Influence of potassium nutrition on gas exchange characteristics and water relations in cotton (*Gossypium hirsutum* L.)

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Abstract

The effects of potassium nutrition [0, 6.25, 12.50, 25.00 g(K) m^{-2} of K_2SO_4 or KCl] on gas exchange characteristics and water relations in four cultivars (CIM-448, CIM-1100, Karishma, S-12) of cotton were assessed under an arid environment. Net photosynthetic rate (P_N) and transpiration rate (E) increased with increased K supply. The leaf pressure potential (Ψ_p) increased significantly by the addition of 25.00 g(K) m^{-2} compared to zero K level. The water use efficiency (P_N/E) was improved by 24.6 % under the highest K dose compared to zero K. There were positive correlations (0.99**, 0.98**, 0.95**, 0.97**) between K-doses and P_N, E, Ψ_p, and P_N/E, respectively.

Additional key words: net photosynthetic rate; osmotic potential; pressure potential; stomatal conductance; transpiration rate; water-use efficiency.

Introduction

Yield and quality in crop plants can be influenced positively through the effects of mineral nutrition on water relations (Mengel and Arneke 1982, Marschner 1995). Lindhauer (1989) reported that source-sink relationship is influenced by osmotic effects of plant nutrients, especially by contribution of K^+ to osmotic potential generation. The application of potassium chloride (KCl) as compared to potassium sulphate (K_2SO_4) caused lower osmotic potential and higher water retention in the leaves of potato plants (Beringer *et al*. 1983). The addition of K_2SO_4 favoured the higher K^+ content in leaves, increasing proportion of K^+ contributing to the rate of phloem transport. Also Arneke (1981) found an increased K^+ content in the leaves of *Phaseolus vulgaris* L. induced by change in K nutrition. The osmotic potential (Ψ_s) was considerably lowered, while the pressure potential (Ψ_p) significantly rose by the higher K supply. Mengel and Arneke (1982) reported that K^+ deficient plants had reduced rates of photosynthesis and transpiration. Potassium deficiency primarily reduced water retention of the tissues and lowering Ψ_p led to growth rate depression. K^+ deficient plants of pearl millet (*Pennisetum glaucum* L.) had lower stomatal conductance (g_s) than those with higher K contents (Ashraf *et al*. 2001). In white clover (*Trifolium repens* L.), the decrease in net CO_2 uptake of K^+-deficient leaves was closely related to decreased g_s (Shamsun-Noor *et al*. 1991) and thus a major influence of K^+ on photosynthesis was realised through stomatal closure. Longstreth and Nobel (1980) found in cotton that net photosynthetic rate (P_N) was reduced when the plants were grown at low content of K^+. Mottram (1987) meant that higher doses of K fertilizer must be used in the dryland to offset the decreased P_N and translocation.

Cotton, a major world fibre crop experiences during its growth drought conditions, which significantly reduce its growth and yield. Therefore, the major objective of the present study was to uncover the cotton response to potassium nutrition with regard to photosynthetic capacity and water relations.

Materials and methods

A field experiment was conducted at the Central Cotton Research Institute, Multan, Pakistan (latitude 30°12′N, longitude 71°28′E, altitude 123 m). The analyses of soil samples collected before imposition of treatments were carried out following Ryan *et al*. (2001). The soil was silt loam having alkaline reaction (pH 8.3). The soil

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contained 0.67 % organic matter, 7.3 mg kg^{-1} available P, and 147 mg kg^{-1} exchangeable K in the 0–30 cm soil depth. The soil belongs to Miani soil series and is classified as Calcaric Cambisoles and Hyperthermic, Fluventic Haplocambids according to the USDA soil classification system (1998).

Four cotton cultivars (CIM-448, CIM-1100, Karishma, and S-12) were fertilized with four potassium doses, 0, 6.25, 12.50, 25.00 g(K) m^{-2} (further mentioned as K_0, $K_{6.25}$, $K_{12.5}$, and $K_{25.0}$, respectively) and two potassium fertilizer sources [sulphate of potash (K_2SO_4) and muriate of potash (KCl)]. The design of the experiment was split plot (main: cultivars, sub-plot: K-rates, sub-sub plot: K source) having four replications. The sizes of main, sub-plot, and sub-sub plot were 512, 128, and 64 m^2, respectively. A uniform dose of 2.2 g(P) m^{-2} at planting and 15.0 g(N) m^{-2} in three splits, *i.e.* planting, flowering, and peak flowering was applied in all experimental units. *Stomp 330E*, 2.5 litre per hectare as pre-emergence herbicide was applied at planting time to control weeds. The crop was kept from insect-pest attack through regular sprays of common pesticides. The crop received normal irrigation and standard production practices throughout the season.

Just before the initiation of flowering stage (60-d old plants) all measurements of gaseous exchange and water relations were made. For measuring leaf water potential (Ψ_l), a fully expanded youngest leaf (fourth from the top) was excised from each plant at 11.00 and a pressure bomb apparatus (*Chas W. Cook Division*, Birmingham, England) was used. For measuring leaf osmotic potential, a proportion of the leaf used for water potential determination was frozen in a freezer for two weeks, thawed, and the frozen sap was extracted by crushing the material with a metal rod. After centrifugation (8 000×*g*) for 4 min, the sap was used for osmotic potential determination in a vapour pressure osmometer (*Wescor 5520*, Logan, USA). Leaf pressure potential was calculated as the difference between leaf osmotic potential and water potential.

The instantaneous measurements of P_N and transpiration rate (E) were made on fully expanded youngest leaves of 10 plants (4th leaf from top) using an open system *LCA-4 ADC* portable infrared gas analyzer (*Analytical Development Company*, Hoddesdon, England). Measurements were performed when plants were 60-d old at 11:00 with the following conditions: molar flow of air per unit leaf area 408.5 mmol m^{-2} s^{-1}, atmospheric pressure 97.8 kPa, water vapour pressure inside the chamber 1 120–1 220 Pa, photosynthetic active radiation (PAR) at leaf surface was maximum up to 1 280 µmol m^{-2} s^{-1}, temperature of leaf was maximum up to 34.4 °C, ambient temperature (32.3–33.9 °C), and ambient CO_2 concentration (351.3 µmol mol^{-1}). Stomatal resistance measurements were made with automatic porometer *MK-3* (*Delta-T Devices*, Burwell, Cambridge, England) and converted into g_s values. Water-use efficiency (WUE) was computed as P_N/E. Canopy leaf temperature was recorded using a canopy temperature thermometer (*Digitron Instrumentation*, Hertford, Herts, England). The leaf blades sampled at 60-d old were analyzed for K content according to Yoshida *et al.* (1976). The measurements on fruit production were obtained on all test plants harvested at five physiological stages of growth, *i.e.* first flower bud at 28 d after planting (DAP), first flower at 61 DAP, peak flowering at 94 DAP, first boll split at 125 DAP, and maturity at 153 DAP. Data included (*a*) number of total fruiting positions (total aggregate number of squares, flowers, and bolls including abscised and retained), and (*b*) number of total fruit (aggregate number of squares, flowers, and bolls whether immature or matured ones) according to Wells and Meredith (1984). Values were analyzed statistically according to Gomez and Gomez (1984).

Results

Cultivars differed significantly with regard to P_N. Potassium doses and sources had also significant effects on P_N (Table 1). P_N ranged from 10.8 to 26.7 µmol(CO_2) m^{-2} s^{-1} under K_0 and at $K_{25.0}$ in the form of K_2SO_4, respectively. Cultivar CIM-448 maintained slightly higher P_N than the other cultivars. The significant interaction ($p<0.01$) of cultivar×dose, cultivar×source, and dose×source demonstrated that addition of K-fertilizer in the form of K_2SO_4 increased P_N.

The significant differences in E were observed among the cultivars (Table 1). Cultivar CIM-1100 maintained higher E over all variants [5.24 mmol(H_2O) m^{-2} s^{-1}] than the other cultivars. E increased with increasing K-supply. Averaged across cultivars and sources, maximum E [5.21 mmol (H_2O) m^{-2} s^{-1}] was observed under $K_{25.0}$ compared to minimum [3.79 mmol(H_2O) m^{-2} s^{-1}] under K_0. However, E was also affected by K-source. The significant interaction ($p<0.01$) of cultivar×dose demonstrated the genetic make-up of cultivars and their individual response to K fertilization.

WUE differed significantly among cultivars (Table 1), ranging from 2.77 to 5.80 in different treatments. The cv. Karishma was the most efficient in WUE compared to the other cultivars under all K doses and sources. WUE increased with concurrent increase in K supply. The maximum average WUE (4.35) was found under $K_{25.0}$ compared to K_0 having value of 3.42. The WUE values were dependent upon interaction of cultivar and K doses.

Cultivars differed significantly in g_s (Table 1). Cultivar S-12 had lower g_s (0.18 cm s^{-1}) than the other cultivars. Stomatal conductance increased with concurrent increase in K-supply. There was a 64.3 % increase in g_s under $K_{25.0}$ compared to K_0. The g_s varied with change in K-nutrition or sources. Crop fertilized with K_2SO_4 and

Table 1. Effect of potassium nutrition on net photosynthetic rate (P_N) [μmol(CO_2) m^{-2} s^{-1}], transpiration rate (E) [mmol(H_2O) m^{-2} s^{-1}], water use efficiency (WUE = P_N/E) [μmol(CO_2) $mmol^{-1}(H_2O)$], stomatal conductance (g_s) [cm s^{-1}], and canopy temperature (T_c) [ºC]. ns: non-significant at the 0.05 level; **significant at the 0.01 level.

	Cultivar	KCl				K_2SO_4		
		K_0	$K_{6.25}$	$K_{12.5}$	$K_{25.0}$	$K_{6.25}$	$K_{12.5}$	$K_{25.0}$
P_N	CIM-448	12.6	16.1	21.2	25.3	16.8	21.6	26.7
	CIM-1100	15.4	18.1	20.0	24.1	18.6	21.1	25.9
	Karishma	11.9	13.6	17.4	20.4	13.9	17.9	21.1
	S-12	10.8	12.2	14.2	17.2	12.5	15.0	17.8
	LSD (p<0.05)	Cultivar (Cv) 0.36**		Dose (D) 0.17**		Source (S) 0.14**	Cv×D 0.34**	Cv×S 0.28** D×S 0.24**
E	CIM-448	3.71	4.55	5.64	5.64	4.56	5.64	6.23
	CIM-1100	4.63	5.07	5.33	5.88	5.12	5.35	5.91
	Karishma	2.89	3.15	3.35	3.61	3.18	3.35	3.64
	S-12	3.90	4.18	4.73	5.35	4.20	4.75	5.42
	LSD (p<0.05)	Cultivar (Cv) 0.04**		Dose (D) 0.04**		Source (S) 0.04*	Cv×D 0.08**	
WUE	CIM-448	3.41	3.54	3.76	4.04	3.69	3.84	4.28
	CIM-1100	3.35	3.56	3.75	4.10	3.63	3.95	4.38
	Karishma	4.12	4.32	5.20	5.66	4.39	5.35	5.80
	S-12	2.77	2.92	2.99	3.22	2.97	3.17	3.29
	LSD (p<0.05)	Cultivar (Cv) 0.08**		Dose (D) 0.05**		Source (S) 0.04**	Cv×D 0.11**	
g_s	CIM-448	0.13	0.15	0.18	0.22	0.16	0.19	0.23
	CIM-1100	0.15	0.16	0.18	0.21	0.16	0.20	0.25
	Karishma	0.13	0.15	0.19	0.22	0.17	0.21	0.26
	S-12	0.14	0.16	0.17	0.18	0.18	0.19	0.23
	LSD (p<0.05)	Cultivar (Cv) 0.04**		Dose (D) 0.05**		Source (S) 0.03**	Cv×D 0.09**	
T_c	CIM-448	31.5	31.1	30.3	29.4	31.1	30.3	29.4
	CIM-1100	30.2	29.7	29.4	29.2	29.6	29.4	29.2
	Karishma	31.0	30.7	30.5	30.2	30.7	30.5	30.1
	S-12	30.0	30.8	30.5	30.2	30.8	30.5	29.9
	LSD (p<0.05)	Cultivar (Cv) 0.21**		Dose (D) 0.30**		Source (S) 0.23**		

Table 2. Effect of potassium nutrition on leaf water potential (Ψ_w), osmotic potential (Ψ_s), and pressure potential (Ψ_p) in four cotton cultivars. **significant at the 0.01 level.

	Cultivar	KCl				K_2SO_4			
		K_0	$K_{6.25}$	$K_{12.5}$	$K_{25.0}$	K_0	$K_{6.25}$	$K_{12.5}$	$K_{25.0}$
Ψ_w	CIM-448	1.68	1.78	1.82	1.87	1.66	1.74	1.80	1.87
[–MPa]	CIM-1100	1.67	1.77	1.80	1.83	1.66	1.72	1.76	1.83
	Karishma	1.64	1.71	1.75	1.79	1.59	1.60	1.70	1.76
	S-12	1.62	1.64	1.67	1.71	1.60	1.61	1.63	1.71
	LSD (p<0.05)	Cultivar 0.03**		Dose 0.02**		Source 0.02**			
Ψ_s	CIM-448	2.28	2.40	2.49	2.59	2.29	2.42	2.54	2.66
[–MPa]	CIM-1100	2.36	2.49	2.60	2.68	2.38	2.49	2.60	2.73
	Karishma	2.13	2.27	2.34	2.43	2.13	2.29	2.38	2.52
	S-12	2.04	2.12	2.22	2.36	2.04	2.17	2.28	2.41
	LSD (p<0.05)	Cultivar 0.05**		Dose 0.03**		Source 0.02**			
Ψ_p	CIM-448	0.60	0.62	0.67	0.72	0.63	0.68	0.74	0.79
[MPa]	CIM-1100	0.69	0.72	0.80	0.85	0.72	0.77	0.84	0.90
	Karishma	0.49	0.56	0.59	0.64	0.54	0.63	0.68	0.76
	S-12	0.42	0.48	0.55	0.65	0.44	0.56	0.65	0.70
	LSD (p<0.05)	Cultivar 0.06**		Dose 0.030*		Source 0.02**		Cv×D 0.06*	

KCl maintained g_s of 0.21 and 0.17 cm s^{-1}, respectively.

The canopy temperature ranged from 29.2 to 31.5 °C in different treatments (Table 1). The cvs. CIM-448, Karishma, and S-12 had canopy temperature 30.3–30.6 °C compared to cv. CIM-1100 maintaining 29.7 °C. The canopy temperature decreased with concurrent changes in K supply.

The cv. CIM-448 maintained slightly lower Ψ_w than

the other cultivars at all K doses (Table 2). Ψ_w decreased gradually in all cultivars with concurrent increase in K supply. The lowest value (–1.80 MPa) was observed under $K_{25.0}$. Ψ_w had a profound effect on reproductive growth of cotton plants. The number of total intact fruit per m^2 increased with concurrent decrease in Ψ_w. There was a positive correlation coefficient ($r = 0.93^{**}$) between Ψ_w and number of intact fruit per m^2. The osmotic potential (Ψ_s) decreased significantly ($p<0.01$) due to varying K-supply and sources (Table 2). Both the K sources affected leaf osmotic potential almost uniformly.

K-nutrition had also a significant effect on leaf pressure potential (Ψ_p) (Table 2). Cultivar CIM-1100 had a higher Ψ_p compared to the other cultivars. The Ψ_p increased with concurrent increase in K-levels. Crop at $K_{25.0}$ maintained 35.7 % higher Ψ_p compared to K-unfertilized crop. Addition of K-fertilizer in the form of K_2SO_4 also showed an edge of 9.5 % over KCl in maintaining higher Ψ_p. With respect to Ψ_p, the cultivars were in decreasing order of CIM-1100>CIM-448>Karishma>S-12.

Addition of various doses of K fertilizer caused a significant increase in K^+ content in leaf tissues but the cultivars did not differ much in this variable (Table 3).

Table 3. Effect of potassium fertilizer doses on potassium content [%] in leaf tissues at bloom stage (on dry mass basis). ns: non-significant at the 0.05 level; ** significant at the 0.01 level.

Cultivar	KCl				K_2SO_4		
	K_0	$K_{6.25}$	$K_{12.5}$	$K_{25.0}$	$K_{6.25}$	$K_{12.5}$	$K_{25.0}$
CIM-448	2.76	3.09	3.22	3.34	3.11	3.25	3.36
CIM-1100	2.69	2.97	3.09	3.24	2.99	3.10	3.29
Karishma	2.75	3.14	3.18	3.28	3.16	3.21	3.31
S-12	2.62	3.09	3.10	3.28	3.10	3.13	3.33
LSD ($p<0.05$)	Cultivar 0.05^{**}			Dose 0.05^{**}		Source 0.06^{ns}	

Discussion

A consistent increase in P_N and g_s was observed in all cotton cultivars with increase in K supply of the growth medium. These data can be related to earlier studies (Longstreth and Nobel 1980, Shamsun-Noor *et al.* 1991) which showed that K deficiency results in decreased P_N due to decreased g_s. The increase in E in all cultivars due to K-supply corroborates with the results of Shamsun-Noor *et al.* (1991) that K deficiency results in decreased E. Longstreth and Nobel (1980) and Ashraf *et al.* (2001) reported that K-deficient plants had greater stomatal diffusive resistance (lower g_s) than those with higher K supply. Zhao *et al*. (2001) also found that K-deficient cotton plants exhibited only 23 % of P_N of the crop receiving a full K supply.

With increasing soil K supply, Ψ_w and Ψ_s were generally decreased, whereas Ψ_p increased. The association of K supply with plant water relations found in the tested cotton cultivars can be explained in view of the fact that K is absorbed both passively and actively and may be important in osmotic adjustment (Brouder 1999, Ashraf *et al*. 2001, 2002). Bar-Tsur and Rudich (1987) reported that cotton plants from the KCl treatment responded by a concomitant decrease in Ψ_s, which enabled maintenance of positive Ψ_p. The main contribution to osmotic adjustment was found from the accumulation of inorganic minerals such as K^+ and Cl^- in leaves and flower buds. They further reported that prolonged KCl stress enabled the cotton plant to withstand successive water stress, but the cotton plant could not overcome growth inhibition. Pettigrew (1999) reported that Ψ_p increased by 17 % in leaves due to addition of K fertilizer compared to that of K deficient cotton plants. However, our results showed that crop receiving $K_{25.0}$ maintained 35.7 % higher Ψ_p than the K unfertilized crop. Mengel and Arneke (1982) reported that addition of K fertilizer raised Ψ_p, which resulted in cell enlargement and continuity in growth.

In our experiment K fertilization resulted in marked improvement of WUE. Similarly, Reddy *et al*. (1997) reported that WUE increased mainly due to increased P_N and partly to reduced canopy E. Some earlier studies (Mottram 1987, Ashraf *et al.* 2001, 2002) also support these data. Hatfield *et al*. (2001) reported that modifying nutrient management practices could increase WUE by 15–25 %.

The high degree of association between K doses and physiological processes imply that high supply of K must be aimed at under dryland conditions (Mottram 1987). Karami *et al.* (1980) reported that Super okra genotype was able to maintain a higher Ψ_p due to lower Ψ_w and Ψ_s and in turn that was related to higher P_N. Thus, improvement in drought tolerance or WUE should be explored genetically despite adopting optimum mineral nutrition and water management strategies.

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