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INFLUENCE OF POTASSIUM NUTRITION ON LEAF AREA INDEX IN COTTON (*GOSSYPIUM HIRSUTUM* L.) UNDER AN ARID ENVIRONMENT

H. PERVEZ[1], M. I. MAKHDUM[2], M. ASHRAF[3] AND SHABAB-UD-DIN[2]

[1]*Department of Chemistry, Bahauddin Zakariya University, Multan, Pakistan.*
[2]*Central Cotton Research Institute, Multan, Pakistan.*
[3]*Department of Botany, University of Agriculture, Faisalabad, Pakistan.*

Abstract

A field experiment was conducted at Central Cotton Research Institute, Multan, Pakistan to study the effects of potassium nutrition on leaf area index in cotton (*Gossypium hirsutum* L.) The treatments consisted of four cotton cultivars (CIM-448, CIM-1100, Karishma, S-12), four potassium-rates (0, 62.5, 125.0, 250.0 kg K ha^{-1}) and two sources of potassium-fertilizer [potassium chloride (KCl), potassium sulphate (K_2SO_4)]. During the early part of the season, leaf area index progressed slowly and required 60 days to reach at 1.5 and then it reached at 4.02 within next 30 days. Thereafter, it declined gradually to minimums of 0.62 at maturity. Cultivar CIM-1100 maintained the highest leaf area index compared to other cultivars. Leaf area index increased with concurrent increase in potassium-levels. The regression analysis indicated a highly significant relationship (r = 0.94**) between potassium levels and leaf area index. Addition of potassium fertilizer in the form of potassium sulphate showed an edge over potassium chloride. There were highly significant ($p<0.01$) relationships between leaf area index and number of total fruit, number of bolls per plant, plant height, total dry weights and leaf dry weights.

Introduction

All factors influencing growth and development of crop plants must be integrated at an optimum level, if the maximum production potential is to be attained. Since leaves are the principal carrier of chlorophyll, an essential material for photosynthesis, their size must have a profound effect on production of crop plants. Leaf area index (LAI) beside its efficiency to produce photosynthate, determines the growth rate and crop yield (Ritchie & Burnett, 1971). Ashley *et al*., (1965) indicated that LAI reached to 1.0 approximately 6 to 8 weeks after emergence. It increased rapidly from 1.0 to 5.0 during the ensuing 6 weeks period. The formation of new fruit was dependent on concurrent vegetative growth until LA1 reached 5.0. Yields of seed cotton increased with an increase in LAI. Taha *et al*., (1982) assumed that full cover for different genotypes of (*Gossypium hirsutum* L.) sown at population of 3.5–4.0 plants per m^{-2} was attained at about 60 days from sowing at LA1 of 1.5, which was also about the time that plants were touching in the rows. Hearn (1972) assumed that an LAI of 2.8 could provide complete canopy cover in different genotypes at usual spacings. The LAI of 2.8 was achieved at about 100 days from planting. Makhdum *et al*., (1984) reported that ground period for leaf area expansion and canopy cover occurred between days 62 to 96 that is flowering phase. Full canopy cover was achieved at an LAI of 5.0 after the appearance of first flower.

Corresponding Author: Email: pdhpervez@hotmail.com Tel: 061-9210083

The decrease in leaf area growth with limiting supply of nitrogen is well documented in cotton and other species. Fernandez *et al*., (1996) reported that nitrogen deficit decreased whole-plant cumulative leaf area to about 40%. A few studies have been addressed how whole plant growth patterns can be altered by varying levels of potassium (K) fertilization in cotton. Cassman *et al*., (1989) reported that the dry weights for the total plant was reduced by K deficiency. Pettigrew & Meredith (1997) did not find significant total dry matter differences between control and K deficient plants, but they did report lower LAI and plant height for the K-deficient plants. Huber (1985) also demonstrated that maximum leaf area expansion of soybean [*Glycine max* (L.) Merr] was reduced under K-deficient conditions. This most likely also happens in cotton and could lead to some of the elevated nutrient concentrations seen in leaves from K-deficient plants (Pettigrew & Meredith, 1997), due to less leaf material being available for dilution of the nutrients (Dibb & Thompson Jr., 1985). Tanaka (1972) reported asymptotic relationship between LA1 and net assimilation rate and had higher optimum LAI values in various rice varieties when the LAI is optimum. Excess nitrogen nutrition enhances leaf growth and the grain yield of rice is depressed because of higher mutual shading. High levels of phosphorus and potassium nutrition cannot counteract this negative effect of nitrogen.

Both fruit production and retention are dependent on leaf development and the leaf's photosynthetic integrity. Jackson & Gerik (1990) found that plant's maximum LAI and boll carrying capacity are linearly related and reported that about 10 dm^2 leaf area is needed to support one boll. The most critical time for cotton leaf growth occurs between 40 and 65 days after planting, which coincides with the time from first square to first flower appearance (Oosterhuis, 1990). Therefore, the objectives of this research were to determine the effects of varying levels of potassium fertilizer and its sources in various cotton (*Gossypium hirsutum* L.) cultivars in the field under semi-arid environment.

Materials and Methods

A field experiment was conducted at the Central Cotton Research Institute Multan, a central location for cotton cultivation in Pakistan. Soil samples were collected before imposition of fertilizer treatments at planting time. The analyses of soil samples were carried out as per methods described by Ryan *et al*., (2001). The soil was silt loam having alkaline reaction (pH 8.3). The soil contained 0.67% organic matter, 7.3 mg kg^{-1} available phosphorus and 80 mg kg^{-1} exchangeable-potassium in the top 0-30 cm profile. The soil was porous, friable, moderately calcareous, weakly structured and developed in an arid sub-tropical continental climate in the areas of sub-recent flood plains. The soil was alluvium of mixed mineralogy with smectites and mica being dominant clay minerals followed by kaolinites and chlorites with various degrees of weathering. The soil belongs to Miani soil series being classified as Calcaric Cambisols and fine silty, mixed hyperthermic Fluventic Haplocambids according to FAO (Anon., 1990) and USDA Soil Classification (Anon., 1998) systems respectively.

The treatments consisted of (a) four cotton cultivars (CIM-448, CIM-1100, Karishma, S-12), (b) four potassium fertilizer doses (0, 62.5, 125.0, 250.0 kg K ha^{-1}) and (c) two potassium fertilizer sources [sulphate of potash (K_2SO_4) and muriate of potash (KCl)]. The design of the experiment was split plot (main: cultivar, sub plot: K- doses; sub-sub plot: K sources having four replications. Crop was sown at a spacing of 75 cm between rows and 20 cm between plants. Cotton seed was dibbled manually at the rate of 25 kg ha^{-1}. Crop also received 22 kg P ha^{-1} as triple superphosphate at planting and 150 kg N ha^{-1} as urea in the split doses i.e., planting, flowering and peak flowering. The whole quantity of potassium and phosphorus was applied at the time of seedbed preparation and incorporated in the plough layer. Stomp-330E, 2.5L ha^{-1} as pre-emergence herbicide was applied to control weeds. Crop was kept free from insect pest attack through regular sprays of common pesticides. The total quantity of applied irrigation water and total precipitation was 2581 m^3 ha^{-1} and 86 mm during the season, respectively. The first post-plant irrigation was applied at day 30 after planting, followed by 15-20 days intervals during the season. The cut-out irrigation was applied during first week of October.

The above ground portion of the plant was removed at five sequential harvests viz., first flower bud, first flower, peak flowering, first boll split and maturity from each treatment. The plants were harvested from one square meter area and partitioned into leaves, stems and fruit in the laboratory. The measurements on leaf area were recorded by employing automatic leaf area measurement system (Delta-T Devices, England). Data on leaf area index were computed according to method of Radford (1967). Data were subjected to statistical analysis according to the methods of Montgomery (1997).

Results

The leaf area index (LAI) progressed slowly, requiring approximately 60 days to reach at LAI of 1.5 during the early part of season. The early period of slow development of LAI was followed by a period in which the LAI increased from 1.5 to 4.02 in approximately 28-45 days. Therefore, the cotton plants had reached an LAI of 4.02 in 90 days after planting and then declined gradually to minimums of 0.62 on the last date of measurement (Fig. 1).

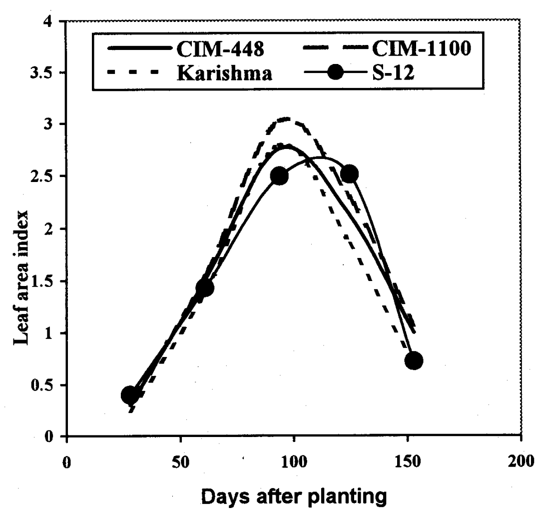

Fig. 1. Pattern of leaf area index production in different cultivars during the season.

Table 1. Leaf area index as influenced by potassium nutrition in four cotton cultivars.

Cultivar	KCl [kg K ha^{-1}]				K_2SO_4 [kg K ha^{-1}]			
	0	**62.5**	**125.0**	**250.0**	**0**	**62.5**	**125.0**	**250.0**
First flower bud								
CIM-448	0.26	0.29	0.31	0.32	0.26	0.30	0.31	0.32
CIM-1100	0.28	0.29	0.32	0.32	0.28	0.29	0.32	0.32
Karishma	0.23	0.23	0.25	0.25	0.23	0.25	0.25	0.25
S-12	0.22	0.23	0.23	0.24	0.22	0.23	0.23	0.24
LSD ($p<0.05$)	Cultivar 0.01**		Dose 0.01**		Source 0.01^{ns}			
First flower								
CIM-448	1.40	1.44	1.53	1.63	1.40	1.45	1.57	1.65
CIM-1100	1.42	1.52	1.56	1.60	1.42	1.53	1.58	1.63
Karishma	1.25	1.27	1.33	1.38	1.25	1.28	1.36	1.39
S-12	1.27	1.29	1.35	1.38	1.27	1.31	1.37	1.40
LSD ($p<0.05$)	Cultivar 0.06**		Dose 0.05**		Source 0.07^{ns}			
Peak flowering								
CIM-448	2.05	2.24	2.72	3.78	2.05	2.29	2.97	3.90
CIM-1100	2.33	2.61	3.00	3.94	2.33	2.73	3.13	4.02
Karishma	1.73	2.03	2.59	3.21	1.73	2.14	2.63	3.42
S-12	1.76	1.83	2.12	2.65	1.76	1.88	2.28	2.76
LSD ($p<0.05$)	Cultivar 0.07**		Dose 0.05**		Source 0.03**		CvxD 0.11**	
First boll split								
CIM-448	1.70	1.88	2.10	2.67	1.70	1.96	2.15	2.74
CIM-1100	1.91	2.16	2.24	2.67	1.91	2.26	2.30	2.81
Karishma	1.37	1.60	1.92	2.35	1.37	1.62	1.99	2.49
S-12	1.51	1.67	2.02	2.19	1.51	1.78	2.03	2.33
LSD ($p<0.05$)	Cultivar 0.04**		Dose) 0.04**		Source 0.03**		CvxD 0.09**	
Maturity								
CIM-448	0.68	0.89	1.12	1.25	0.68	0.90	1.15	1.27
CIM-1100	0.84	1.03	1.17	1.22	0.84	1.03	1.18	1.23
Karishma	0.62	0.66	0.68	0.71	0.62	0.67	0.69	0.71
S-12	0.68	0.71	0.74	0.75	0.68	0.71	0.74	0.75
LSD ($p<0.05$)	Cultivar 0.01*		Dose 0.02*		Source 0.01*		CvxD 0.05**	

ns = non-significant at the 0.05 level, *,** = Significant at 0.05 and 0.01 level respectively

Data for leaf area index differed significantly due to cultivar (Cv), K-doses (D) and K-sources (S). However, it was affected non-significantly because of sources during first flower bud and first flower stage. The interaction terms, (CvxS, DxS, CvxDxS) were non-significant (Table 1). Cultivars differed significantly amongst themselves in attaining LAI at different stages of growth. Cultivar CIM-1100 maintained the highest LAI compared to other cultivars. The differences occurred because of their genetic make-up in attaining LAI at different stages of growth. The LAI increased significantly under varying levels of K-fertilizer. Crop maintained the highest LAI under 250 kg K ha^{-1} compared to K-unfertilized treatment during the growth period. The regression analysis indicated a highly significant relationship (r = 0.94**) between K-levels and leaf area index with regression equation as Y= 1.839+0.006x. The increase in LAI values resulted due to higher nitrogen concentration in leaf tissues through sustained supply of potassium content in the presence of sufficient availability in soil-plant continuum. Regression analysis showed a highly significant relationship (r = 0.91**) between nitrogen and potassium in leaf blade with regression equation as Y= 2.764+0.002211x. The application K fertilizer in the form of KCl or K_2SO_4 had a little affect on LAI during early stages of growth, however, differences were cropped up during peak flowering stage and onwards. Addition of K in the form of K_2SO_4 showed an edge over KCl in increasing LAI. Cultivar CIM-1100 attained maximum LAI of 4.02 at 250 kg K ha^{-1} compared to K-unfertilized treatment having 2.33 value at peak flowering stage.

Correlation coefficients presented in Table 2 show a positive relationship throughout the period of measurement, between LAI and total number of fruits m^{-2} and between LAI and number of bolls per plant. The relationship between LAI and number of bolls indicates that boll set is also influenced by leaf area. The relationships between LAI and total fruit indicate that flower bud initiation was highly dependent on concurrent vegetative growth, and that a minimum LAI of 2.3 to 3.5 was required if fruit set was to exceed shedding during peak flowering stage. A high degree of correlation (r= 0.91**) was measured between LAI and dry weight of leaves. Dry weight and plant heights were both directly related to LAI. Other growth factors that were directly related were dry weight and plant height, dry weight and total number of fruit, and plant height and number of total fruit.

The results indicated that K addition resulted in large cotton plants with higher number of leaves to produce and retain large quantities of fruit. The vigorous growth and development under 250 kg K ha^{-1} treatment produced the highest yield (Table 3). Furthermore, data for seed cotton yield differed significantly due to cultivars, K-doses and K-sources. The correlation co-efficient between LAI and seed cotton yield was r=0.98**. The relationship could be described by an equation (Y=-2691.5188 +3805.1465x-1012.3261x^2+102.87x^3). These data showed that plant size had a much greater influence on yield potential.

Discussion

The increase in leaf area index values resulted due to high maintenance of nitrogen concentration in leaf tissues under sustained supply of K^+ in soil-plant continuum. Mengel *et al*., (1976) and Silberbush & Lips (1991) also reported the much higher N and K^+ uptake with higher K-rate. Huber (1985) also reported that K^+ affects photosynthetic capacity positively because of the dependence of protein synthesis and developmental processes on K^+. Thus, the carbon exchange rates of an expending leaf is restricted rapidly after the onset of K^+ deficiency. In addition, maximum leaf expansion may be reduced as a result of K^+ deficiency, whereas leaf initiation proceeds unaffected. The results of this study are in contrast with the findings reported by Suevanarit & Sestapukdee (1989) that the size of leaf area was not affected by K application and agreed with results of (Lonhaed & Nemeth, 1989; Ashraf *et al*. 2002), who found an increase in leaf area approximately of 20 percent with the application of potassium. The results of this study are in contrast with those of Suevanarit & Sestapukdee (1989) that the size of leaf area was not affected by K-nutrition. These results agree with those of Lonhard & Nemeth (1989) and Ashraf *et al*., (2002) who found an increase in leaf area approximately 20% with application of K fertilizer. Ritchie & Burnette (1971) also indicated a close relationship between vegetative vigour and fruiting of cotton crop. These data demonstrate that leaf area index is the determinant factor for increasing yield potential of cotton crop.

Table 2. Relationships between leaf area index (LAI) with vegetative characteristics and fruiting of cotton plant.

Variables	Regression equation	Correlation co-efficient (*r*)
LAI vs. number of total fruit m^{-2}	236.41+87.034x	0.56**
LAI vs. number of bolls $plant^{-1}$	$-42.887+53.216x-15.028x^2+1.493x^3$	0.94**
LAI vs. Plant height (cm)	$-19.779+101.971x-30.838x^2+3.342x^3$	0.95**
LAI vs. total dry weights	$-732.976+1021.19x-253.744x^2+21.343x^3$	0.91**
LAI vs. Leaf dry weights	-365.94+437.277x-130.625+13.266	0.90**
Total dry wt. vs. plant height	-232.54242+8.35212x	0.71**
Total dry wt. vs. number of total fruit m^{-2}	$-203.189+3.497x-0.00866x^2$	0.97**
Plant height vs. number of total fruit m^{-2}	-224.872+7.405x	0.53**

** = Significant at the 0.01 level.

Table 3. Effect of different doses and sources of potassium fertilizer on seed cotton yield (kg ha^{-1}) in four cotton cultivars.

Cultivar	KCl [kg K ha^{-1}]				K_2SO_4 [kg K ha^{-1}]			
	0	**62.5**	**125.0**	**250.0**	**0**	**62.5**	**125.0**	**250.0**
CIM-448	2204	2504	2601	2856	2204	2548	2680	3065
CIM-1100	1854	1940	2154	2332	1854	2167	2380	2470
Karishma	1548	1811	1818	2098	1548	1902	2003	2280
S-12	1340	1426	1775	1891	1340	1456	1799	2094

LSD ($p < 0.05$)

Cultivar (Cv)	51.12**	Cv x S	69.92**
Dose (D)	37.72**	D x S	57.06**
Sources (S)	34.96**	Cv x D x S	114.12**
Cv x D	75.43**		

** = Significant at the 0.01 level.

Good agronomic practices are essential to make efficient use of K fertilizer. This includes the early establishment of a good cover crop to minimize run-off of pesticides application in cotton. In cotton, the reduction in photosynthesis caused by a moderate K deficiency was related primarily to increased mesophyll resistance (Longstreth & Nobel, 1980). Imposition of K deficiency at any stage of leaf expansion resulted in decreased leaf K^+ concentration relative to unstressed plants. The photosynthesis was restricted when leaves contained less than 15 to 20 g K kg^{-1} (Cooper *et al*., 1967).

Potassium is the most important inorganic osmotic component and stimulates growth primarily by its effects on cell extension (Mengel & Arneke, 1982). The maximum leaf expansion may be reduced as a result of K^+ deficiency, even when the water relation of the leaves are normal (Pettigrew, 1999). In an earlier study, Huber (1985) reported that total photosynthetic leaf area was markedly reduced in soybean [*Glycine max* (L.) Merr.] plants. This most likely also happens in cotton and could lead to lowering leaf area index (LAI) from K deficient plants (Pettigrew & Meredith, 1997); due to less leaf material being available for dilution of nutrients (Dibb & Thompson 1985). K is taken up by plants together with an anion (Kufkafi *et al*., 2002), particularly Cl^- or NO_3^-. The substantial proportion of the effects of K on plant growth and sugar concentration are presumably the combined effects of both K and its accompanying anion.

In an earlier study, analogous results have been obtained for potatoes (*Solanum tuberosum* L.) by Haeder (1975), who also reported that K_2SO_4 promoted photosynthate transport better than did KCl. In the recent study Pervez *et al*., (2004) reported that addition of K-fertilizer in the form of K_2SO_4 showed an edge of 9.5% over KCl in maintaining higher leaf water potential. With respect to leaf water potential, the cultivars were found in decreasing order of CIM-1100 > CIM-448 > Karishma > S-12. Furthermore, Pervez *et al*., (2004) also found a significant interaction between cotton cultivar and form of potassium fertilizer for seed cotton yield. The positive influence of K_2SO_4 was due to its accompanying anion (SO_4^{2-}) of potash. The application of potassium fertilizer in the form of KCl had a depressing effect on yield under an arid environment.

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