Effect of Water Potential on Uptake and Accumulation of Cations by *Sorghum* Seedlings

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Summary: A laboratory experiment was conducted to evaluate the effect of five different levels of water potential (ψ) viz., 0.00; -4.09; -8.18; -12.28 and -16.36 bars on the uptake and accumulation of K^+, Ca^{2+} and Na^+ contents of six cultivars of *Sorghum bicolor* L. seedlings. Mannitol was used as an osmoticum alongwith half strength Hoagland culture solution. Results depicted that in relation to different levels of water potential all mentioned cations responded significantly ($P < 0.05$). Cultivars response was also found to be significant. Results further revealed that as water potential level increased, K^+, Ca^{2+} and Na^+ contents of both root and shoot were generally decreased. Maximum level of K^+ (13.69 mg g^{-1}) and Na^+ contents (308.10 mg kg^{-1}) in roots were obtained for water potential level of - 4.09 bars. While in case of shoot, maximum level of K^+ (25.37 mg g^{-1}) was also recorded in - 4.09 bars. Whereas, maximum Ca^{2+} both for root and shoot (7.47 and 4. 050 mg g^{-1}) was found in control level of water potential. Data also showed that in general there was an increase uptake of 39. 08 and 79.75 % in Ca^{2+} and Na^+ contents of root over shoot, respectively. Whereas, shoot K^+ contents was 14.16 % greater over their respective roots. Relatively much higher concentration of cations in root than in shoot suggests that the upward translocation/ uptake of these ions were influenced by imposed water potential levels. Results based on cumulative drought tolerance index (%) of cations accumulation, *Sorghum bicolor* cv. Giza-3 could be rated as drought tolerant and cv. ICSV = 107 and Pak. S.S.II as drought sensitive. While remaining three cultivars viz., 1747, S.E.T P = 14 - 2 and ICSH = 479 could be rated as drought intermediate in response, respectively.

Introduction

Sorghum bicolor L. Moench is a crop, which is widely grown all over the world for food and feed. It is a key staple in many parts of the developing world, especially in the drier and more marginal areas of the semi tropics [1]. It is also an important kharif grain crop of the country. Many cultivars of this crop are being grown in irrigated and rain-fed areas. In Pakistan, it is grown over an average of 3,46,700 ha y^{-1} with an average annual production of 2,41,767 t or 0.697 t ha^{-1} [2]. While in Balochistan province, it is grown on an area of 21,333 ha with a total production of 18,835 t or an average of 883 kg ha^{-1} [3]. The cultivation and production of both the country as well as of province is very low as compared with the production potential of the said crop.

Potassium (K^+) is one of the sixteen essential nutrients required for plant growth and reproduction. It plays a vital role in regulation of water content, upkeep of turgor pressure, resistance of drought and plant diseases, photosynthesis, divert of photosynthate to plant stores, movement and transmission of signals. Therefore, K^+ deficiency causes a variety of dysfunctions in plants metabolic processes, which result in, decreased productivity and quality of the crop yield [4]. All living cells have an absolute requirement for K^+, which must be taken up from the external medium.

If K^+ is limiting then Na^+ could substitute for K^+ in some cellular functions, but in others it is toxic. In the vacuole Na^+ is not toxic and can undertake osmotic functions, reducing the total K^+ requirements and improving growth when the lack of K^+ is a limiting factor. Because of these physiological requirements, the terrestrial life of plants depends on high-affinity K^+ uptake systems and benefits from high-affinity Na^+ uptake systems. In plants, both systems have received extensive attention during recent years and a clear insight of their functions is emerging [5].

Among various constraints responsible for low grain yield, inadequate water supply (water stress) at its critical developmental stages and high sensitivity of different sorghum cultivars to water stress/ deficit are of immense importance [6-7]. Water stress can be measured in terms of water potential, and water potential is the chemical potential of water. Water stress not only modifies the morphology of plants but also adversely affects its metabolism [8]. Morgan [9] showed that yields were higher in genotypes or cultivars, which were capable of adjusting osmotically under water deficit. The compound involved in osmotic adjustment are mostly soluble sugars, K, Organic acids, chloride and free amino acids [10-11]. Research revealed that a wide range of compounds have been found to accumulate by different plant species subjected to water stress [12-15]. It is very important for scientists to find some sorghum cultivars with the capability of absorbing and accumulating extraordinarily high amounts of cations under water stress/deficit conditions. The present study was, therefore, designed to select a suitable sorghum cultivar with high uptake and accumulation of cations under water stress conditions.

Materials and Methods

The work presented here deals with the effect of four different levels of water potential (Ψ) i.e., 0.00, -4.09, -8.18, -12.28 and –16.36 bars on the seedling growth of six cultivars of sorghum (*Sorghum bicolor* L.) viz., Giza-3, ICSH=479, ICSV=107, Pak. S. S. II, S.E.T P=.14-2 and 1747. These cultivars were then designated as cv_1, cv_2, cv_3, cv_4, cv_5 and cv_6, respectively. The water potential treatments (Ψ) were prepared by dissolving calculated amount of mannitol ($C_6H_{14}O_6$) in deionized water, using the formula as described by Ting [16]. Half strength of Hoagland culture nutrients was also dissolved separately in each treatment. The treatments were then designated as

Ψ_1, Ψ_2, Ψ_3, Ψ_4 and Ψ_5.

$$\Psi\text{ (bars)} = \frac{-21.8 \times M \times T}{273}$$

After treating with 1.0 % mercuric chloride solution, the seeds of each cultivar were soaked in respective water stress treatments and incubated in petri-dishes of 9 cm in diameter at 30 ^{0}C. Each treatment was replicated thrice and arranged in a Completely Randomized Design (CRD). The detail procedure is found in Achakzai and Bazai [17]. After 15 days of germination, root and shoot of sorghum seedlings were kept separately in an oven at 80 ^{0}C for 24 hours. After weighing, root and shoot of each treatment was separately digested by wet digestion method using nitric acid and perchloric acid [18]. For possible extraction of metal ions, plant material was neutralized to pH 7.5-8.5 by the addition of NaOH. Thereafter each of the samples was separately analyzed for K^+, Ca^{2+} and Na^+ contents. These cations were determined by Flame Photometry using Corning 400 model Flame Photometer equipped with methane burner.

Data obtained for cations of sorghum seedlings were statistically analyzed following the procedure as described by Steel and Torrie [19]. MSTAT-C computer software package was used for the purpose. Drought tolerance index (DTI) was Calculated following the formulae given below:-

1. DTI for cations Accumulation (%) =

$$\frac{\text{Individual cation accumulation by Seedlings of } \Psi_5 \text{ treatment (-16.36 bars)}}{\text{Individual cation accumulation by Seedlings of } \Psi_1 \text{ treatment (0.00 bars)}} \times 100$$

2. Cumulative Drought Tolerance Index (%) =

$$\frac{\text{Average amount of all cations in } \Psi_5 \text{ treatment (-16.36 bars)}}{\text{Average amount of all cations in } \Psi_1 \text{ Treatment (0.00 bars)}} \times 100$$

Results and Discussion

Results presented in Table- 1 showed that in relation to various levels of water potential, all mentioned species of cation as well as their cultivars responded significantly ($P < 0.05$). The interaction between water potential and sorghum cultivars are also found significant (except of root K^+ content). Similar findings have been also obtained by Achakzai (2006) for cations accumulation in six maize cultivars.

Data presented in Table- 2 and 3 depicted that various levels of water potential significantly reduced the shoot K^+ contents (except in ψ_2), but remained unaffected in case of roots when compared with their respective control level of water potential. Maximum uptake of K^+ by roots (13.69 mg g^{-1}) and shoots (25.37 mg g^{-1}) is recorded in ψ_2. Data also enumerated that based on grand mean values, K^+ content in shoot (17.740 mg g^{-1}) was much greater than their respective roots (9.906 mg g^{-1}). Research revealed that K^+ is one of the major and active osmotic contributors and is actively involved in the osmotic adjustment by

Table-1. Analysis of variance (ANOVA) for endogenous levels of few metabolites of *Sorghum bicolor* L cultivars in response to imposed water potential levels.

Variables	F-value of variables			
	Cultivars (CV)	Water potential levels (ψ)	CV x ψ	Cf.V (%)
1) Root K^+ content (mg g^{-1})	1.8 *	1.6 *	0.1ns	102.23
2) Shoot K^+ content (mg g^{-1})	3885.9 *	30800.4 *	1489.0 *	0.84
3) Root Ca^{2+} content (mg g^{-1})	294.4 *	246.0 *	140.0 *	4.45
4) Shoot Ca^{2+} content (mg g^{-1})	332.3 *	94.5 *	66.3 *	3.99
5) Root Na^+ content (mg kg^{-1})	10910.2 *	11641.3 *	3168.0 *	0.88
6) Shoot Na^+ content (mg kg^{-1})	24631.3 *	26576.1 *	9940.1 *	0.64

* Significant at 5 % level of probability and ns = non-significant.
Cf. V = coefficient of variation

Table- 2. Effect of five different level of water potential on root K^+ content (mg g^{-1}) of six cultivar of *Sorghum bicolor* L.

Water Potential Levels (ψ)	Sorghum Cultivars (CV) CV_1	CV_2	CV_3	CV_4	CV_5	CV_6	*Mean
ψ_1	14.87 ab	17.90 ab	16.30 ab	7.50 ab	8.40 ab	8.33 ab	12.22 ab
ψ_2	18.10 ab	19.40 a	15.90 ab	8.33 ab	9.90 ab	10.50 ab	13.69 a
ψ_3	15.03 ab	10.60 ab	9.20 ab	4.77 ab	9.00 ab	6.93 ab	9.26 ab
ψ_4	13.33 ab	10.60 ab	8.03 ab	7.73 ab	6.00 ab	3.73 ab	8.24 ab
ψ_5	9.77 ab	6.67 ab	10.17 ab	2.77 b	2.73 b	4.67 ab	6.13 b
*Mean	14.22 a	13.03 ab	11.92 ab	6.22 b	7.21 ab	6.83 ab	9.906

LSD (for CV) = 7.396; LSD (for ψ) = 6.572; LSD (for ψ x CV) = 16.540

Values followed by the same letter within columns (cv) and rows (ψ), and similarly mean values (*) followed by the same letter within a column and row are not significantly differ with each other at 5% level of probability using LSD test.

Table-3. Effect of four different levels of water potential on shoot K^+ content (mg g^{-1}) of six cultivar of *Sorghum bicolor* L.

Water Potential Levels (ψ)	Sorghum Cultivars (CV) CV_1	CV_2	CV_3	CV_4	CV_5	CV_6	*Mean
ψ_1	21.60 h	26.40 c	23.80 e	21.60 h	23.80 e	17.10 l	22.38 b
ψ_2	26.60 c	28.00 a	23.10 f	22.80 g	27.20 b	24.50 d	25.37 a
ψ_3	21.00 i	15.20 n	12.90 q	12.40 r	24.50 d	17.40 k	17.23 c
ψ_4	19.20 j	15.20 n	11.40 s	6.20 vw	16.50 m	10.80 t	13.22 d
ψ_5	13.80 p	9.60 u	14.40 o	6.30 v	6.00 w	12.90 q	10.50 e
*Mean	20.44 a	18.88 c	17.12 d	13.86 f	19.60 b	16.54 e	17.740

LSD (for CV) = 0.1083; LSD (for ψ) = 0.0989; LSD (for ψ x CV) = 0.2422

Values followed by the same letter within columns (cv) and rows (ψ), and similarly mean values (*) followed by the same letter within a column and row are not significantly differ with each other at 5% level of probability using LSD test.

solute accumulation in drought tolerant genotypes under increasing water deficit [11]. On the basis of grand mean values, relatively much higher concentration (44.16 %) in shoot than root suggests that the uptake and translocation of this ion was not affected by imposed water potential treatments. This increased level of K^+ may attribute to non-antagonistic effects of Na^+. Because in present study Na^+ was not used in osmoticum, and water potential levels were produced by the addition of mannitol. Results further revealed that sorghum cultivars are also responded significantly. Maximum root and shoot K^+ contents (14.22 and 20.44 mg g^{-1}) is obtained for sorghum cv. Giza-3 and minimum contents (6.83 and 13.86 mg g^{-1}) for cv. 1747 and cv. Pak. S. S. II. Similar differential but increased response is also recorded by Khan *et al.*, (1999) in eight wheat genotypes subjected to 10 and 20 days of water stress treatment. More or less similar trend of results have been achieved by Achakzai (2006) for six maize cultivars, but the grand mean value of K^+ content in present study is at par than those of maize. This clearly indicates that *Sorghum bicolor* is comparatively more drought tolerant than maize. Results based on drought tolerance index of root and shoot K^+ accumulation, *Sorghum bicolor* cv. Giza-3 and cv. 1747 could be rated as drought tolerant and cv. S.E.T P=14-2 as drought sensitive. While remaining four cultivars were found as drought intermediate in response (Fig. 1).

Results regarding Ca^{2+} content of root and shoot (Table-4 and 5) reflected that imposed water potential treatments in general significantly and linearly reduced the uptake of this cation when compared with its control (ψ_1). Minimum accumulation of Ca^{2+} both in shoot and root (3.15 and 5.13 mg g^{-1}) is recorded in water potential level of −8.18 and −12.28 bars, respectively. Results based on grand mean values enumerated that Ca^{2+} content in root (6.003 mg g^{-1}) was 39.08% greater than that of shoot (3.657 mg g^{-1}). Relatively low amount of Ca^{2+} indicates that this specie of cation does not involve in contributing osmotic adjustment by sorghum seedlings. Similarly, [11] reported that Ca^{2+} did not show any considerable change under water stress and control treatment in eight wheat genotypes subjected to 10 and 20 days of water stress treatments. Results further deciphered that cultivars also responded significantly. Maximum root & shoot Ca^{2+} contents (7.90 and 4.60 mg g^{-1}) are obtained for cv. S.E.T P=14-2 and cv. Giza-3. While, minimum contents for cv. 1747 and cv. Pak. S.S.II. Likewise, differential response is also obtained by Khan *et al.*, (1999) in eight wheat genotypes and Achakzai (2006) in maize cultivars. Data based on drought tolerance index of root and shoot Ca^{2+} accumulation, *Sorghum bicolor* cv. Giza-3 and cv. ICSH=479 could be ranked as drought tolerant and cv. ICSH=479 and ICSV=107 as drought sensitive, while remaining cultivars are found as drought intermediate in response (Fig. 1).

Data obtained for Na^+ contents depicted that in response to different levels of water potential, root (except ψ_2) and shoot Na^+ contents significantly decreased when compared it with their respective control treatment. Statistically minimum amount of Na^+ both for shoot (37.08 ppm) and root (187.5 ppm) are obtained for ψ_3 and ψ_5 level of

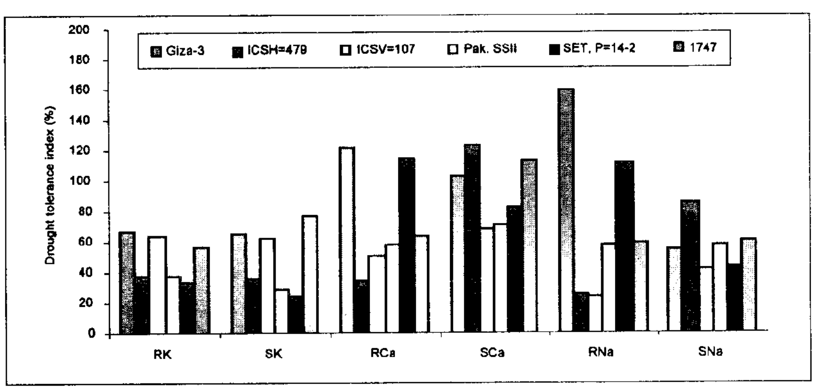

Fig. 1: Drought tolerance index (%) for various cations accumulation (RK = root potassium; SK = shoot potassium; RCa = root calcium; SCa = shoot calcium; RNa = root sodium and SNa = shoot sodium) by six cultivars of *Sorghum bicolor* L. as influenced by highest water potential levels.

Table-4. Effect of five different levels of water potential on root Ca^{2+} content ($mg\ g^{-1}$) of six cultivar of *Sorghum bicolor* L.

Water Potential Levels (ψ)	Sorghum Cultivars (CV)						*Mean
	CV_1	CV_2	CV_3	CV_4	CV_5	CV_6	
ψ_1	5.30 h	8.60 b	8.00 cd	9.30 a	8.30 bc	5.30 h	7.47 a
ψ_2	6.00 g	6.00 g	7.30 ef	1.00 m	7.60 de	6.30 g	5.70 c
ψ_3	7.00 f	4.60 i	7.30 ef	7.60 de	7.30 ef	5.30 h	6.52 b
ψ_4	7.60 de	3.30 k	6.30 g	2.60 l	7.00 f	4.00 j	5.13 d
ψ_5	6.30 g	3.00 kl	4.00 j	5.30 h	9.30 a	3.30 k	5.20 d
*Mean	6.44 b	5.10 c	6.58 b	5.16 c	7.90 a	4.84 d	6.003

LSD (for CV) = 0.1946; LSD (for ψ) = 0.1777; LSD (for ψ x CV) = 0.4352

Values followed by the same letter within columns (cv) and rows (ψ), and similarly mean values (*) followed by the same letter within a column and row are not significantly differ with each other at 5% level of probability using LSD test.

Table-5. Effect of five different levels of water potential on shoot Ca^{2+} content ($mg\ g^{-1}$) of six cultivar of *Sorghum bicolor* L.

Water Potential Levels (ψ)	Sorghum Cultivars (CV)						*Mean
	CV_1	CV_2	CV_3	CV_4	CV_5	CV_6	
ψ_1	4.50 c	4.00 d	4.50 c	3.00 h	5.30 a	3.00 h	4.050 a
ψ_2	5.00 b	2.80 h	3.80 de	2.80 h	3.60 ef	3.50 fg	3.583 c
ψ_3	4.00 d	2.00 k	3.80 de	2.30 ij	2.80 h	4.00 d	3.150 d
ψ_4	5.00 b	4.00 d	3.00 h	2.50 i	4.50 c	4.00 d	3.833 b
ψ_5	4.50 c	4.80 b	3.00 h	2.10 jk	4.30 c	3.30 g	3.667 c
*Mean	4.60 a	3.52 c	3.62 c	2.54 d	4.10 b	3.56 c	3.657

LSD (for CV) = 0.1058; LSD (for ψ) = 0.09662; LSD (for ψ x CV) = 0.2367

Values followed by the same letter within columns (cv) and rows (ψ), and similarly mean values (*) followed by the same letter within a column and row are not significantly differ with each other at 5% level of probability using LSD test.

Table- 6. Effect of five different levels of water potential on root Na^{+} content ($mg\ kg^{-1}$) of six cultivar of *Sorghum bicolor* L.

Water Potential Levels (ψ)	Sorghum Cultivars (CV)						*Mean
	CV_1	CV_2	CV_3	CV_4	CV_5	CV_6	
ψ_1	206.7 p	270.0 l	320.0 g	370.0 c	310.0 h	190.0 q	277.8 b
ψ_2	280.0 j	280.0 j	323.7 f	340.0 d	385.0 a	240.0 o	308.1 a
ψ_3	310.0 h	175.0 r	378.0 b	240.0 o	265.0 m	210.0 p	263.0 c
ψ_4	290.0 i	105.0 t	260.0 n	100.0 u	275.0 k	100.0 u	188.3 d
ψ_5	320.0 g	70.0 w	80.0 v	210.0 p	335.0 e	110.0 s	187.5 d
*Mean	281.3 b	180.0 e	272.3 c	252.0 d	314.0 a	170.0 f	244.944

LSD (for CV) = 1.567; LSD (for ψ) = 1.430; LSD (for ψ x CV) = 3.503

Values followed by the same letter within columns (cv) and rows (ψ), and similarly mean values (*) followed by the same letter within a column and row are not significantly differ with each other at 5% level of probability using LSD test.

Table-7. Effect of five different levels of water potential on shoot Na^+ content ($mg\ kg^{-1}$) of six cultivar of *Sorghum bicolor* L.

Water Potential Levels (ψ)	Sorghum Cultivars (CV) CV_1	CV_2	CV_3	CV_4	CV_5	CV_6	*Mean
ψ_1	85.0 c	90.0 b	65.0 f	40.0 l	60.0 g	45.0 k	64.17 a
ψ_2	65.0 f	65.0 f	55.0 h	21.0 q	50.0 i	50.0 i	51.00 c
ψ_3	55.0 h	20.0 r	40.0 l	22.5 p	40.0 l	45.0 k	37.08 d
ψ_4	65.0 f	30.0 m	70.0 e	30.0 m	110.0 a	46.0 j	58.50 b
ψ_5	46.0 j	75.0 d	27.0 n	22.5 p	26.0 o	27.0 n	37.25 d
*Mean	36.2 a	56.0 c	51.4 d	27.2 f	57.2 b	42.6 e	49.600

LSD (for CV) = 0.2333; LSD (for ψ) = 0.2129; LSD (for ψ x CV) = 0.5216

Values followed by the same letter within columns (cv) and rows (ψ), and similarly mean values (*) followed by the same letter within a column and row are not significantly differ with each other at 5% level of probability using LSD test.

water potentials [Table-6 and 7]. Results based on grand mean values depicted that Na^+ content in root (244.944 ppm) was 79.75% greater than that of shoot (49.600 ppm) of their respective seedlings. Contrasting results have been received by [11] and [20]. They stated that Ca, Mg, Na and P concentrations did not exhibit any remarkable change under stress and control treatments. Results further depicted that cultivars response are also significant. Maximum root and shoot Na^+ contents (314.0 and 36.2 ppm) are obtained for cv. S.E.T P = 14-2 and cv. Giza-3, as well as minimum contents (170.0 & 27.20 ppm) for cv. 1747 and cv. Pak. S. S. II, respectively. Likewise, differential response is also obtained by Khan *et al.*, (1999) in eight wheat genotypes subjected to impose water stress treatment. Results based on drought tolerance index of root and shoot Na^+ accumulation, *Sorghum bicolor* cv. Giza-3 and cv. ICSH=479 could be ranked as drought tolerant and cv. ICSH=107 as drought sensitive, respectively. While remaining cultivars are found as drought intermediate in response (Fig. 1).

Results based on cumulative drought tolerant index (%), *Sorghum bicolor* cv. Giza-3 could be rated as drought tolerant and cv. ICSV=107 and Pak. S.S.II as drought sensitive. While remaining three cultivars viz., 1747, S.E.T P=14-2 and ICSH=479 could be rated as drought intermediate in response, respectively (Fig. 2). These findings are not in agreement with the seedling growth results explained by Achakzai and Bazai (2006) for the same set of experiment.

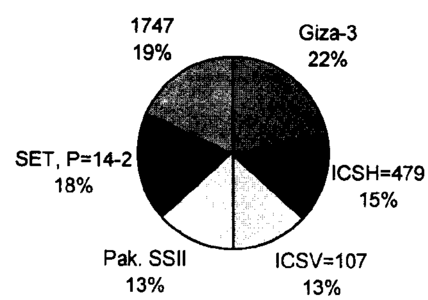

Fig. 2: Cumulative drought tolerance index (%) of cations accumulation by roots and shoots of six cultivar of *Sorghum bicolor* L.

References

1. K. S. Duodu, J. R. N. Taylor, P. S. Belton and B. R. Hamaker, *J. Cereal Sci.*, **38**, 117 (2003).
2. G O P. Monthly Bulletin of Statistics: February 2005. Government of Pakistan (GOP), Statistics Division, Federal Bureau of Statistics, Islamabad, Pakistan (2005).
3. G O B. Agriculture Statistics Balochistan. Government of Balochistan (GOB). Statistical Wing, Directorate General Agriculture (Extension) Balochistan, Quetta (2002-03).
4. W. G. Hopkins and P. A. Hűner, Introduction to Plant Physiology. 3rd. Edi. John Wiley and Sons, Inc., pp. 245 (2004).
5. A. Rodriguez-Navarro and F. Rubio, *J. Expt. Bot.*, Salinity Special Issue, pp. 1-12 (2006).
6. W. Link, A. A. Abdelmula, E. Von Kittlitz, S.

Bruns, H. Riemer and D. Stelling, *Plant Breeding,* **118**, 477 (1999).
7. Y. Shakhatreh, O. Kafawin, S. Ceccarelli and H. Saoub, 2001. *J. Agron. and Crop Sci.,* **186,** 119 (2001).
8. A. H. Khan, M.Y. Ashraf, S. S. M. Naqvi and K.A. Siddiqui, *Acta Physiol. Plant.,* **16,** 193 (1994).
9. J. M. Morgan, *Ann. Rev. Plant Physiol.,* **35,** 299 (1984).
10. N. C. Turner, *Adv. in. Agr.,* **39,** 1 (1986).
11. A. H. Khan, S. M. Mujtaba and B. Khanzada, *Pak. J. Bot.,* **31,** 461 (1999).
12. J. E. Begg, and N. C. Turner, *Adv. in Agr.,* **28,** 161 (1976).
13. C. W. Ford and J. R. Wilson, 1981. *Aust. J. Plant Physiol.,* **8,** 77 (1981).
14. A. H. Khan, M. Y. Ashraf and A. R. Azmi, *Pak. J. Sci. Ind. Res.,* **36,** 151 (1992).
15. I. N. Abreu and P. Mazzafera. *Plant Physiol and Biochem.,* **43,** 241 (2005).
16. I. P. Ting, *Plant Physiology.* Addinson-Wesley Services in Life Sciences, New York, USA (1982).
17. A. K. K. Achakzai and Z. A. Bazai, *Int. J. Biol. and Biotech.,* (2006).
18. S. J. Toth, A. L. Prince, A. Wallace and D. S. Mikkelsen, *Soil Sci.,* **66,** 459 (1948).
19. R. G. D. Steel and V. H. J. Torrie. *Principles and Procedures of Statistics.* McGraw-Hill Publ. U. K., pp. 481 (1980).
20. A. K. K. Achakzai, *J. Chem. Soc. Pak.,* (2006).