *et al.*, 2006). Sulfur is essential to protein production in all plant species (Brosnan and Brosnan, 2006). In crop species producing appreciated secondary metabolites containing S, such as Brassicaceae and Allium, achieving optimal S application is particularly important (McGrath and Zhao, 1996; Lancaster *et al.*, 2001; Al-Fraihat, 2009; Garg *et al.*, 2018). Sulfur is available to plants only as sulfate (Haneklaus *et al.*, 2006), hence most S fertilizers consist of sulfate salts, such as gypsum ($CaSO_4{\cdot}2H_2O$), sulfate of potassium (SOP, K_2SO_4), ammonium sulfate, or various phosphor-sulfates.

Polysulphate™ (produced by Cleveland Potash Ltd., UK) is the trade mark of the natural mineral 'polyhalite', which occurs in sedimentary marine evaporates, consisting of a hydrated sulfate of K, calcium (Ca) and magnesium (Mg) with the formula: $K_2Ca_2Mg(SO_4)_4{\cdot}2(H_2O)$. The deposits found in Yorkshire, in the UK, typically consist of K_2O: 14%, SO_3: 48%, MgO: 6%, CaO: 17%. As a fertilizer providing four key plant nutrients – S, K, Mg, and Ca – polyhalite may offer attractive solutions to crop nutrition. In addition, polyhalite releases the nutrients considerably slower than other S-containing fertilizers, which may also be significant for soil K availability.

The objective of this study was to compare the effects of polyhalite, potassium sulphate (SOP), and potassium chloride (KCl, MOP) fertilizers on onion bulb yield, nutrient uptake, and on bulb quality properties.

Materials and methods

The experiment was carried out in the Antalya region of Turkey (Map 1) on slightly alkaline, K-poor sandy-loam soil (Table 1).

Photo 2. Experimental onion field under preparation. Photo by the authors.

Map. 1. The experiment site in Antalya, Turkey. *Source:* Google Maps.

Table 1. Physical and chemical properties of the experimental soil.

Soil property		
pH (1:2.5)	8.2	Slightly alkaline
$CaCO_3$ (%)	19.9	High
EC (micromhos cm^{-1}) (25°C)	89	No salinity
Sand (%)	61	
Clay (%)	11	Sandy loam
Silt (%)	28	
Organic matter (%)	2.1	Medium
Phosphorus (mg kg^{-1})	5	Poor
Potassium (mg kg^{-1})	58	Poor
Calcium (mg kg^{-1})	2,631	Medium
Magnesium (mg kg^{-1})	102	Medium
Iron (mg kg^{-1})	7.6	High
Manganese (mg kg^{-1})	5.8	Sufficient
Zinc (mg kg^{-1})	0.2	Insufficient
Copper (mg kg^{-1})	0.8	Sufficient

Onion was sown in a nursery early in September 2016, transplanted on 1 November, and harvested as bulbs on 24 May 2017. Irrigation was practiced when necessary and all the other agricultural practices were carried out on time. Nitrogen (N)-phosphorus (P)-K fertilization was carried out pre-planting according to soil nutrient status (Table 1) and onion crop requirements for a target yield, as follows: 200 kg N ha^{-1}, 170 kg P_2O_5 ha^{-1}, and 270 kg K_2O ha^{-1}. Di ammonium phosphate (DAP) and urea were supplied as N and P fertilizers, while MOP (KCl), SOP (K_2SO_4), or polyhalite were examined as the K donors. Sulfur was provided through SOP or polyhalite, in accordance with the treatments. A detailed description of the five treatments included in the experiment is given in Table 2.

The experiment layout was a randomized block design with four replications. Just prior to bulb initiation, the recommended leaf sampling time for onion, leaf macronutrients (N, P, K, Ca, Mg and S [%]) and essential micronutrients (iron [Fe], zinc [Zn], manganese [Mn], and copper [Cu] [mg kg^{-1}]) were determined. At harvest, measurements including bulb yield (kg ha^{-1}), bulb weight (g), and economic evaluation were taken. Total soluble solids (TSS, %), total phenol (mg kg^{-1}), vitamin C (mg 100 g^{-1}), and antioxidant activity (%) were determined as onion quality indicators.

Following harvest, plant macro- and essential micronutrient concentrations were determined according to Mills and Jones (1996) and crop nutrient uptake was calculated. The effects of different fertilizers on the above given parameters were statistically analyzed using ANOVA. The correlations between essential plant nutrients at bulb initiation and quality parameters were determined.

Results

Fertilizer treatments significantly affected bulb size (Fig. 1A). Polyhalite, when applied as the only K donor, brought about the largest mean bulb size, 359 g. Bulb weight under SOP was insignificantly smaller, and declined further under the mixed SOP + polyhalite treatment. KCl (MOP) treatment gave rise to a considerably smaller average bulb size, 309 g, which was still significantly larger than that of the control. Since planting density was similar in all treatments, bulb size had a clear consequent effect on the yield (Fig. 1B) with the same order: polyhalite > SOP + polyhalite > KCl > Control, while under SOP yield did not differ significantly from that of polyhalite or the combined fertilizers treatment.

Table 2. A detailed description of the five fertilization treatments employed.

Treatment	N	P_2O_5	K_2O	S	Notes
	--------------*kg ha^{-1}*--------------				
Control	200	170	0	0	
KCl (MOP)	200	170	270	0	443 kg MOP ha^{-1}
K_2SO_4 (SOP)	200	170	270	97	540 kg SOP ha^{-1}
Polyhalite	200	170	270	370	1,928 kg polyhalite ha^{-1}
K_2SO_4 + polyhalite (1:1)	200	170	270	234	270 + 964, kg ha^{-1} of SOP + polyhalite, respectively

Bulb quality properties were also significantly influenced by the fertilizer treatments (Fig. 2). SOP and polyhalite - each fertilizer applied on its own - had the highest TSS values, 7.80-7.95%, and

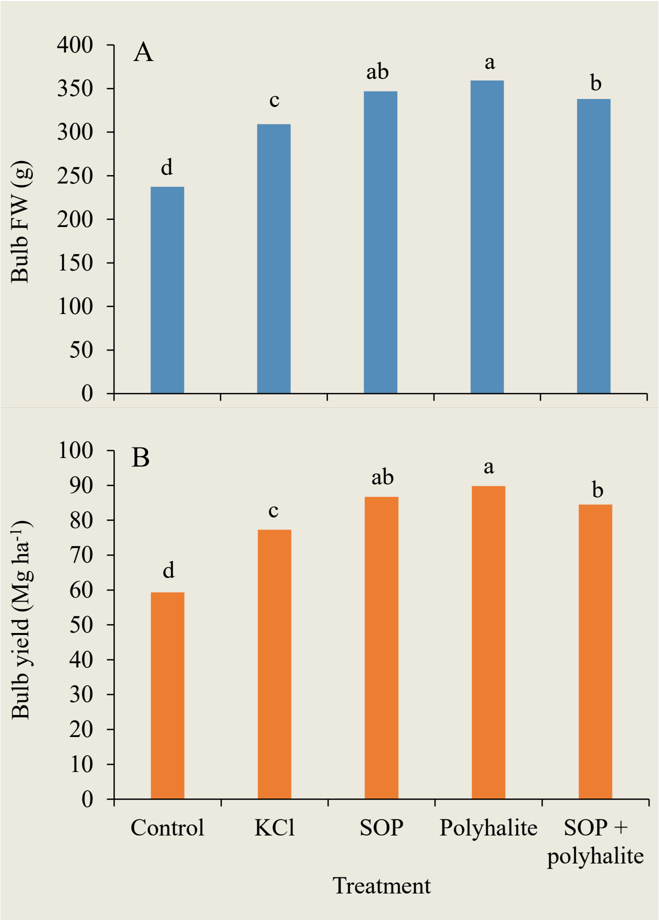

Fig. 1. Effects of different K and S fertilizers on onion bulb fresh weight (A) and on onion yield (B). Similar letters indicate no significant differences at $P < 0.01$.

Photo 3. Effect of different potassium fertilizers on onion plants. Photo by the authors.

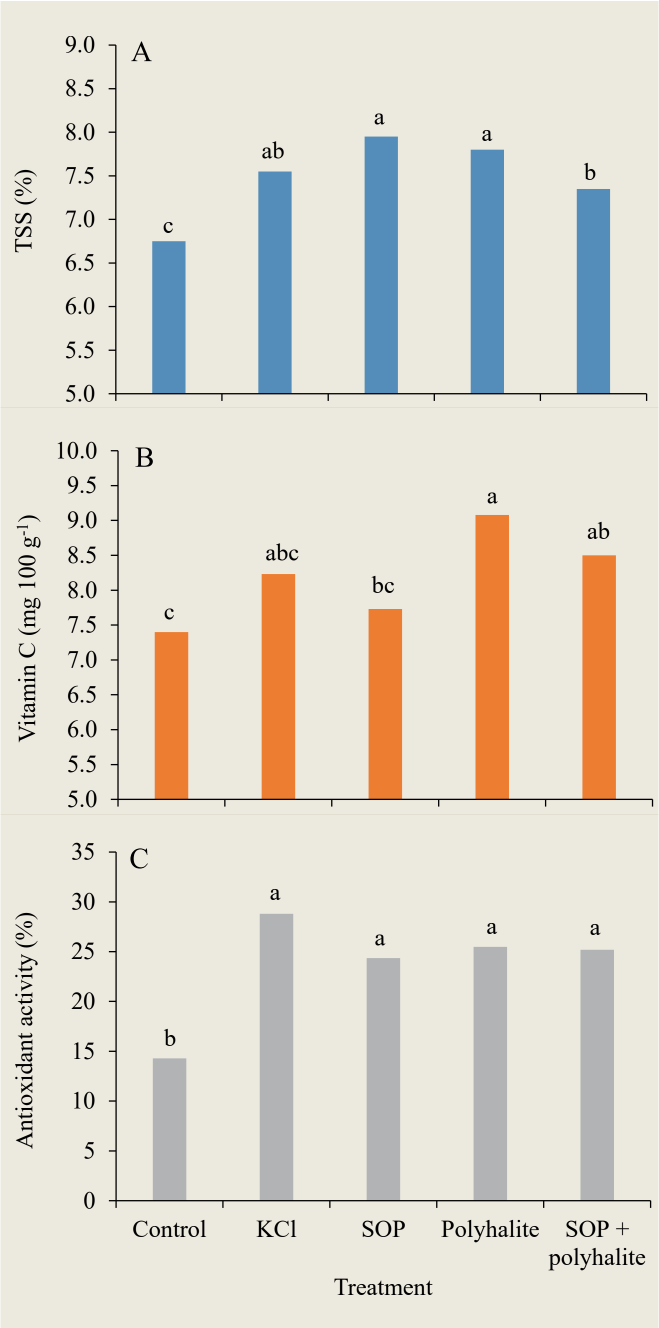

Fig. 2. Effects of different K and S fertilizers on onion bulb TSS (A), vitamin C content (B), and antioxidant activity (C). Similar letters indicate no significant differences at $P < 0.01$ for TSS and antioxidant activity, and at $P < 0.05$ for vitamin C content.

were significantly higher than in the combined treatment and far better than that of the control. KCl had an intermediate TSS, significantly higher than the control, but statistically it could not be distinguished from the other treatments (Fig. 2A). Total phenols content ranged from 160 to 190 mg kg^{-1} bulbs and was unaffected by the fertilizers. Vitamin C, on the contrary, displayed the highest content in bulbs grown under polyhalite, 9.08 mg 100 g^{-1}, significantly higher than SOP and the control, but was not significantly different from the bulb vitamin C contents under KCl or mixed SOP + polyhalite (Fig. 2B).

Antioxidant activity in the bulbs was significantly lower in the control, 14.3%, and ranged from 24 to 29% among the other treatments, displaying no significant differences (Fig. 2C).

Leaf K content prior to bulb initiation was significantly higher in the four treatments supplied with K fertilizers, compared to the control (Table 3). Among these treatments, leaf K content in the mixed SOP and polyhalite applications was significantly higher than in KCl-supplied plants, while those of SOP or polyhalite alone had intermediate values. Leaf S content just prior to bulb initiation was significantly higher in plants supplied with S fertilizers, compared to KCl-supplied plants or the control. Interestingly, the latter treatments also differed significantly in leaf S content, although both were not supplied with S fertilizers (Table 3). Leaf content of the other macro- and micronutrients were unaffected by the fertilizer treatments. Phosphorus and Ca among the macronutrients, and Zn, Mn, and Cu among the micronutrients were above the values recommended by Maynard and Hochmuth (1996).

At harvest, bulb macronutrient concentrations, excluding Ca and Mg, differed significantly between treatments (Table 4). Bulb N concentrations were higher under MOP or SOP and declined in the other treatments, but although being significant, these differences were limited to a narrow range, 2-2.3%. Bulb P concentrations were considerably higher, ranging from 0.6 to 0.7%, with slight yet significant differences between treatments. Bulb K concentration at harvest was strongly influenced by the fertilizer treatments, being significantly higher in all K-applied plants compared to the control (Table 4). Among these treatments, polyhalite had the highest bulb K concentration, SOP had slightly lower values, while bulb K concentrations of the KCl and the mixed fertilizer treatments were significantly smaller. Polyhalite treatment also exhibited the highest bulb S concentration, which significantly differed from those of SOP and the mixed fertilizer treatments. Bulb S concentration of KCl applied plants was significantly lower than all of the other treatments, except the control which displayed the lowest S levels (Table 4). Bulb Fe concentration at harvest did not differ among treatments, however, values were considerably higher than in the leaves at bulb initiation (Tables 3 and 4). Also, bulb Mn and Cu did not differ among treatments and did not change from bulb initiation to harvest. Bulb Zn, on the other hand, was significantly lower in S-applied plants (Table 4).

Table 3. Macro- and micronutrients in onion leaves just prior to bulb initiation.

Treatment	Macronutrient						Micronutrient			
	N	P	K	Ca	Mg	S	Fe	Zn	Mn	Cu
	%						mg kg^{-1}			
Control	3.02	0.56	1.36c	1.48	0.25	0.47c	73	24	50	12
KCl	2.94	0.58	1.92b	1.54	0.25	0.54b	71	23	47	11
K_2SO_4	3.04	0.56	2.46ab	1.68	0.29	0.67a	82	25	50	11
Polyhalite	2.92	0.55	2.41ab	1.64	0.25	0.63a	84	25	47	11
K_2SO_4 + polyhalite	3.02	0.54	2.55a	1.69	0.27	0.64a	74	25	47	10
Significance level	ns	ns	*	ns	ns	*	ns	ns	ns	ns
References values	2.0-3.0$^{(1)}$	0.2-0.5$^{(1)}$	1.5-3.0$^{(1)}$	0.6-0.8$^{(1)}$	0.15-0.30$^{(1)}$	0.20-0.60$^{(1)}$	60-300$^{(2)}$	15-20$^{(1)}$	10-20$^{(1)}$	5-10$^{(1)}$

*: $p \leq 0.001$; ns: non-significant; similar letters within a column indicate no significant differences.
Reference values were taken from: Maynard and Hochmuth, 2007$^{(1)}$; Mills and Jones, 1996$^{(2)}$.

Table 4. Bulb macro- and micronutrient concentrations at harvest.

Treatment	Macronutrient						Micronutrient			
	N	P	K	Ca	Mg	S	Fe	Zn	Mn	Cu
	%						mg kg^{-1}			
Control	2.07cd	0.64b	1.62c	1.57	0.29	0.63d	253	44a	50	15
KCl	2.22ab	069a	2.09b	1.46	0.30	0.76c	257	45a	45	15
K_2SO_4	2.29a	0.60c	2.30ab	1.35	0.27	0.92b	226	35c	41	13
Polyhalite	2.15bc	0.68a	2.56a	1.64	0.32	1.03a	272	39bc	41	14
K_2SO_4 + polyhalite	2.03d	0.64b	2.27b	1.60	0.30	0.90b	255	39b	45	13
Significance level	*	*	**	ns	ns	**	ns	**	ns	ns

*: $p \leq 0.01$; **: $p \leq 0.001$; ns: non-significant; similar letters within a column indicate no significant differences.

Crop N uptake ranged from 194 to 290 kg ha^{-1}, thus exceeding, in the K-applied treatments, the annual N rate applied (Table 5). Among these treatments, K uptake was significantly higher under SOP and polyhalite fertilizers alone, and moderate (though significantly higher than the control) under KCl and the mixed fertilizer treatments. Phosphorus uptake was far below the applied rate, ranging from 45 to 70 kg ha^{-1}. Under polyhalite, P uptake was significantly higher than in all other treatments, while the control had the lowest values. Potassium uptake under S-applied treatments was equal or slightly higher than the applied K dose (270 kg K_2O ha^{-1}), considerably lower under KCl, and very low under the control. Polyhalite also gave rise to a significantly higher K uptake rate, while descending levels were recorded under SOP and the mixed fertilizers. Uptake rates were lower in the KCl application and the control, which had the lowest value (Table 5). This response pattern repeated with small differences for Ca, Mg and the micronutrients. Sulfur uptake by control plants was minimal, 50 kg ha^{-1}, and it increased considerably (50%) under KCl application, although these two treatments were not supplied with S. Among the other treatments, S uptake varied significantly, being highest under polyhalite and lowest under the mixed fertilizers. Nevertheless, no correlation occurred between S application (Table 2) and uptake rates (Table 5).

Discussion

Results clearly demonstrate the significance of fulfilling onion K requirements with adequate fertilizer supply. KCl application gave rise to significant increase in bulb weight, thus directly enhancing onion yield (Fig. 1). These results are in agreement with recent studies which showed that onion yield and quality were dependent on a considerable K supply (Behairy *et al.*, 2015; Díaz-Pérez *et al.*, 2016; Garg *et al.*, 2018). However, under a similar K application rate (270 kg K_2O ha^{-1}), additional S supply brought about significant further yield increases of 10-20%, depending on fertilizer type. This may suggest that the agronomic K efficiency differs among the tested fertilizers. Also, it may indicate positive interactions between S and other macronutrients.

Nitrogen was similarly supplied in all treatments at a rate of 200 kg N ha^{-1}, which was pretty close to the N uptake of the control (Table 5; Fig. 3). KCl application (270 kg K_2O ha^{-1}) caused a 27% N uptake increase, from 194 to 250 kg N ha^{-1}, indicating that K

Table 5. Macro- and micronutrient uptake rates as a function of fertilizer treatments.

Treatment	Macronutrient						Micronutrient			
	N	P	K	Ca	Mg	S	Fe	Zn	Mn	Cu
	kg ha^{-1}									
Control	194.3c	44.4c	133.1d	150.6d	28.0d	50.3e	2.24d	0.29c	0.50b	0.102c
KCl	252.5b	60.5b	223.0c	190.6c	35.2c	76.5d	2.81c	0.39ab	0.58ab	0.131b
K_2SO_4	288.3a	61.5b	283.2b	202.4bc	38.5b	103.8b	3.04b	0.36b	0.62a	0.129b
Polyhalite	282.3a	68.7a	312.4a	248.5a	43.2a	114.7a	3.54a	0.40a	0.63a	0.143a
K_2SO_4 + polyhalite	251.8b	58.6b	265.5b	218.2b	38.8b	94.6c	3.03b	0.39ab	0.62a	0.126b
Significance level	**	**	**	**	**	**	**	**	*	*

*: $p \leq 0.05$; **: $p \leq .001$; similar letters within a column indicate no significant differences.

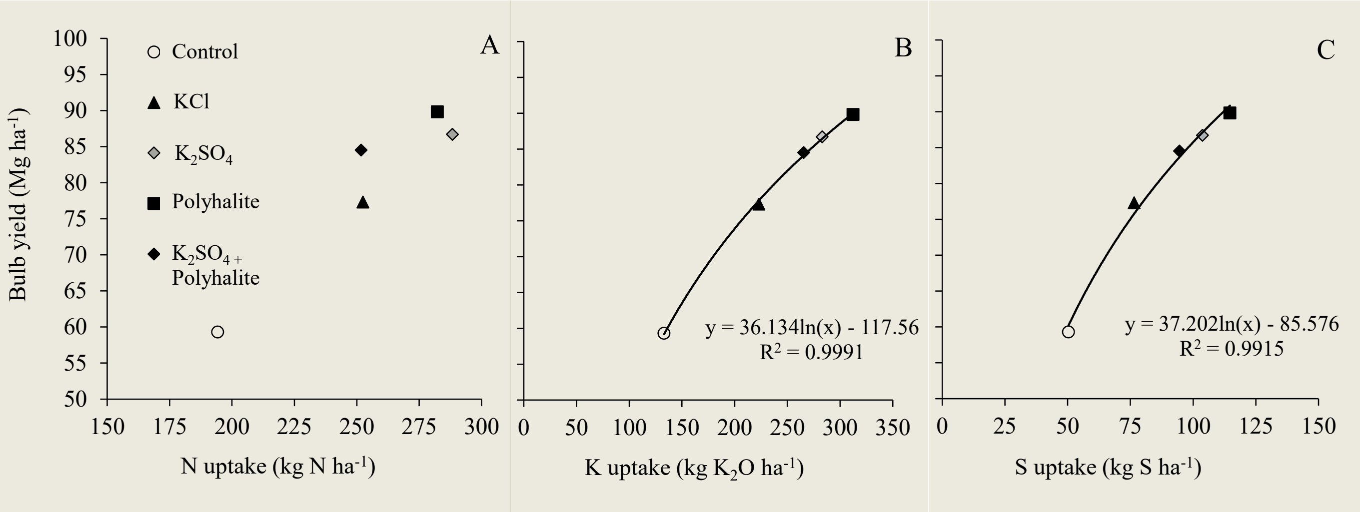

Fig. 3. Onion bulb yield as a function of N (A), K_2O (B), and S (C) uptake under different fertilizers. For further details see Table 2.

was a major limiting factor in the control, and that N requirements have been underestimated in the present study. Additionally, when the same K rate was applied through SOP (K_2SO_4), polyhalite, or as a mixture of the two fertilizers, bulb yields were significantly higher, and furthermore, N uptake substantially increased further under polyhalite or SOP alone (Fig. 3A).

While N is elementary to protein synthesis, S is a constituent of the amino acid methionine, which is essential for the initiation of protein synthesis (Brosnan and Brosnan, 2006). Therefore, positive interactions between N and S are expected and, indeed, have been reported, mainly in Brassicaceae (McGrath and Zhao, 1996), but also in onion (Al-Fraihat, 2009). Kopriva *et al.* (2002) determined regulatory interactions between N and S assimilation in plants, according to which S availability regulates N utilization efficiency in plants, and thus affects photosynthesis, growth, and dry mass accumulation by crops. Thus, S limitation might lower the use of other nutrients, particularly N, and vice versa, when supplied.

The relationships between K and S might seem even stronger (Fig. 3B). In the present study, K uptake by onion crop under no K supply (control) was considerably higher, 133 kg K_2O ha^{-1}. Naturally, K uptake increased significantly under KCl application, but remained below the supplied dose (223 vs. 270 kg K_2O ha^{-1}, respectively). Potassium uptake climbed further (as did bulb yields) when S was supplied in addition to the same K dose. Three explanations may be suggested for this result: positive interactions between K and S; salinity effects by KCl; or differences between fertilizers in K availability/uptake efficiency. The interaction between K and S is not fully understood. Garg *et al.* (2018) claimed a clear interaction and determined the necessary K:S ratio, and similar conclusions were published regarding garlic (Magray *et al.*, 2017). However, in both cases, data regarding the fertilizer compositions used in their experiments were not given, and thus no further interpretation of the results could be made. On the other hand, Díaz-Pérez *et al.* (2016) found no interactions to occur in a wide range of K:S ratios, probably due to the very fertile soil.

Onion is relatively sensitive to salt stress (Shannon and Grieve, 1998), the osmotic component of which might cause root shrinkage, while the toxic component might lead to inhibited plant development (Kiełkowska, 2017). Although the soil of the present study was not saline, a single application of the seasonal KCl dose often causes a transient salt stress, which may negatively affect early plant development. Naher *et al.* (2017) has recently demonstrated the advantage of SOP over MOP in this respect, which may provide some explanation to improved onion performance under SOP.

Nevertheless, the most tempting explanation to the apparently synergistic relationship between K and S found in the present study is rather simple - soil K availability throughout the crop cycle. Excluding the control, the K application dose was similar in the other four treatments. A single KCl application provides surplus K nutrition, accompanied by salt stress, at the early stages of crop development, however, due to the high mobility of K^+ in the soil, the availability of this ion steeply declines, and thus may limit optimum bulb growth and development. Foliar K applications were shown to amend such situations in onion (Behairy *et al.*, 2015). Still, the improved K status at the early stages enhanced N as well as S uptake, yielding significantly better crop performance. These effects may be very similar under SOP, without the transient salt stress. Therefore, plant establishment was probably improved, enabling a better crop

Photo 4. Experimental onion field, Antalya, Turkey. Photo by the authors.

Photo 5. Effect of different potassium fertilizers on onion bulbs. Photo by the authors.

performance later on. In contrast to the two former fertilizers, polyhalite releases the nutrients at a much slower rate. When applied as a single K donor at the sufficient dose, polyhalite supplies all K requirements throughout the crop cycle, providing opportunities for interactions with N, S, and other nutrients along plant development. This may explain the greater N and S uptake rates and crop performance under polyhalite application. Under the mixed SOP + polyhalite treatment, soil K availability might have slightly declined, probably because the half strength SOP or polyhalite did not meet the maximum crop K requirements at certain developmental stages, with negative consequences on crop performance.

The pattern of S uptake was especially interesting (Fig. 3C), particularly in relation to S application rates (Table 2). Similar to the case of K, the onion crop took up about 50 and 75 kg S ha^{-1} under the control and KCl treatments, respectively, where no exogenous S application had occurred. In the other three treatments, S uptake rates increased but hardly correlated to the application rates. In fact, an increase in S application rates from 97 (SOP) to 370 (polyhalite) kg S ha^{-1} gave rise to uptake rates ranging from 95 to 115 kg S ha^{-1} - a very low marginal response - with subsequently poor increases in yield. It appears that S is essential to onion crop development at a minimum threshold required for a given crop status, which is primarily determined by the other macronutrients. From this basic threshold, S uptake increased only when K or N limitations were released, and was strongly correlated with crop development and yield (Tables 3 and 5) and not with S availability. As indicated by the huge gap between S application and uptake rates, surplus S application alone would not promote plant growth.

Onion quality parameters also responded significantly to the basic improvement of soil K rather than to S availability (Fig. 2). Previous studies that examined S application on onion quality had equivocal results. In general, the type of S source and soil properties, mainly soil pH, had significant influences on bulb quality (Brown and LeClaire-Conway, 2014). Under hydroponic conditions, which eliminated soil influences, S application increased bulb firmness through dry matter allocation to the cell wall, whereas no effects occurred on other quality parameters (Lancaster *et al.*, 2001). Often, S application tended to increase the levels of S-containing secondary metabolites, while its effects on TSS or antioxidant contents were much weaker (Bloem *et al.*, 2006; Forney *et al.*, 2010). In many cases, including in the present study, S effects on bulb quality parameters could not be elucidated under strong interactions with the application of other macronutrients such as N and K (Bloem *et al.*, 2005; Al-Fraihat, 2009; Forney *et al.*, 2010; Díaz-Pérez *et al.*, 2016; Shankar *et al.*, 2017; Garg *et al.*, 2018).

In conclusion, the findings of the present study demonstrate the significance of K supply in obtaining high onion yield and quality. Interactions between K, N, and S, when adequately supplied, further increase onion yields. Polyhalite application brought about the highest yields, probably due to its slow-release character, providing constant soil K availability throughout the crop cycle. High rates of S application did not correlate with high yield. While polyhalite's advantageous agronomic efficiency is obvious, suitable rates of application remain subject to economic considerations.

Acknowledgements

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The paper "Effect of Different Potassium and Sulfur Fertilizers on Onion (*Allium cepa* L.) Yield and Quality" also appears on the IPI website at:

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