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Effect of potassium fertilization on leaf physiology, fiber yield and quality in cotton (*Gossypium hirsutum* L.) under irrigated Mediterranean conditions

Ioannis T. Tsialtas[a,*], Sergey Shabala[b], Demetrios Baxevanos[c], Theodora Matsi[a]

[a] *Faculty of Agriculture, Aristotle University of Thessaloniki, 541 24 Thessaloniki, Greece*
[b] *School of Land and Food, University of Tasmania, Tas 7001, Hobart, Australia*
[c] *Hellenic Agricultural Organization—"Demeter", Institute of Industrial and Fodder Plants, 413 35 Larissa, Greece*

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ABSTRACT

The aim of this work was to study the physiological, yield and quality responses of two upland cotton cultivars (Greek and Australian), grown on light-textured soil under irrigated, Mediterranean conditions, to three potassium levels (0, 80, 160 kg K_2O ha^{-1}). Despite its pivotal role in plant physiology and growth, K supplementation is often neglected by growers due to high cost and complexity with identifying optimal K levels. A rate of 80 kg K_2O ha^{-1} was adequate to increase both seedcotton and lint yield and improve fiber length. This was despite the absence of any response of leaf cation concentrations (K, Na, Ca, Mg, their sum and ratios) to K fertilization. On a contrary, K application affected leaf gas exchange physiology by increasing CO_2 assimilation rate and stomatal conductance thus leading to reduced leaf temperature and higher leaf water potential and carbon isotope discrimination (Δ). Cultivars did not differ in the leaf gas exchange characteristics and yield but the Australian (Carmen) had markedly better fiber quality, was water conservative and sustained higher leaf K concentrations compared to Greek (Elina). Growth stage (first open flower, full bloom, first open bolls) impacted significantly leaf gas exchange physiology and cation concentrations resulting in reductions of CO_2 assimilation rate, stomatal conductance, leaf water potential, specific leaf area (SLA) and N and K concentrations through the growing season. Regardless the growth stage, the lint yield was negatively correlated with Δ, Na and Na/Mg ratio highlighting the importance of the conservative use of water on cotton yield and the detrimental role of Na despite the theoretical cotton's tolerance. Fiber length was closely correlated to leaf K at the first open boll stage indicating a putative deficiency of K which possibly accelerates cotton maturity. Overall, results of the present work emphasize the essentiality of adequate K supply for cotton physiology, growth, yield and quality, highlight the interactions of K with other nutrients and stress the cultivar selection as a means to encounter soil K inadequacy.

1. Introduction

Upland cotton (*Gossypium hirsutum* L.) is the major spring cash crop in Greece, which is the biggest cotton producer in EU and, along with Australia, are at the top dozen of world producing countries (Cotton Incorporated, 2015). Both countries share common problems (e.g. soil nutrient deficiencies, drought, salinity) and solutions in terms of that some cultivars of Australian origin enjoy high popularity among Greek growers.

Macronutrients' availability, mainly nitrogen (N), phosphorous (P) and potassium (K), along with water availability and short growing season, at the utmost fringes of cotton growing belt, are the major restrictors of crop's productivity (Morrow and Krieg, 1990; Girma et al., 2007). In Greece, under irrigated Mediterranean conditions, most growers fully recognize the essentiality of N fertilization but often ignore and/or neglect the potential impact of other nutrients. This is specifically true for K, the second (after N) most abundant element in plant tissues (Oosterhuis et al., 2014). The high cost of K fertilization is usually blamed.

Though abundant in the earth's crust, K can be of a limited availability for plant growth under certain soil (soil type, clay content, competition with other nutrients) and environmental (e.g. water availability) conditions making its supplementation an indispensable necessity (Zörb et al., 2014). In Greece, particularly at the northernmost growing areas with the shortest growth season, cotton often lays on light-textured soils with K concentrations

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* Corresponding author.
E-mail address: tsialtas01@windowslive.com (I.T. Tsialtas).

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$\leq$160 mg K kg^{-1}, a threshold posited as deficient (Adeli and Varco, 2002). However, soil K deficiency level is hard to be diagnosed since deficiencies have been detected even in soils where such a malignancy was unexpected. In this context, premature senescence disorder, diagnosed in Australia on K rich soils, has a symptomatology reminiscent of K deficiency but was ascribed to source-sink imbalance deterring K from accessing the upper leaves (Wright, 1999). Therefore, one needs to clearly distinguish between *chemical* and *biological* availability of soil K. Cultivar has been recognized as a crucial factor since those with high fruiting load and earliness proliferate and show higher susceptibility to K deficiency (Oosterhuis et al., 2013). As a consequence, a means recruited to fight back K deficiency is the use of K efficient cultivars (López et al., 2008; Yang et al., 2011; Hao et al., 2015).

It is widely accepted that K plays a protagonist role in a multitude of plant functions with enzyme activation, charge balance maintenance, turgor provision and water homeostasis and the concomitant solute transport as most prominent (Cakmak, 2005; Maathuis, 2009; Benito et al., 2014). A prominent signaling role of K has also recently emerged (reviewed by Anschütz et al., 2014). In particular in cotton, K inadequacy has been accused of low chlorophyll and photosynthesis as a result of restrictions in stomatal conductance and the subsequent thermal stress (Bednarz and Oosterhuis, 1999; Zhao et al., 2001; Pervez et al., 2004; Reddy and Zhao, 2005; Pettigrew and Gerik, 2007) and high ATP and carbohydrate contents in leaves due to limitations in phloem load and translocation (Bednarz and Oosterhuis, 1999; Oosterhuis et al., 2013). These effects concur to shorter plants, lower leaf area index (LAI), and thus lower light interception; finally, less biomass is allotted to the reproductive plant parts (Pettigrew and Meredith, 1997; Zhao et al., 2001; Pettigrew, 2003; Clement-Bailey and Gwathmey, 2007). Thus, the boll weight increase by K amendment is consequential (Dong et al., 2010). Inconspicuous but still of high agronomic importance is K contribution to pest and disease resistance (Amtmann et al., 2008). Piecing all these effects together, K supplementation has been accounted for a straightforward increase in yields (Cassman et al., 1990; Pettigrew and Meredith, 1997; Pettigrew, 2003) but its role on fiber quality was less clear with length and micronaire to be more influenced (Pettigrew, 2003; Read et al., 2006; Girma et al., 2007).

Much of the information regarding K nutrition effects on cotton physiology comes from controlled conditions or is contradictory. Thus, there is still a need for the field work in order to understand cotton adaptation to K deficiency, especially at the different growth stages, if we aim growers to effectively tackle the problem (Oosterhuis et al., 2013).

To achieve such goals, apart from instantaneous assessments like gas exchange measurements, long-term determinations should be employed. To this direction, stable carbon and nitrogen isotope determinations can be helpful. Carbon isotopes, expressed as carbon isotope discrimination (Δ), could assess cotton water economy and functioning in the long-term since their relationship with water use efficiency (WUE, the ratio of the dry biomass produced or CO_2 assimilated per unit of water consumed for) is well-established (Saranga et al., 1998, 1999). On the other hand, natural abundance of ^{15}N ($\delta^{15}N$) has been used as a proxy for the processes that N undergoes both in the soil and in the plant (Robinson, 2001). In cotton, $\delta^{15}N$ was found to relate with leaf N-P-K concentrations making it a useful tool for the diagnosis of element deficiencies (Stamatiadis et al., 2006). Since K in cotton was found to interact with both macro- and micro-nutrients (Pettigrew et al., 1996; Rochester, 2010), $\delta^{15}N$ could provide insights of indirect nutritional effects on growth as it has been found under salinity (El-Hendawy et al., 2007).

Cotton is a glycophyte with relatively high tolerance to salinity and drought, conditions under which K nutrition plays a critical role for crop growth and productivity (Pettigrew and Gerik, 2007; Oosterhuis et al., 2014). However, even under non-saline conditions, K interacts with its homologous monovalent Na and the divalent Ca and Mg cations sporting both antagonistic and synergistic relations to them (Benito et al., 2014). Under K deficiency, the other cations could facilitate the role of K. Thus, Na substitutes for K as an osmoticum (Rengel and Damon, 2008) and leaf Ca defined yield and quality of cotton when grown on low-K soil under Mediterranean conditions (Tsialtas et al., 2016). Although increased levels of Ca and Mg have been ascribed with reductions of Na uptake (e.g. Anil et al., 2005; Shabala et al., 2005), these two elements failed to alleviate the toxic effects of Na at the early growth stages in cotton (Severino et al., 2014). In any case, the interactions between the four cations (K, Na, Ca, Mg) and their effects on cotton physiology and productivity are very sparsely studied under non-saline conditions.

The aim of the present work was to study the response of two upland cotton cultivars of Greek and Australian breeds grown under Mediterranean conditions, to three K levels (0, 80, 160 kg K_2O ha^{-1}) on a soil considered as K-deprived. Instantaneous (gas exchange measurements, leaf water potential) and long-term determinations (C and N isotopes, specific leaf area) along with elemental concentrations (N, C, K, Na, Ca, Mg) were employed to get insights on factors affecting cotton yield and fiber quality. These assessments took place at three growth stages (first open flower, full bloom and first open bolls on the first fruiting branches) in the course of growth season attempting to define the critical one for the response to K. Our results emphasize the essentiality of adequate K supply not only for vegetative growth but also yield and quality and highlight the complexity of interaction of K with other nutrients, as well as different roles (and requirements) for K at different stages of plant ontogeny.

2. Materials and methods

2.1. Site and experiment set up

During 2008 and 2009 growing seasons, field experiments were conducted at NAGREF-Cotton & Industrial Plants Institute (CIPI), Sindos, Greece (40° 41′N, 22° 48′E; 14 m a.s.l.). The soil was a Typic Xerofluvent (Table 1) with winter cereal as a preceding crop. The climate is Mediterranean with growth season (May-October) rainfall from 190 mm (2008) to 242 mm (2009) and mean monthly temperatures ranging between 16 °C and 28 °C (Fig. 1).

Two upland cotton cultivars (Elina-CIPI and Carmen-Bayer CropScience, Bayer Hellas SA) were hand-seeded on 5 May 2008 and 30 April 2009 in a split-plot design with four replications; three potassium (K) levels [0 (K_0), 80 (K_{80}) and 160 kg K_2O ha^{-1} (K_{160})] were in the main plots and the two cultivars in subplots. Potassium sulphate (0-0-50) was distributed by hand before sowing and incorporated into the soil. Each subplot was comprised of four rows 5 m long and 1 m apart (20 m^2). Plants were hand-thinned, at the two-leaf stage (BBCH 12 stage), leaving 20–22 plants per m^2. Nitrogen (N) as NH_4NO_3 (33.5-0-0) was top-dressed at a rate of 100 kg N ha^{-1} when the first floral buds were visible (BBCH 52 stage).

Irrigation was applied by sprinklers and a total of 350 mm was delivered from blooming till mid-August in 2008. In 2009, irrigation stopped at the end of July, when it had delivered only 100 mm, because August was much rainy for the local standards (Fig. 1). Weeds were eliminated by hand-weeding at early stages and by hoeing later in the season.

To monitor populations of cotton bollworm (*Helicoverpa armigera*) and pink bollworm (*Pectinophora gossypiella*) were used

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