Research Findings

Photo 1. Experiment site. Photo by the authors.

Effect of Different Potassium Fertilizers on Cotton Yield and Quality in Turkey

Eryuce, N.[(1)], C.F. Ozkan[(2)], D. Anac[(1)*], F.Ö. Asri[(2)], D. Güven[(2)], E.L. Demirtas[(2)], M. Simsek[(2)], and N. Ari[(2)]

Abstract

Cotton (*Gossypium hirsutum* L.) is an important cash crop in Turkey, which supports a long tradition of textile industry and trade. Aiming at enhancing cotton production and quality, the Turkish authorities are promoting a transition from traditional to modern agriculture practices, including the revision of advice regarding mineral nutrition. Beyond the common basal nitrogen (N) and phosphorus (P) application, potassium (K), which is usually ignored by Turkish farmers, is required to enhance yield and quality. There is also increasing awareness of sulfur's (S) significance as an essential macronutrient for cotton crop growth. Muriate of potash (KCl) and sulfate of potash (K_2SO_4) are very common fertilizers. Both are donors of soluble K, and the latter also supplies S. Polyhalite is a natural mineral, which occurs in sedimentary marine evaporates, and consists of a hydrated sulfate of K, calcium (Ca) and magnesium (Mg) with the composition of 14% potassium oxide (K_2O), 48% sulfur trioxide (SO_3), 6% magnesium oxide (MgO), and 17% calcium oxide (CaO).

[(1)]Ege University, Faculty of Agriculture, Soil Sciences and Plant Nutrient Department, Bornova-Izmir, Turkey
[(2)]Batı Akdeniz Agicultural Research Institute, Antalya, Turkey
*Corresponding author: dilek.anac@ege.edu.tr

The objective of this study was to compare the effects of three different K sources – K_2SO_4, polyhalite, and KCl – on cotton yield, quality, and nutrient content and uptake. Standard N and phosphorus pentoxide (P_2O_5) rates of 250 and 184 kg ha^{-1}, respectively, were employed throughout all four treatments. The control treatment was applied with N and P only, while the other four treatments received an equal dose of 210 kg K_2O ha^{-1} in the forms of K_2SO_4, polyhalite, or KCl. Unequivocally, the results of the present study demonstrate the pivotal role of K in cotton production, highlighting the need to enhance its application practices. Results indicate KCl as the preferable K donor to obtain high cotton yields, with 6.3 Mg ha^{-1}, compared to 2.7, 5.6, and 4.8 Mg ha^{-1} for the control, K_2SO_4, and polyhalite, respectively. However, some of the quality properties, such as fiber fineness, length, and elongation performed better under polyhalite and K_2SO_4 fertilizers. The direct and indirect influences of nutrients such as S and Ca on lint development and quality remains to be revealed. Nevertheless, compromising between yield and quality, S containing fertilizers must be considered. While polyhalite appears too slow to stand alone as K donor, this fertilizer shows significant potential, on less calcareous soils, as a slow-release donor of S, Ca, Mg, and K. Basal polyhalite application, in combination with other NPK fertilizers and included in practices suited to meet crop requirements during the season, can provide the Turkish cotton industry with a significant step towards enhancing yields and quality.

Keywords: Gossypium hirsutum L.; MOP; SOP; polyhalite; potassium.

Introduction

Cotton (*Gossypium hirsutum* L.), also known as upland cotton, is a major row crop grown primarily for fiber and oil seed. Worldwide cotton lint production in 2018 was about 26 million tonnes (USDA, 2019). India and China are the leading world producers, with about 6 million tonnes each, followed by the USA, Brazil, Pakistan, and Australia with 4.55, 1.9, 1.8, and 1.05 million tonnes, respectively (Statista, 2018).

Turkey is the world's seventh largest cotton lint producer, with 870,000 tonnes in 2017/2018, produced from 540,000 ha. However, to maintain its significant textile industry, Turkey requires a continuous flow of cotton into the country and accordingly, imported about 650,000 tonnes cotton lint in 2017/2018. The Turkish government's current policy is to substitute expensive cotton imports with a consistent increase in local production (Karadas *et al.*, 2017). Achieving this goal requires an expansion of the cotton producing areas, which is promoted by the Turkish government through 'Fiber vs. Food Approach' to boost farmer incentives to grow cotton as a cash crop instead of staple food crops (e.g., corn) (Demirdöğen *et al.*, 2016). An alternative and more promising approach would be increasing lint yields in the country. Although Turkey is already ranked third in the world's average lint yields with 1,655 kg ha^{-1}, (Indexmundi, 2019), this value comes from wide-ranging agricultural methods – from rain-fed low-input to intensive modern high-input cropping systems. While the world's average lint yield stands at about 800 kg ha^{-1}, the estimated potential yield is 5,000 kg ha^{-1}, given the most favorable environmental conditions and cultural practices, and before genetic manipulations (Constable and Bange, 2015). Improving the standard cultural practices while optimizing the inputs may therefore be key to enhancing the Turkish cotton yields and production.

Classification is essential to the cotton pricing system and is required for high-level quality control in textile production. The major lint quality parameters include: 1) fiber fineness and maturity, measured by Micronaire (MIC); 2) fiber length (mm); 3) length uniformity index (LUI, %); 4) fiber strength (g Tex^{-1}); and, 5) fiber elongation, as the percentage of its initial length (Zhao *et al.*, 2013). All these parameters are directly influenced by environmental conditions and practices, including crop nutritional status.

The cotton plant is a perennial shrub with an indeterminate growth habit; however, its commercial cultivation is mostly annual. The growth and development of the cotton plant proceeds through a number of stages, which may practically be divided into four main stages (Oosterhuis, 2001): 1) germination, emergence and seedling establishment; 2) leaf area-canopy development; 3) flowering and boll development; and, 4) boll maturation. Nevertheless, as the vegetative growth continues, the indeterminate growth mode of the cotton shoots generates a consecutive leaf and flower formation on young shoots side-by-side with boll development and maturation on the older ones. Beyond the competition between vegetative growth, flower formation, and boll maturation on the plant resources, the upper floor of new foliage produces shade, which quite often limits the current carbon exchange rates at the older, sub-floors. This complex development habit might lead to significant yield losses, either through the shedding of flowers and bolls at diverse developmental stages or by interrupting boll maturation, leading to reduced lint quality. Associated with this complex growth habit is an extreme sensitivity to adverse environmental conditions, which is reflected in excess fruit abscission and poor lint quality (Oosterhuis, 2001).

Since cotton plants continue to grow vegetatively after fruiting is initiated, the vegetative to fruiting balance of the plant is critical. Excess vegetative growth from abundant fertility and water can delay maturity and increase problems with insects and boll rot. Excess fruiting, on the other hand, may cause seed abortion with associated early fruit shed and lessen yield potential (Oosterhuis, 2001). Beyond strict irrigation management, optimized mineral nutrition is a powerful tool to control the vegetative-reproductive balance. Nitrogen (N), which is the element needed in the greatest amount and is often limiting, is involved in numerous fundamental processes such as protein synthesis, photosynthesis, dry matter partitioning, as well as enzyme and hormonal activity (Marschner, 2012). Nitrogen deficiency results in short, stunted plants, with pale green leaves (Geng *et al.*, 2015). Excess N, on the other hand, promotes surplus vegetative growth, which might interfere with the optimum balance of boll production. Total seasonal N requirement ranges from 50-300 kg N ha^{-1}, depending on the growing season and the achievable yield potential. N drawn to the lint and seed accounts for 43-60% of total plant N. The developing fruit becomes the dominant sink for N in the plant and redistribution within the plant occurs. Peak daily N uptake in irrigated cotton crop ranges from 1.5-4.6 kg ha^{-1} day^{-1}, dependent on crop conditions and actual yield (Oosterhuis, 2001). Increasing N use efficiency is among the major challenges facing the cotton industry (Ali, 2015).

Potassium (K) is integrally involved in the plant's metabolism and in plant water status, although it is not a constituent of any known plant components. Its primary role is as an enzyme activator. Potassium has been implicated in over 60 enzymatic reactions, which are involved in many processes in the plant such as photosynthesis, respiration, carbohydrate metabolism, translocation and protein synthesis (Marschner, 2012; Zörb *et al.*, 2014; Shen *et al.*, 2017). Potassium balances charges of anions and influences their uptake and transport. Another important function is the maintenance of osmotic potential and water uptake. These two functions of K are manifest in its role in stomatal opening when stomatal conductance and turgor are coupled (Pettigrew, 2008; Wang *et al.*, 2013; Oosterhuis *et al.*, 2014). Another major role of K is in photosynthesis by directly increasing leaf growth and leaf area index, and therefore, CO_2 assimilation. Thus, K increases the outward translocation of photosynthate from the leaf (Hu *et al.*, 2015; 2017; 2018).

In cotton, K also plays a particularly important role in fiber development (Pettigrew, 2008) and a shortage will result in poorer fiber quality and lowered yields (Xiangbin *et al.*, 2012). Potassium deficiency occurs more frequently and with greater intensity on cotton than for most other agronomic crops (Pettigrew, 2008). Typical K deficiency symptoms occur in the leaves, the damage to which might be followed by shedding of flower buds (Loka *et al.*, 2019) and by ceased boll development (Pettigrew, 2003). Immature dwarfed fruit are a typical symptom of severe K deficiency in cotton. The K deficiency syndrome may be the outcome of numerous reasons that include low soil K status; K fixation in the soil; a greater demand for K by modern cultivars; less storage of K prior to flowering by modern cultivars; and, the inability of the root system to supply the needed K during boll development (Oosterhuis, 2001). Total seasonal K requirement ranges from 60-400 kg K_2O ha^{-1} for irrigated cotton, depending on crop conditions and on the achievable target yield (Constable and Bange, 2015). Potassium removal by the lint and seed accounts for 7.5-46% of total plant K, as a function of yield. Peak daily K uptake occurs during boll development and ranges from 1.8-5.2 kg K_2O ha^{-1} day^{-1} in irrigated crops.

Although often underestimated, sulfur (S) is an important nutrient influencing cotton plant growth, development and yield. Sulfur is an essential constituent of cysteine, the amino acid that initiates protein buildup (Haneklaus *et al.*, 2008). Sulfur activates many enzyme systems (Najafian and Zahedifar, 2015), as well as being a pivotal constituent of the enzymes involved in N metabolism, such as nitrate reductase and nitrite reductase (Swamy *et al.*, 2005). A positive interaction between N and S in increasing crop biomass and yield was observed by Salvagiotti and Miralles (2008). Sulfur application improved N use efficiency in wheat by increasing N uptake (Salvagiotti *et al.*, 2009). Likewise, a surge in leaf photosynthesis correlated with increased S supply (Terry, 1976).

While the worldwide use of S fertilizers was limited to cases of critical S deficiency, the sharp decline in S pollution during the last few decades (Kovar and Grant, 2011) has resulted in a consistently rising trend of S deficiency symptoms in many crops. Rates of S removal by crops have become greater than that of soils' ability to restore available S (Chen *et al.*, 2005), a phenomenon which calls for the employment of S fertilizers. Nevertheless, crop responses to S application have been found to vary widely due to differences in location, soil type, various S containing compounds in the soil and consequent S availability, crop genotype, environmental conditions and crop management (Björkman *et al.*, 2011).

In cotton, experiments discovered that application of S coated urea gives rise to higher cotton yields compared with a polymer-coated urea, which indicates that the additional S supply increased the plant biomass Geng *et al.* (2015). Indeed, a more recent study demonstrated that S fertilizer application to soil resulted in significantly higher cotton yields compared to corresponding controls (Geng *et al.*, 2016). These studies indicate that the cotton industry might find benefits in the inclusion of S fertilizer in the crop management toolbox.

In Turkey, straight K fertilizers are not used much, since soils are traditionally conceived as rich in this nutrient. However, the authorities, aiming to enhance production and quality, and maintain sustained soil fertility, are currently focusing on measuring K requirements, N/K ratios, target yields, and crop quality. As a result, cotton growers in Turkey are gradually moving to fertilization practices that generally include 15:15:15 complex N-P-K fertilizers applied at sowing, and ammonium nitrate or calcium ammonium nitrate applied during the second half of the vegetative phase. Nevertheless, further accuracy is required concerning adequate K doses, timing of application, and K interactions with other nutrients before a reliable and widely accepted K fertilization recommendation can be established for cotton in Turkey.

Potassium sulphate (SOP, K_2SO_4) is rarely recommended as a cotton fertilizer. In the framework of enhancing the Turkish cotton industry, the means to improve nutrient use efficiency are considered, including the use of slow-release fertilizers and the introduction of S (Gormus and El-Sabagh, 2016). Polysulphate (Cleveland Potash Ltd., UK) is the trade mark of the natural mineral 'polyhalite', which occurs in sedimentary marine evaporates, and consists 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 14% K_2O, 48% sulfur trioxide (SO_3), 6% magnesium oxide (MgO), and 17% calcium oxide (CaO). In addition to being a natural, multi-nutrient fertilizer, polyhalite is much less soluble. Thus, with significantly slower nutrient release rates, basal application of polyhalite at sowing may provide extended K and S availability during cotton crop development.

Map. 1. The location of the experiment. Turkey, located at the northeast edge of the Mediterranean basin (top image); Antalya region in the south of Turkey. *Sources:* https://c.tadst.com/gfx/citymap/tr-10.png?9; and, https://upload.wikimedia.org/wikipedia/commons/6/61/Antalya_in_Turkey.svg, respectively.

The major objective of this study was to evaluate the effects of polyhalite, SOP, and potassium chloride (MOP) on cotton production in Turkey. Cotton yield, quality properties, and macro and micro nutrient content and uptake under these fertilizer treatments were examined and compared.

Materials and methods

Experiments took place in the Antalya region, located on the Mediterranean coast in southwestern Turkey (Map 1). The soil was sandy-loam, slightly alkaline, and poor in phosphorus (P) and K (Table 1). Net cotton water requirements range from 400-800 mm through the entire crop growth season in Turkey, from April-May to October. In most years, precipitation during this time is very low so the crop relies mainly on irrigation. Drip irrigation, which was employed in the present study, is still rare.

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

Soil properties		
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
Available P (mg kg^{-1}) (Olsen)	5	Poor
Available K (mg kg^{-1})	58	Poor
Available Ca (mg kg^{-1})	2,631	Medium
Available Mg (mg kg^{-1})	102	Medium
Available Fe (mg kg^{-1})	7.6	High
Available Mn (mg kg^{-1})	5.8	Sufficient
Available Zn (mg kg^{-1})	0.2	Insufficient
Available Cu (mg kg^{-1})	0.8	Sufficient

Seasonal macronutrient (NPK) doses were 250, 184, and 210 kg ha^{-1} of N, phosphorus pentoxide (P_2O_5) and K_2O, respectively, according to the official recommendations for cotton. The experiment included four fertilizer treatments: 1) control (N+P+no K); 2) K_2SO_4+N+P; 3) polyhalite+N+P; and, 4) potassium chloride (KCl)+N+P. All treatments received the mentioned doses of NPK, excluding the control, which lacked any K fertilizers. Nitrogen and P were supplied to all treatments through di-ammonium phosphate (DAP) and ammonium nitrate (AN), whereas K was supplied using K_2SO_4, polyhalite, and KCl. All fertilizers were applied basally, before sowing.

The experiment layout employed a randomized block design with four treatments and four replications. Each experimental unit (plot) was 5 m long and 2.8 m wide and consisted of 4 rows. Cotton cv. Gloria was sown on 9 May at a distance of 0.2 m apart and within rows spaced 0.7 m apart, giving rise to a density of 71,500 plants ha^{-1}. Drip irrigation was practiced according to the weekly current evaporative demands, supplying a total of 760 mm water over the entire cropping season.

An early harvest took place on 4 October and a final harvest on 27 October. Lint quality parameters were determined at the Cotton Research Institute, Aydin, Turkey. Lint and seed macro and micro nutrient contents were determined at the Plant and Soil Laboratories of the West Mediterranean Agricultural Research Institute in Antalya, Turkey.

Results and discussion

The highest early and total yields were obtained under the KCl treatment, although the yield of the K_2SO_4 treatment did not differ significantly (Fig. 1). Cotton yields above 5 Mg ha^{-1} are considered very high and beyond the recently defined potential of this crop (Constable and Bange, 2015). Polyhalite application gave rise to a high yield of 4.75 Mg ha^{-1}, which did not differ significantly from that of the K_2SO_4 treatment. The substantially lower yield obtained by the control, 2.7 Mg ha^{-1}, clearly demonstrates the production limits imposed by a lack of K (Fig. 1). Nevertheless, these results do not show any convincing evidence of the significance of S with regard to cotton yield levels.

Fiber fineness, maturity, length, strength and elongation are the most important physical parameters that describe lint quality. It is generally considered that concerning lint fineness, both too low and too high micronaire cottons should be avoided, the ideal range being between about 3.8 and 4.2 MIC for upland cotton (International Trade Center, 2019). In the present study, the control lint was very close to this 'premium range' at 3.74 MIC (Fig. 2). Lint fineness of cotton applied with K_2SO_4 or polyhalite displayed a much higher MIC value but still within the acceptable range (below 4.9). KCl application, on the other hand, promoted thicker fibers that fell into the discount range of above 5 MIC (Fig. 2). The thickness of these particular fibers might be one of the reasons why this treatment had the highest yield (Fig. 1).

Maturity, which is largely determined by growing conditions, can be defined as the relative wall thickness of the fiber (International Trade Center, 2019). Maturity generally has a greater effect on fabric appearance and defects than any of the other fiber properties. Measuring the maturity of a cotton sample in addition to its fineness is essential to whether the determined fineness is an inherited characteristic or is a result of immaturity. Percentage maturity (Pm) above 80% is desirable (International Trade Center, 2019). All treatments of the present study, including control, obtained a Pm greater than 85%, meaning the produce was classified among the 'high maturity' range (Fig. 2). Nevertheless, Pm values were significantly higher among K applied cotton, with or without S. Thus, K supply clearly improved this quality parameter, in agreement with previous studies that have demonstrated the role of K in sugar transport into the developing boll, and in cellulose buildup in the fiber cell wall (Xiangbin *et al.*, 2012; Hu *et al.*, 2015).

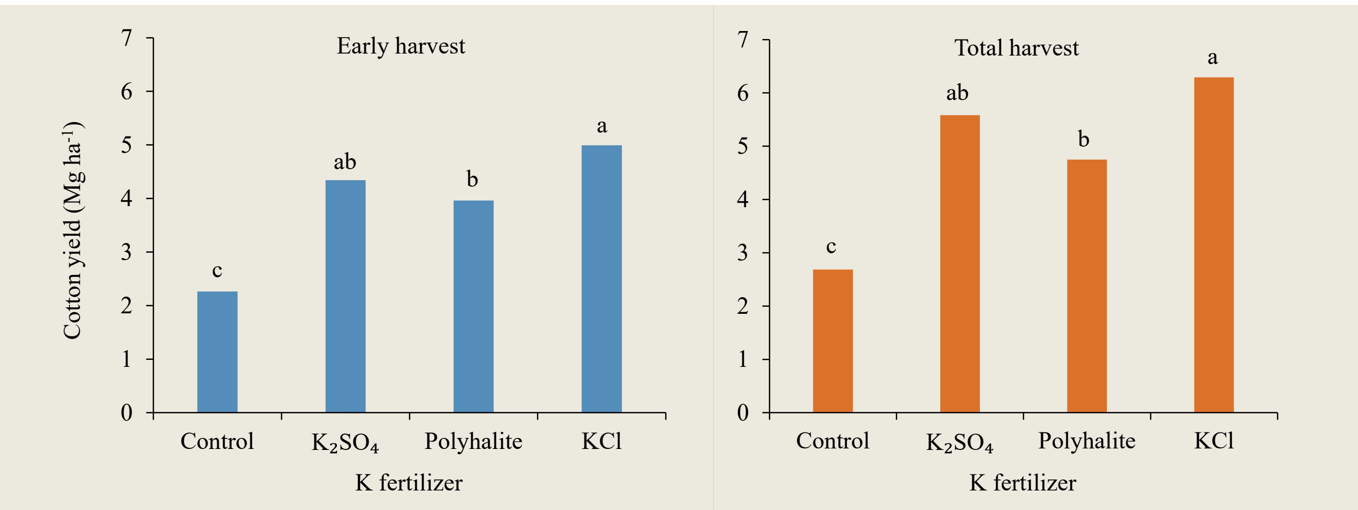

Fig. 1. Effects of different K and S fertilizer treatments on early and total cotton yields. Similar letters indicate no significant differences between treatments ($p<0.05$).

Length, length uniformity, and length distribution, including short fiber content, are probably the most important cotton fiber properties. An increase of 1 mm in fiber length increases yarn strength by some 0.4 g tex^{-1} or more. The staple length, upper half-mean length (UHML), and 2.5% span length, all provide similar but not identical measures, approximating the length of the fibers when carefully detached from the seed by hand. Fiber length characteristics are determined mainly by genetic (cotton variety) factors, however, the genetic potential requires suitable growing conditions to be pronounced.

A fiber length of above 28 mm is desirable in most cases, yet, longer fibers enable smoother and more efficient processing, thus facilitating the production of finer, stronger, more even and less hairy yarns, as well as stronger fabrics with better appearance (International Trade Center, 2019). All treatments, including the control, displayed a fiber length greater than 30 mm and within the desired range (Fig. 2). However, K applied and furthermore, K+S applied plants gave rise to significantly longer fibers. These results provide indications that, in addition to K significance in fiber construction, S may be strongly and positively involved in processes determining fiber length.

The strength of individual cotton fibers is largely determined by the fineness of the fibers, whereas the tenacity (i.e. fineness or cross section-corrected strength) of cotton is largely determined genetically. Cotton fiber tenacity is measured on standard fiber bundles (tex), and values above 30 g tex^{-1} are generally desirable (International Trade Center, 2019). Cotton bundle tenacity in the present study ranged from 36-38 g tex^{-1}, with no significant differences between treatments. A recent study under Mediterranean conditions showed that S applied at a modest range of 15-45 kg ha^{-1} through K_2SO_4 significantly enhanced lint length and strength (Gormus and Al-Sabagh, 2016).

Fiber elongation (extension at break) is a measure of fiber, and consequently, yarn elasticity; to be useful, textile products must conform to a certain level of elasticity. While the industry classifies fiber elongation above 8% as highly elastic and beyond the desired optimum, recent studies claim that elasticity should be further increased through breeding and genetic manipulations (Kelly *et al.*, 2019).

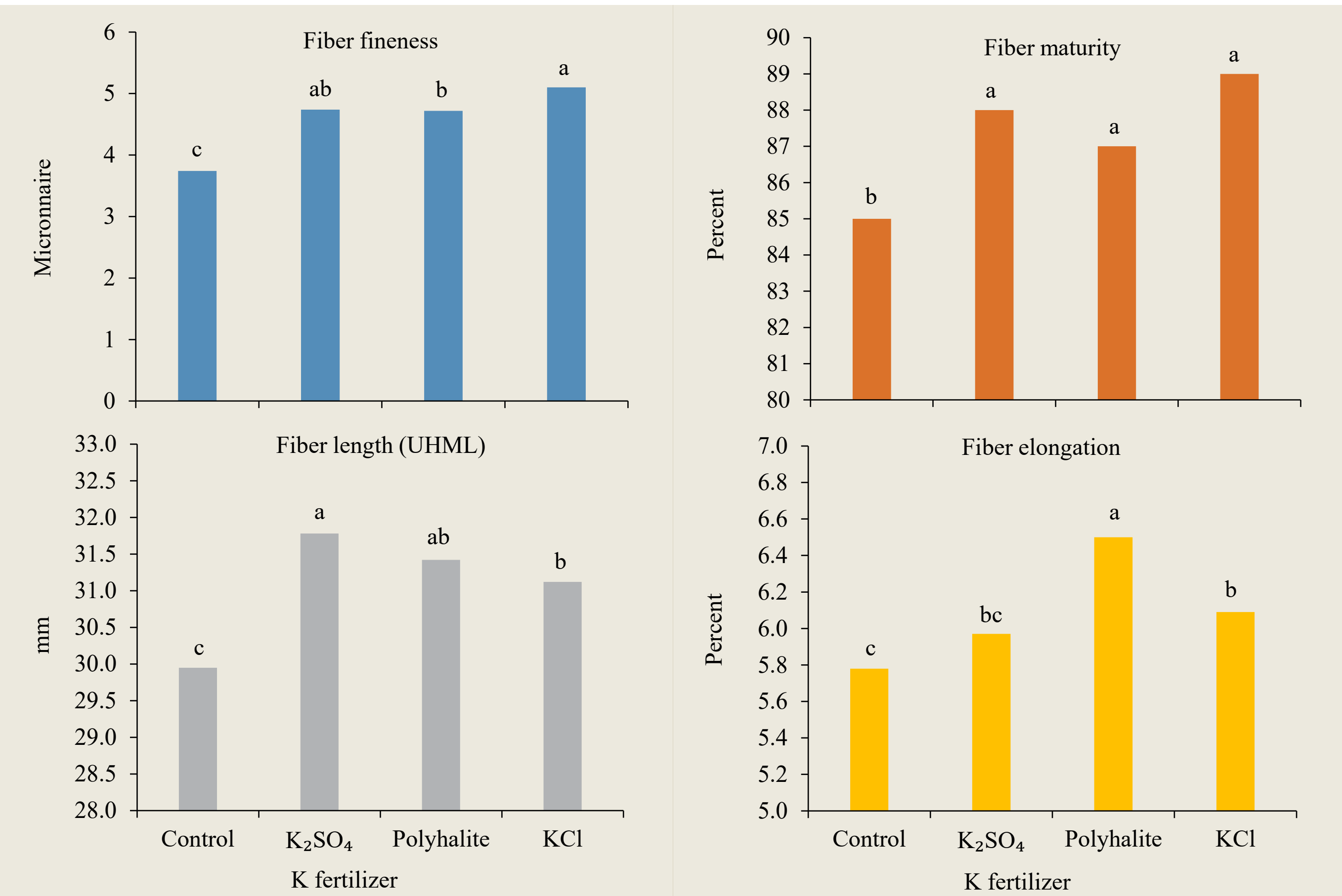

Fig. 2. Effects of different K and S fertilizer treatments on lint quality parameters. Similar letters indicate no significant differences between treatments (p<0.05).

In the present study, polyhalite applied cotton displayed a significantly higher value of fiber elongation than other treatments at 6.5%, followed by KCl and K_2SO_4, which were within the elastic category range of 5.9-6.8%. The control cotton fell into the low elasticity range (Fig. 2). These results indicate that in addition to S, other nutrients donated by polyhalite, such as Ca and Mg, may enhance fiber elasticity.

Lint N and P contents were slightly higher in both the control and K_2SO_4 applied plants at 0.21 and 0.35% N and P, respectively, compared to polyhalite or KCl applied plants (0.12 and 0.31% N and P, respectively). Lint K content was significantly lower in control plants, compared to that of the other treatments, which were quite similar (Fig. 3). As anticipated, lint Ca content was significantly higher in polyhalite applied plants, as this treatment was the only one to include the nutrient (Fig. 3). Similarly, lint S content was the highest under polyhalite and significantly lower under KCl. Control was the exception, with lint S content relatively higher than presumed (Fig. 3).

No differences in the macronutrient content of seeds was observed between treatments, suggesting that seeds are always first to fulfill their nutritional requirements, regardless of current nutrient availability. Seed nutrient contents were 5.75, 0.88, 0.9, 0.12, 0.37, and 0.37% for N, P, K, Ca, Mg, and S, respectively.

Macronutrient uptake by the cotton yield (lint + seeds) was significantly lower in control plants, articulating the lower yield rather than the nutrient content (Table 2). Consequent to the increasing yields (Fig. 1), K application boosted bolls' N and P uptake by about 100% compared to control. Among the three treatments supplied with K, polyhalite plants displayed slightly but significantly lower N and P uptake rates. Of note is that N uptake to the cotton yield of the K applied treatments reached 65-88% of the total N dose supplied, demonstrating the interaction between the two nutrients and the significant role of K in supporting yield buildup.

A similar pattern occurred with K uptake; however, in this case, only 17-22% of the K dose applied reached the cotton bolls (Table 2). This makes sense, as K is not incorporated to the plant structures but remains as a soluble cation, facilitating plant water relations and biochemical processes throughout all plant tissues and organs (Marschner, 2012). Although not supplied to the control, K uptake by the bolls of this treatment was as high as 18 kg ha^{-1}, suggesting that cotton plants drag remarkable amounts of K even from poor soils. Plants applied with polyhalite obtained significantly lower K uptake compared to those applied with KCl or K_2SO_4, indicating a relatively lower K availability where this fertilizer stands alone as a K donor.

Uptake of Ca, Mg, and S to cotton bolls was significantly higher under the KCl and K_2SO_4 treatments, whereas polyhalite applied plants displayed considerably lower Mg and S uptake rates (Table 2). These results indicate that on calcareous soils, the relative advantage of polyhalite as a Ca and Mg donor might decline.

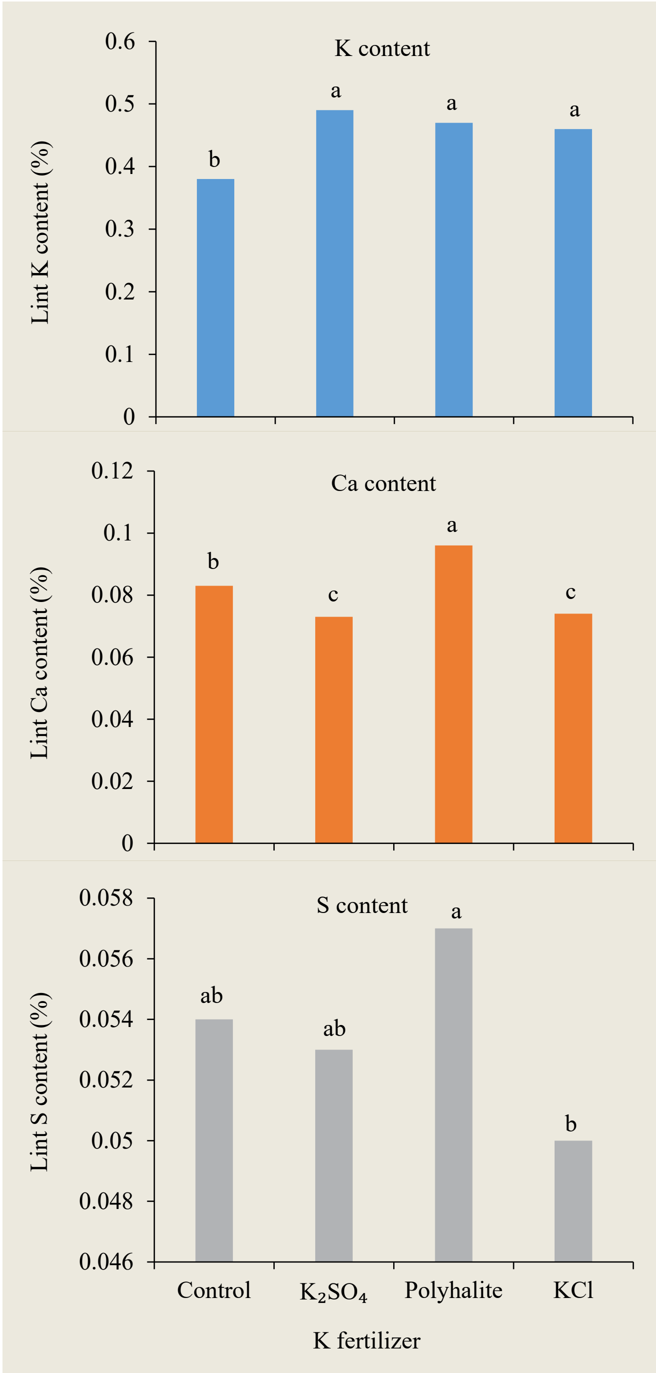

Fig. 3. Effects of different K and S fertilizer treatments on lint Ca, Mg, and S contents. Similar letters indicate no significant differences between treatments ($p<0.05$).

Table 2. Effects of fertilizer treatments on the macronutrient uptake by the total (lint + seeds) yield.

Treatment	N	P	K	Ca	Mg	S
	--------------------		*kg ha^{-1}*	--------------------		
Control	95.1c	14.7c	17.7c	2.8c	6.6c	6.2c
K_2SO_4	191.7a	29.6a	40.8ab	5.5b	13.6a	13.5ab
Polyhalite	161.3b	24.5b	35.6b	5.5b	11.4b	12.0b
KCl	218.5a	31.8a	45.5a	6.3a	14.7a	15.0a
Significance level	*	*	*	*	*	*
LSD	11.4	1.6	2.5	2.5	0.63	0.72

* $p \geq 0.001$.

Table 3. Effects of fertilizer treatments on the micronutrient uptake by the total (lint + seeds).

Treatment	Fe	Zn	Mn	Cu
	--------------------	*g ha^{-1}*	--------------------	
Control	121.9c	78.1d	30.1c	28.6c
K_2SO_4	210.2ab	174.7b	61.6a	54.1ab
Polyhalite	179.2b	144.4c	50.7b	43.7b
KCl	228.7a	201.9a	69.0a	63.8a
Significance level	**	**	**	*
LSD	0.72	8.7	0.72	4.9

* $p \geq 0.01$; ** $p \geq 0.001$.

Micronutrient uptake by the cotton bolls also reflected fertilizer influence on the boll yield rather than on element content. Thus, micronutrient uptake under the control treatment was significantly low; under KCl, uptake rates were the highest; and under K_2SO_4 and polyhalite it was intermediate (Table 3). Among four microelements examined, zinc (Zn) was the most responsive, as its uptake rates were 2-3 fold higher in K applied than in control plants, compared with iron, manganese, and copper, which increased 1.5-2 fold by comparison.

Photo 2. Basal polyhalite application can benefit cotton yield. Photo by the authors.

Conclusions

Unequivocally, the results of the present study demonstrate the pivotal role of K in cotton production, highlighting the need to enhance practices of its application. Overall, results indicate KCl among the fertilizers examined as the preferable K donor to obtain high cotton yields. However, the global cotton and textile industries currently tend to focus on lint quality enhancement rather than yield levels. Some of the quality properties, such as fiber fineness, length, and elongation performed better under polyhalite and K_2SO_4 fertilizers.

The direct and indirect influence of nutrients such as S, Ca, and Zn on lint development and quality remains to be revealed. Nevertheless, S containing fertilizers must be considered to achieve good results for both yield and quality. While polyhalite appears too slow to stand alone as a K donor, this fertilizer shows significant potential on less calcareous soils as a slow-release donor of S, Ca, Mg, and K. Basal polyhalite application, used in combination with other NPK fertilizers and included in practices suited to meet crop requirements during the season, can provide the Turkish cotton industry with a significant step forward.

Acknowledgements

The authors gratefully acknowledge the financial support of this study from the International Potash Institute (IPI), Switzerland.

References

Ali, N. 2015. Review: Nitrogen Utilization Features in Cotton Crop. Am. J. Plant Sci. 6:987-1002.

Björkman, M., I. Klingen, A.N.E. Birch, A.M. Bones, T.J.A. Bruce, T.J. Johansen, R. Meadow, J. Mølmann, R. Seljåsen, L.E. Smart, and D. Stewart. 2011. Phytochemicals of Brassicaceae in Plant Protection and Human Health - Influences of Climate, Environment and Agronomic Practice. Phytochemistry 72:538-556.

Chen, L., W.A. Dick, and S. Nelson. 2005. Flue Gas Desulfurization Products as Sulfur Sources for Alfalfa and Soybean. Agron. J. 97(1):265-271.

Constable, G.A., M.P. Bange. 2015. The Yield Potential of Cotton (*Gossypium hirsutum* L.). Field Crops Research 182:98-106.

Demirdöğen, A., E. Olhan, and J.P. Chavas. 2016. Food vs. Fiber: An Analysis of Agricultural Support Policy in Turkey. Food Policy 61:1-8.

Geng, J., Q. Ma, J. Chen, M. Zhang, C. Li, Y. Yang, X. Yang,

W. Zhang, and Z. Liu. 2016. Effects of Polymer Coated Urea and Sulfur Fertilization on Yield, Nitrogen Use Efficiency and Leaf Senescence of Cotton. Field Crops Research, 187:87-95.

Geng, J., Q. Ma, M. Zhang, C. Li, Z. Liu, X. Lyu, and W. Zheng. 2015. Synchronized Relationships between Nitrogen Release of Controlled Release Nitrogen Fertilizers and Nitrogen Requirements of Cotton. Field Crops Research 184:9-16.

Gormus, O., and A. El-Sabagh. 2016. Effect of Nitrogen and Sulfur on the Quality of the Cotton Fiber under Mediterranean Conditions. J. Experimental Biology and Agricultural Sciences 4(6):662-669.

Haneklaus, S., E. Bloem, and E. Schnug. 2008. History of Sulfur Deficiency in Crops. *In:* Jez, J. (ed.). Agronomy Monographs 50: Sulfur: A Missing Link between Soils, Crops, and Nutrition. ASACSSA-SSSA, Madison, WI 53711-5801, USA. p. 45-58. DOI: 10.2134/agronmonogr50.c4.

Hu, W., T.D. Coomer, D. Loka, D.M. Oosterhuis, and Z. Zhou. 2017. Potassium Deficiency Affects the Carbon Nitrogen Balance in Cotton Leaves. Plant Physiology and Biochemistry 115:408-417.

Hu, W., D. Loka, T.R. Fitzsimmons, Z. Zhou, and D.M. Oosterhuis. 2018. Potassium Deficiency Limits Reproductive Success by Altering Carbohydrate and Protein Balances in Cotton (*Gossypium hirsutum* L.). Environmental and Experimental Biology 145:87-94.

Hu, W., J. Yang, Y. Meng, Y. Wang, B. Chen, W. Zhao, and Z. Zhou. 2015. Potassium Application Affects Carbohydrate Metabolism in the Leaf Subtending the Cotton (*Gossypium hirsutum* L.) Boll and its Relationship with Boll Biomass. Field Crops Research 179:120-131.

Indexmundi. 2019. https://www.indexmundi.com/agriculture/?commodity=cotton&graph=yield.

International Trade Center. 2019. Cotton Exporter's Guide. http://www.cottonguide.org/cotton-guide/cotton-value-addition/.

Karadas, K., S. Celik, S. Hopoglu, E. Eyduran, and F. Iqbal. 2017. New Agricultural Politics in Turkey: The Econometric Assessment of Cotton Production and Yield 1925-2015. JAPS: J. Animal & Plant Sciences 27(3):1005-1014.

Kelly, C.M., J. Osorio-Marin, N. Kothari, S. Hague, and J.K. Dever. 2019. Genetic Improvement in Cotton Fiber Elongation Can Impact Yarn Quality. Industrial Crops and Products 129:1-9.

Kovar, J.L., and C.A. Grant. 2011. Nutrient Cycling in Soils: Sulfur. Publications from USDA-ARS/UNL Faculty. Paper 1383. http://digitalcommons.unl.edu/usdaarsfacpub/1383.

Loka, D.A., D.M. Oosterhuis, D. Baxevanos, D. Vlachostergios, and W. Hu. 2019. How Potassium Deficiency Alters Flower Bud Retention on Cotton (*Gossypium hirsutum* L.). Archives of Agronomy and Soil Science 65(4):521-536.

Marschner, P. 2012. Marschners's Mineral Nutrition of Higher Plants. London: Elsevier.

Oosterhuis, D. 2001. Physiology and Nutrition of High Yielding Cotton in the USA. Informações Agronômicas 95:18-24.

Oosterhuis, D.M., D.A. Loka, E.M. Kawakami, and W.T. Pettigrew. 2014. The Physiology of Potassium in Crop Production. *In:* Advances in Agronomy 126:203-233.

Pettigrew, W.T. 2008. Potassium Influences on Yield and Quality Production for Maize, Wheat, Soybean and Cotton. Physiol. Plant. 133:670-681.

Pettigrew, W.T. 2003. Relationship between Insufficient Potassium and Crop Maturity in Cotton. Agron. J. 95:1323-1329.

Salvagiotti, F., and D.J. Miralles. 2008. Radiation Interception, Biomass Production and Grain Yield as Affected by the Interaction of Nitrogen and Sulfur Fertilization in Wheat. Eur. J. Agron. 28(3):282-290.

Salvagiotti, F., J.M. Castellarín, D.J. Miralles, and H.M. Pedrol. 2009. Sulfur Fertilization Improves Nitrogen Use Efficiency in Wheat by Increasing Nitrogen Uptake. Field Crops Research 113(2):170-177.

Shen, C., J. Wang, X. Shi, Y. Kang, C. Xie, L. Peng, and Y. Xu. 2017. Transcriptome Analysis of Differentially Expressed Genes Induced by Low and High Potassium Levels Provides Insight Into Fruit Sugar Metabolism of Pear. Frontiers in Plant Science 8:938.

Statista. 2018. https://www.statista.com/statistics/263055/cotton-production-worldwide-by-top-countries/.

Swamy, U., M. Wang, J.N. Tripathy, S.K. Kim, M. Hirasawa, D.B. Knaff, and J.P. Allen. 2005. Structure of Spinach Nitrite Reductase: Implications for Multi-Electron Reactions by the Iron-Sulfur: Siroheme Cofactor. Biochem. 44(49):16054-16063.

Terry, N. 1976. Effects of Sulfur on the Photosynthesis of Intact Leaves and Isolated Chloroplasts of Sugar Beets. Plant Physiol. 57 (4): 477–479.

USDA. 2019. https://www.usda.gov/oce/forum/2019/outlooks/Cotton.pdf.

Wang, M., Q. Zheng, Q. Shen, and S. Guo. 2013. The Critical Role of Potassium in Plant Stress Response. Int. J. Molecular Sciences 14(4):7370-7390.

Xiangbin, G., W. Youhua, Z. Zhiguo, and D.M. Oosterhuis. 2012. Response of Cotton Fiber Quality to the Carbohydrates in the Leaf Subtending the Cotton Boll. Journal of Plant Nutrition and Soil Science 175(1):152-160.

Zhao, W.Q., Z.G. Zhou, Y.L. Meng, B.L. Chen, and Y.H. Wang. 2013. Modeling Fiber Fineness, Maturity, and Micronaire in Cotton (*Gossypium hirsutum* L.). J. Integrative Agriculture 12(1):67-79.

Zörb, C., M. Senbayram, E. Peiter. 2014. Potassium in Agriculture: Status and Perspectives. J. Plant Physiol. 171:656-669.

The paper "Effect of Different Potassium Fertilizers on Cottton Yield and Quality in Turkey" also appears on the IPI website.