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DIFFERENTIAL POTASSIUM INFLUX INFLUENCES GROWTH OF TWO COTTON VARIETIES IN HYDROPONICS

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Abstract

Potassium uptake rate of two cotton (*Gossypium hirsutum* L.) varieties viz., NIBGE-2 and MNH-786 was investigated in nutrient solution culture having deficient K @ 0.3 mM and deficient K+ Na @ 0.3 +2.7 mM. Depletion of K from solution was monitored over a period of 24 h at regular time intervals after 0, 0.5, 1.0, 1.5, 2, 3, 4, 5, 6, 8, 10, 12 and 24 h to estimate K uptake kinetics of the roots i.e. maximum influx, I_{max} and the Michaelis-Menten constant, K_m. NIBGE-2 had about 2-fold higher (2.0 mg g rdw^{-1} hr^{-1}) I_{max} value for K uptake rate at deficient K+Na than that (1.207 mg g rdw^{-1} hr^{-1}) for MNH-786. Higher, Michaelis-Menten constant, K_m (12.82 ppm) for K uptake rate was observed in both cultivars NIBGE-2 and MNH-786 at deficient K+Na than that at deficient K. Main effects of treatments and varieties had significant ($p< 0.05$) effect on shoot dry matter, root dry matter, total dry matter and leaf area per plant. Maximum K influx in NIBGE-2 at deficient K and deficient K +Na was attributed to enhanced growth response as compared to that in MNH-786.

Introduction

Root is the main organ of nutrient and water uptake in plants. The uptake rate of a nutrient correlates with its concentration in root medium. Generally, the absorption of mineral nutrients by plant roots requires expenditure of metabolic energy. This is particularly true when absorption proceeds against a concentration gradient. The active nutrient uptake is characterized by a considerable degree of selectivity. Discrimination on the part of living cells between K and Na is unusual (Epstein and Hagen, 1952). Potassium uptake, against an electrochemical gradient, is generally considered to be an active uptake mechanism. It is more preferentially accumulated in living cell than Na, even when the external environment is more concentrated with later nutrient. Carriers, metabolically produced binding compounds, combines with ions at the outer surface of cell membrane. Upon reaching the inner cell membrane surface, the carriers are chemically altered and the ions are set free (Mengel & Farber, 1974; Marschner, 1995). This ion absorption mechanism is similar to enzyme activity, the carrier as enzyme, and the ion as a substrate. Kinetic parameters for nutrient uptake can be estimated by a number of methods. Most techniques determine net ion uptake, which is a function of both influx and efflux (BassiriRad *et al*.1999). Silberbush (2001) studied K influx to roots of two sorghum varieties that differed in their salt tolerance. In young barley plants, one day of K starvation caused a decline in the K_m (i.e., an increased apparent affinity for K) from 53 µM to 11 µM, without alteration to I_{max}. After longer periods of K starvation, I_{max} further increased while the K_m remained at the same low value (Drew *et al*., 1984). Ismat *et al.*, (2006) found that substantial variation was observed in the biomass accumulation, allocation and K uptake and use efficiency among 15 maize genotypes at

two varying levels of K when grown in hydroponics. K uptake was highly correlated with shoot dry weight production at deficient K and hence could be utilized as a selection criterion for K-efficient genotypes. Ashraf *et al*., (2008) conducted field experiments with two sugarcane varieties using K (150 kg K_2O ha^{-1}), P (100 kg P_2O_5 ha^{-1}) & N (100 & 200 kg N ha^{-1}) and concluded that the concentration of K was increased by applying K under normal as well as under saline conditions in both sugarcane varieties. They further explained that only salinity and fertilizers significantly affected K uptake.

A technique of measuring nutrient uptake by intact roots *in situ* is the depletion method. The difference between initial and final amount of nutrients in solution can be attributed to root uptake (McFarlane & Yanai, 2006). The depletion method had been used in various studies measuring uptake of N, P, K and Ca by pines (Escamilla & Comerford, 1998a, b; 2000; Lucash *et al*., 2005). Pre-treatment with K caused a decrease in rates of K uptake in the two tomato species. K-depleted roots of tomato (*Lycopersicon cheesmanii*) absorbed Na at greater rate than those of other tomato (walter), whereas K pre-treated roots of (walter) absorbed Na at a greater rate than those of *Lycopersicon cheesmanii*. Closely related varieties exhibited widely different responses to the two alkali cations K and Na (Wrona & Epstein, 1985). K influx isotherms were obtained for 10 cultivars of barley using plants which had been grown with and without K (high K and low K plant respectively) and the cultivars ranked with respect to K_m or V_{max} values for influx (Glass, 1980). The varieties studied in the present experiment may differ in K uptake kinetics. Hence, the study was conducted to measure K^+ uptake kinetics parameters of two selected cotton varieties in nutrient solution culture.

Materials and Methods

Two cotton varieties viz., NIBGE-2 and MNH-786 were grown in half strength modified Johnson's nutrient solution in a wire house of the Institute of Soil and Environmental Sciences, University of Agriculture, Faisalabad. Seeds were planted in iron trays lined with polythene containing thoroughly washed river-bed sand. Distilled water was used for irrigation during seed germination. One week old, uniform seedlings were transplanted in thermopal sheets floating on half strength modified Johnson's nutrient solution (2L) (Johnson *et al*., 1957) in polythene lined plastic beakers. The solution was continuously aerated during the growth period. Nutrient solution contained 6 mM N, 0.25 mM P, 3.0 mM K, 2mM Ca, 1mM Mg, 2mM S, 50µM Cl, 25µM B, 2µM Mn, 2µM Zn, 0.5µM Cu, 0.5µM Mo and 50µM Fe. The study was designed according to completely randomized design (CRD) with four replications. The pH of nutrient solution was monitored daily and adjusted to 5.5 ± 0.5 during the plant growth period. The plants were supplied with adequate K @ 3 mM for 21 days. Thereafter, the plants were again transferred into half strength modified Johnson's solution containing all nutrients except K. The plants were starved for one day by omitting application of K. After 24 hours, two treatments i.e., deficient K (0.3 mM), and deficient K (0.3 mM) +Na (2.7 mM) were applied. Starvation treatments are generally applied for a day or longer (Lee, 1982), not a mere few hours. Conversely, earlier exposure to high concentrations may have resulted in saturation of root exchange sites (Siddiqui *et al.,* 1990) representing subsequent uptake. Samples were taken from the nutrient solution at 0 hours, then after 0.5, 1, 1.5, 2, 3, 4, 5, 6, 8, 10, 12 and 24 hours to measure depletion in K concentration, as a result of its uptake by plants. Epstein (1972) suggested that similar to enzyme substrate relationships, the carrier mediated ion transport across the root can be similarly described by the Michaelis-Menten model (Michaelis & Menten, 1913).

$$\upsilon = V_{max}\,[c] / (K_m + [c])$$

where, c is the concentration of an individual ion whose uptake rate, υ is controlled by uptake capacity, V_{max}, when all available carriers are occupied, and by the apparent affinity of the transporters, K_m. The equation describes the relationship between the uptake rate of the nutrient and the nutrient concentration. Uptake rate reaches a constant or 'saturated' rate (V_{max}) at high ambient concentration. Lineweaver & Burk (1934) pointed out that the above equation becomes linear in forms upon taking the reciprocal of both sides of the equation to calculate the key parameters in the Michaelis-Menten equation:

$$\upsilon = V_{max}\,[c] / (K_m + [c]) \rightarrow 1/\upsilon = K_m / V_{max} \times 1/[c] + 1/V_{max} \text{ i.e. } (y = m\,x + b)$$

A straight line can be resulted by plotting 1/v against 1/c. The ordinate intercept is 1/V, and the slope, $K_m/V_{max,}$ thus giving a convenient method for determining both V_{max} and $K_{m.}$

Potassium absorption kinetics was measured using solution culture experiment with a day length of 24 hours. Nutrient influx (absorption rate per mg of root dry weight) was measured on the 22nd day. Influx was determined by measuring rate of ion depletion from solution. The depletion of ions was followed by continuous sampling of solution by removing 10 ml of solution. Relation between time and concentration in solution was used to calculate influx into the root by the solution depletion method of Claassen & Barber (1974). Influx followed Michaelis-Menten kinetics, so that the relation between ion concentration and uptake may be expressed in terms of I_{max}, (the maximum influx); and K_m, the Michaelis-Menten constant, (the concentration where influx I was one half of I_{max}).

After taking samples of nutrient solution, the plants were harvested and separated into shoots and roots. Samples were washed with distilled water and blotted dry with filter paper. Leaf area was measured by using leaf area meter. The plant samples were then air dried in wire house for two days. Air dried samples were oven dried at 72°C for 48 hours in a forced air oven to record dry matter yield (g plant^{-1}) of plant tissues. Oven dried samples of shoot and root were fine ground in a Wiley Mill to pass through 1 mm (40-mesh) sieve. Uniform ground samples were digested in di-acid mixture (3:1) of nitric and perchloric acid (Miller, 1998). K: Na ratio in shoot and root was calculated by dividing K concentration of respective tissue with its Na concentration. The data obtained were subjected to statistical analysis using computer software "MSTAT-C" (Russell & Eisensmith, 1983) by following the methods of Gomez & Gomez (1984). Differences in uptake rate were tested by using regression analysis.

Results

A depletion method was used to measure the ion uptake by roots. Nutrient concentration in the solution was measured at a series of different time intervals. The difference between initial and final amounts of nutrient in solution was attributed to root uptake. The objective of this investigation was to examine differences in ion influx (uptake rate per root dry weight) of both cotton varieties. They were grown for 21 days in Johnson's nutrient solution and the influx parameters of K were determined by measuring the K depletion in the solution.

Dry matter yield (g plant^{-1}): Various treatments and varieties had a significant ($p<0.05$) effect on shoot dry matter, root dry matter, total dry matter and leaf area. Total dry

weight ranged from 2.52 g plant^{-1} in varieties MNH-786 at deficient K (0.3 mM) to 3.67 g plant^{-1} in varieties NIBGE-2 at deficient K (0.3 mM) +Na (2.7 mM). Main effects of treatments, varieties and their interaction varied non-significantly with respect to shoot root ratio (Table 1). Interaction between treatment and varieties affected shoot dry matter, root dry matter and total dry matter, non-significantly.

Leaf area plant^{-1} (cm^2 plant^{-1}): Main effects of treatments and varieties had a significant ($p<0.05$) effect on leaf area. It ranged from 404 cm^2 plant^{-1} to 690 cm^2 plant^{-1} at deficient K (MNH-786) and deficient K + Na (NIBGE-2), respectively. Interaction between treatments and varieties affected leaf area plant^{-1}, non-significantly (Table 1).

Depletion of K concentration in nutrient solution: Concentration of K (ppm) in nutrient solution decreased progressively with the passage of time. Both the varieties and the treatments influenced concentrations of K in solution significantly (Table 2). Deficient K +Na caused more average depletion of K (9.870 ppm) followed by (8.917 ppm) at deficient K in solution. Similarly, variety MNH-786 showed maximum average depletion of K (9.865 ppm) as against (8.922 ppm) for variety NIBGE-2. Interaction between treatments and varieties influenced depletion of K concentration, non-significantly.

K uptake rate (mg plant^{-1} hr^{-1}): Uptake rate of K and Na in two cotton varieties varied significantly ($p<0.01$) with the passage of time at deficient K and deficient K +Na. K uptake rate was calculated from decrease in their content in nutrient solution with time (hr) by both cotton varieties (Table 3). Average decreased K uptake rate (1.457 mg plant^{-1} hr^{-1}) was observed in MNH-786 as compared to (1.720 mg plant^{-1} hr^{-1}) for NIBGE-2. Similarly maximum K uptake rate of 1.629 mg plant^{-1} hr^{-1} was observed at deficient K +Na than that at deficient K (1.549 mg plant^{-1} hr^{-1}). Maximum mean K uptake rate of 3.60 mg plant^{-1} hr^{-1}was noted at 0.5 hour as against at 24 hour (0.21 mg plant^{-1} hr^{-1}) for the both varieties. Interaction between (time × treatment × variety) was found significant ($p<0.01$). Highest K uptake rate of 5.40 mg plant^{-1} hr^{-1} was noted in NIBGE-2 at deficient K after 0.5 hour followed by MNH-786 (3.80 mg plant^{-1} hr^{-1}) at deficient K +Na after 1.5 hour. Four times higher Na uptake rate (21.40 mg plant^{-1} hr^{-1}) was demonstrated in NIBGE-2 at deficient K +Na as compared to K uptake rate (5.40 mg plant^{-1} hr^{-1}) at deficient K after 0.5 hour. NIBGE-2 exhibited 30 % higher average Na uptake rate (9.269 mg plant^{-1} hr^{-1}) at deficient K+Na than that of MNH-786 (6.097 mg plant^{-1} hr^{-1}). The average uptake rate decreased with plant age in both varieties. At deficient K, in solution, the K uptake rate of NIBGE-2 was about 5.40 mg plant^{-1} hr^{-1} in the first half hour which declined later on to 0.11 mg plant^{-1} hr^{-1} after 24 hr. Initial K uptake rate in NIBGE-2 was two times higher than MNH-786 at deficient K level. At deficient K+Na both the varieties had 3 times higher K uptake rate than that at deficient K after 24 h. Final Na uptake rate in both varieties was about 2-fold higher than K uptake rate at deficient K+Na.

K: Na ratio in shoot and root: Varieties differed significantly with respect to K: Na ratio in shoot (Table 4). At deficient K+ Na, maximum shoot K: Na ratio was observed in NIBGE-2 as compared to MNH-786. The treatment did not influence the root K: Na ratio in both varieties. Both varieties differed non-significantly for K: Na ratio in root.

Table 1. Shoot dry matter, root dry matter, total dry matter, leaf area and shoot root ratio of two cotton varieties grown with deficient K and deficient K+Na. (Values are means of 4 replicates)

Parameters	Deficient K (0.3 mM)		Deficient K (0.3 mM) +Na (2.7 mM)	
	NIBGE-2	MNH-786	NIBGE-2	MNH-786
Shoot dry matter (g plant^{-1})	2.38 ns	2.31	3.42	2.88
Root dry matter (g plant^{-1})	0.24 ns	0.21	0.25	0.23
Total dry matter (g plant^{-1})	2.62 ns	2.52	3.67	3.11
Leaf area (cm^2 plant^{-1})	439 ns	404	690	550
Shoot root ratio	10.17 ns	11.71	14.13	12.54

ns= Non-significant
Means with different letter(s) differ significantly according to Duncan's Multiple Range Test (p=0.05)

Table 2. Depletion of K concentration (ppm) in nutrient solution with time (hr) by two cotton varieties at deficient K, and deficient K+ Na. (Values are means of 4 replicates)

Time (hours)	Deficient K (0.3 mM)		Deficient K (0.3 mM) +Na (2.7 mM)			
	K concentration (ppm)		K concentration (ppm)		Na concentration (ppm)	
	NIBGE-2	MNH-786	NIBGE-2	MNH-786	NIBGE-2	MNH-786
0	11.80 ns	12.10 ns	12.75 ns	13.17 ns (12.45 A)*	60.10 b	62.41 a
0.5	10.76	11.71	12.18	12.86 (11.88 B)	58.40 c	53.30 f
1	10.29	11.14	11.60	12.42 (11.36 C)	56.60 d	53.00 f
1.5	9.70	10.90	11.32	11.77 (10.92 D)	53.90 e	52.50 g
2	9.08	10.45	10.70	11.35 (10.39 E)	50.80 i	52.40 g
3	8.56	9.60	10.45	10.84 (9.86 F)	46.30 k	51.20 h
4	8.31	9.22	9.90	10.40 (9.45 G)	42.10 l	48.60 j
5	7.82	9.12	9.50	10.12 (9.14 H)	39.70 n	42.30 l
6	7.31	8.76	8.08	9.19 (8.33 I)	33.50 p	40.10 m
8	7.05	8.10	7.52	8.47 (7.78 J)	30.30 q	37.80 o
10	6.47	7.90	7.12	8.20 (7.42 K)	28.40 r	33.20 p
12	6.09	7.40	6.56	7.50 (6.88 L)	25.20 t	30.10 q
24	5.40	6.80	5.65	7.00 (6.21 M)	20.10 u	26.50 s
NIBGE-2	8.922 B	**Deficient K**	8.917 B		**NIBGE-2**	41.954 B
MNH-786	9.865 A	**Deficient K +Na**	9.870 A		**MNH-786**	44.878 A

ns = Non-significant
*****Values in parenthesis are means of K concentration for time variable
LSD for K concentration for (time) = 0.149
LSD for Na concentration for interaction (time × variety) = 0.380
Interaction for K concentration for (time× treatment × variety) = non significant

K uptake kinetics: Varieties NIBGE-2 exhibited about 2-fold higher I_{max} value (2.0 mg grdw^{-1} hr^{-1}) for K uptake rate than that (1.207 mg grdw^{-1} hr^{-1}) in MNH-786 at deficient K+Na (Table 5). Higher value of K_m, (Michaelis-Menten constant) for K uptake rate was observed at deficient K+Na as compared to that at deficient K in both varieties. Fig. 1 and Fig. 2 shows that the rate of depletion of K varied at deficient K and deficient K+Na in nutrient solution. The minimum K concentration after 24 hr was below 6 ppm for NIBGE-2 and 7 ppm for MNH-786. For both varieties at both levels the rate of K-depletion was slow i.e., the concentration only decreased by < 6 to 7 ppm and C_{min} was not reached.

Table 3. Rate of K and Na uptake (mg plant^{-1} hr^{-1}) in two cotton varieties grown with deficient K, and deficient K+ Na.
(Values are means of 4 replicates)

Time (hours)	Deficient K (0.3 mM)		Deficient K (0.3 mM) +Na (2.7 mM)			
	K uptake rate (mg plant^{-1} hr^{-1})		K uptake rate (mg plant^{-1} hr^{-1})		Na uptake rate (mg plant^{-1} hr^{-1})	
	NIBGE-2	MNH-786	NIBGE-2	MNH-786	NIBGE-2	MNH-786
0	0	0	0	0	0	0
0.5	5.40 a	2.80 h	3.60 c	2.60 j (3.60 A)*	21.40 A	13.80 D (17.60 a)**
1	2.80 h	3.20 e	3.40 d	2.80 h (3.05 B)	13.40 E	3.40 O (8.4) g
1.5	3.20 e	2.20 l	2.20 l	3.80 b (2.85 C)	15.80 B	10.40 H (13.10 b)
2	2.94 g	2.45 k	3.10 f	2.45 k (2.73 D)	14.20 C	8.40 L (11.30 c)
3	1.50 q	2.20 l	1.20 s	1.60 p (1.62 G)	12.60 F	5.40 M (9.00 f)
4	1.85 n	1.47 q	2.12 m	1.68 o (1.78 F)	11.30 G	9.20 J (10.25 d)
5	1.50 q	1.00 t	1.60 p	1.50 q (1.40 H)	9.90 I	9.80 I (9.850 e)
6	1.50 q	1.30 r	2.70 i	2.10 m (1.90 E)	11.40 G	8.80 K (10.10 d)
8	0.85 u	0.38 y	0.81 u	0.68 v (0.68 I)	4.10 N	3.50 O (3.80 h)
10	0.50 x	0.30 z	0.40 y	0.30 z (0.37 K)	2.40 P	4.00 N (3.20 i)
12	0.51 wx	0.23	0.57 w	0.49 x (0.45 J)	3.40 O	1.80 Q (2.60 j)
24	0.11	0.08	0.37 y	0.28 (0.21 L)	0.60 R	0.76 R (0.68 k)
NIBGE-2	1.720 A	**Deficient K**	1.549 B		**NIBGE-2**	9.269 A
MNH-786	1.457 B	**Deficient K +Na**	1.629 A		**MNH-786**	6.097 B

* = Values in parenthesis are means of K uptake rate for time variable
** =Values in parenthesis are means of Na uptake rate for time variable
LSD for K uptake rate (time) = 0.031
LSD for K uptake rate for interaction (time × treatment × variety) = 0.062
LSD for Na uptake rate (time) = 0.199
LSD for Na uptake rate (time × variety) = 0.281

Table 4. K: Na ratio in shoot and root of two cotton varieties grown with deficient K+Na.
(Values are means of 4 replicates)

Parameters	Deficient K (0.3 mM) +Na (2.7 mM)	
	Varieties	
	NIBGE-2	MNH-786
K: Na ratio in shoot	0.63 a	0.51 b
K: Na ratio in root	0.17 ns	0.15

ns= Non-significant
Means with different letter(s) differ significantly according to Duncan's Multiple Range Test (p=0.05)

Table 5. Kinetic parameters (I_{max} and K_m) values of K uptake rate in two cotton varieties grown with deficient K and deficient K+Na.
(Values are means of 4 replicates)

Treatments	Deficient K (0.3 mM)		Deficient K (0.3 mM) +Na (2.7 mM)	
Kinetics parameters	NIBGE-2	MNH-786	NIBGE-2	MNH-786
I_{max} (mg K g rdw^{-1} hr^{-1})	0.677	0.366	2.0	1.207
K_m (ppm)	9.52	10.52	12.82	12.82

Potassium influx derived from the rate of depletion and plotted as a function of concentration and regression line fitted gave a reasonable calculation of kinetics parameters. I_{max} was obtained from the slope of the line and K_m from the intercept on the X- axis and C_{min} was not reached because the rate of depletion was not so faster for K.

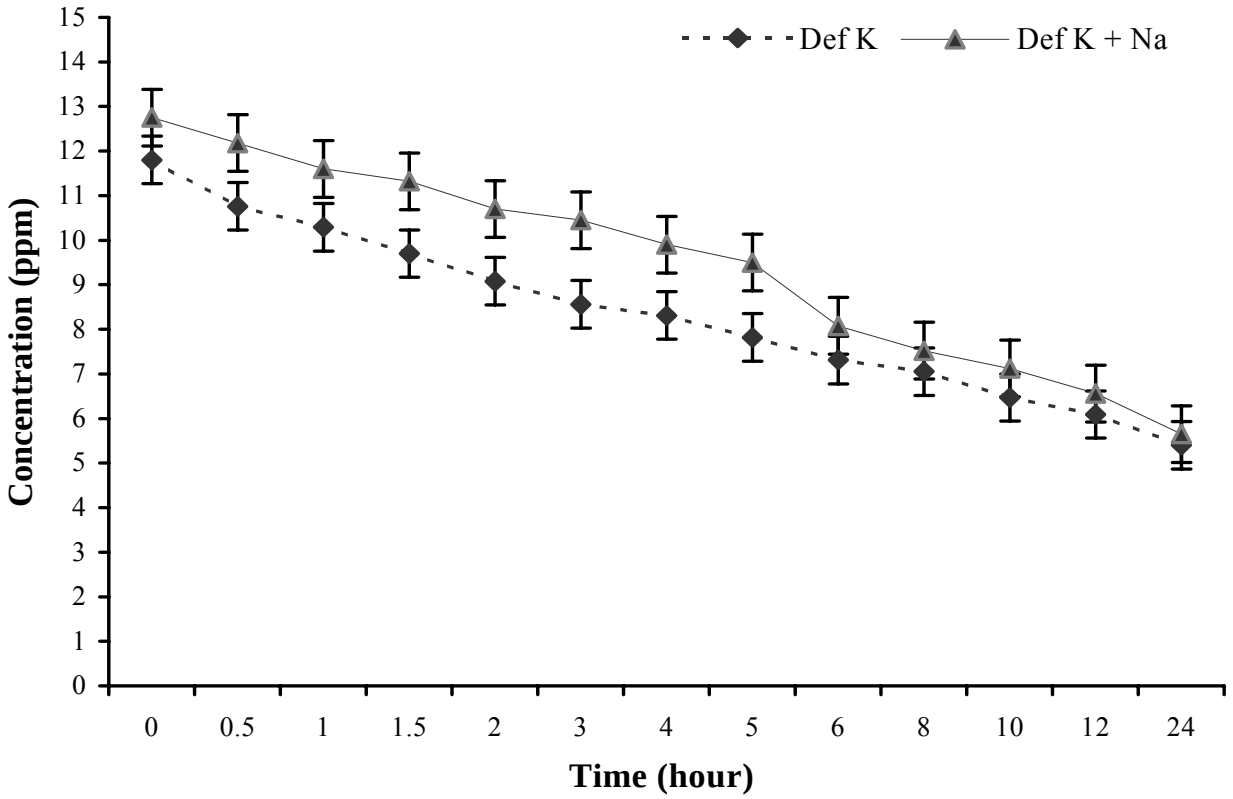

Fig. 1. Changes in K concentration (ppm) in nutrient solution with time (hour) in NIBGE-2 at deficient K and deficient K + Na.

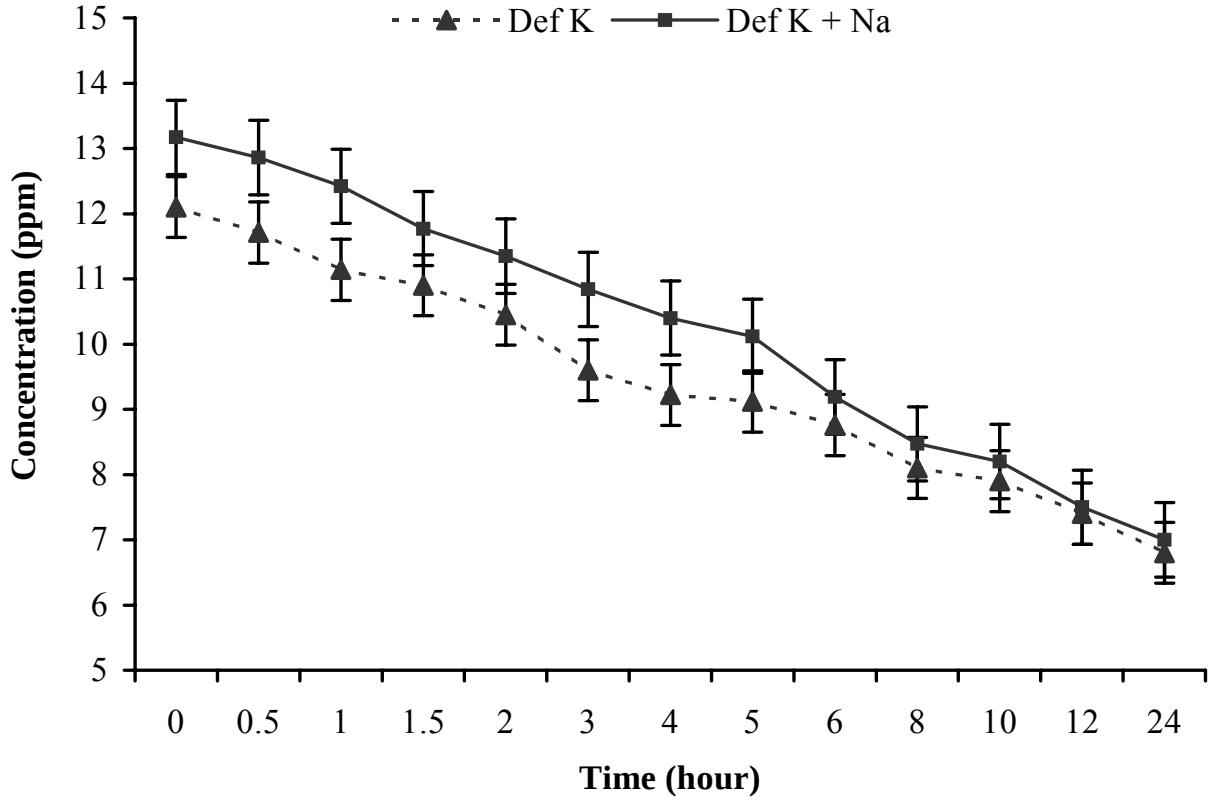

Fig. 2. Changes in K concentration (ppm) in nutrient solution with time (hour) in MNH-786 at deficient K and deficient K + Na.

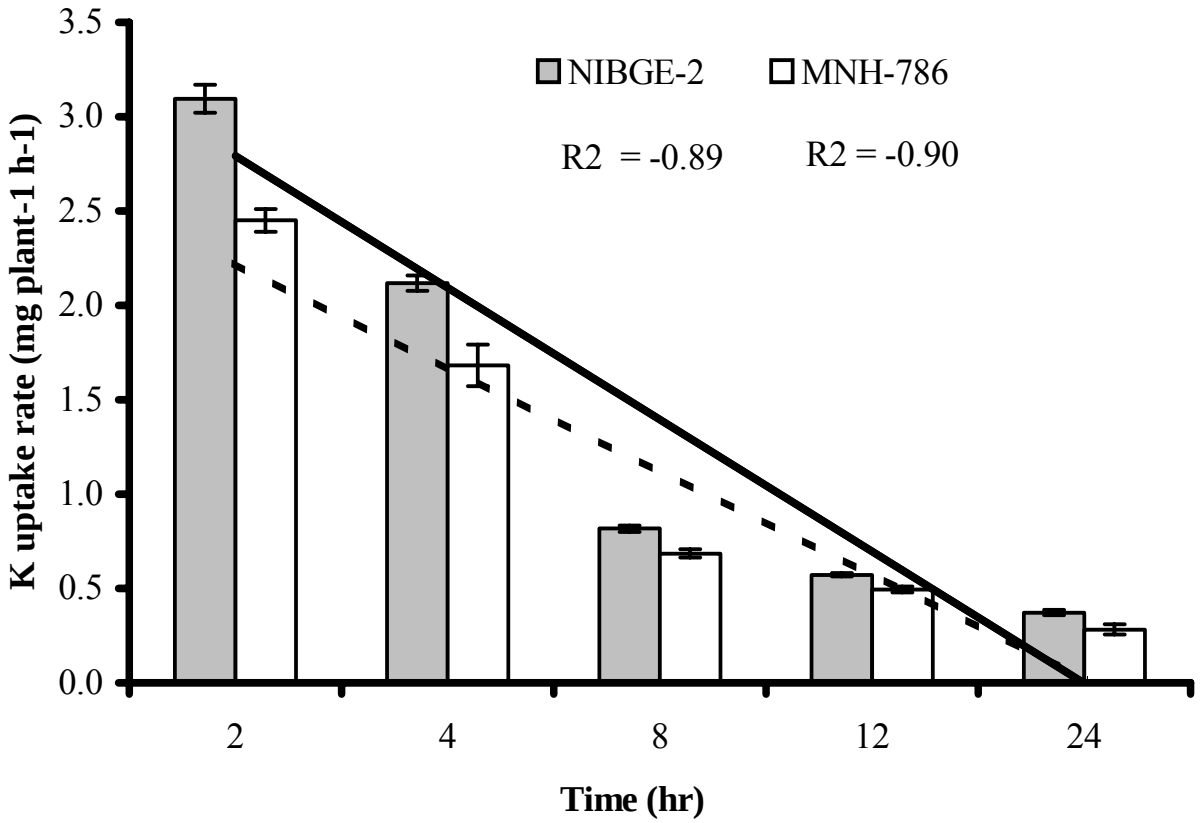

Fig. 3. Changes in K uptake rate with time in both cotton genotypes at deficient K + Na.

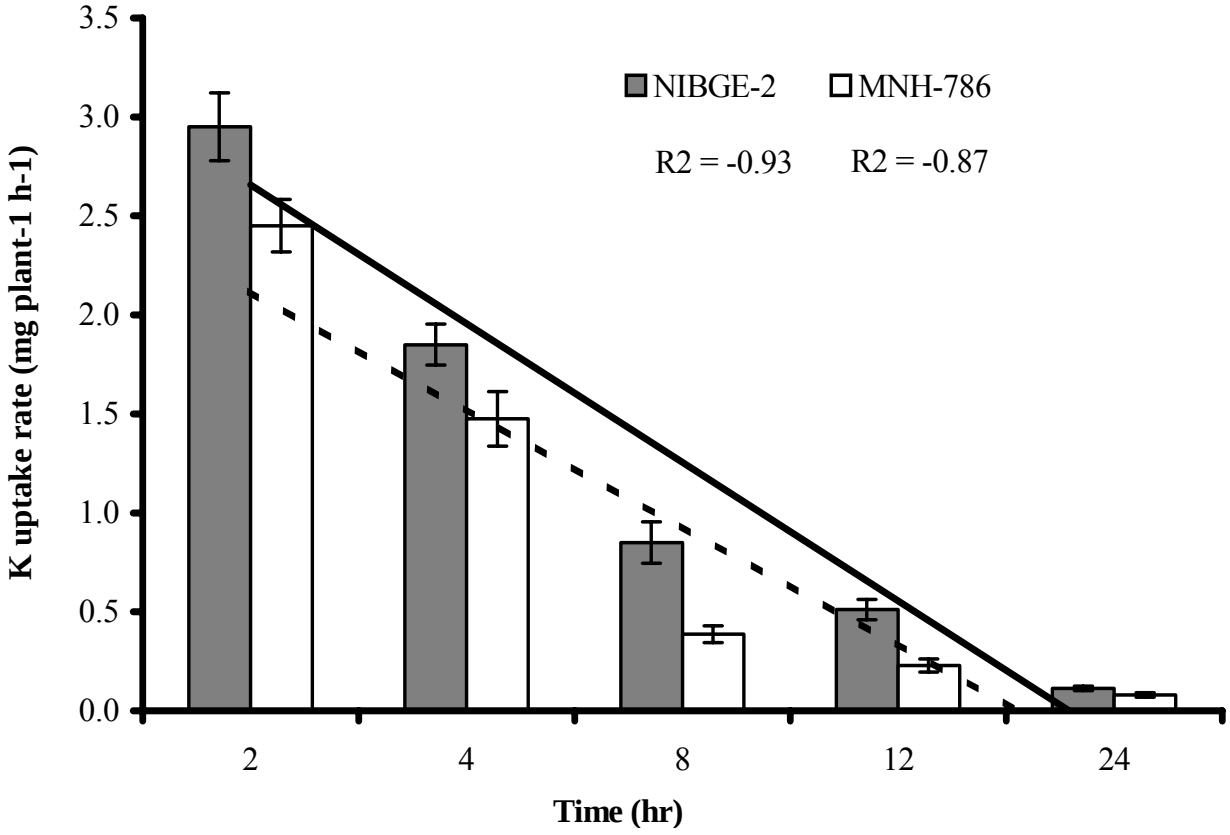

Fig. 4. Changes in K uptake rate with time in both cotton genotypes at deficient K.

Discussion

Uptake rate measured by depletion method was dependent on the time period roots are exposed to nutrient solutions. Because the solutions are typically depleted over time (Escamilla & Comerford, 1998 b), uptake rates decline, resulting in lower average rates calculated for longer time intervals (Lucash *et al*., 2005). Researchers using the depletion method have used time periods ranging from 15 minutes to several days. Mcfarlane & Yanai (2006) selected two-hour interval because in earlier experiments they found that two hours were sufficient to cause a measurable change in solution concentrations. And the periods of one to several days incur the risk of depleting the solution to such a degree that net uptake rates approach zero. In cases where solutions are highly depleted, the average rate of uptake over the time interval is not very meaningful and the average solution concentration is unknown.

The differences in K and Na influx of both varieties in nutrient solution culture can be elucidated by differences in their uptake kinetics. The data showed that for the plants grown at deficient K+Na concentration, about 2 times larger I_{max} (Table 5) explained the higher influx of K in NIBGE-2 as compared to MNH-786. Adaptations of K uptake kinetics to K status of the plant, especially by an increased $I_{max,}$ have been reported by several scientists (Silberbush**,** 2001; Classen &Barber, 1974; Escamilla & Comerford, 1998 a, b). Lucash *et al*., (2005) demonstrated uptake of N, P and K using variations of the depletion method. Drew *et al*., **(**1984) found that one day of K-starvation to 14 days plants caused a decline in the K_m (i.e. an increased apparent affinity for K) from 53 µM to 11 µM, without alteration in I_{max}. After longer periods of K-starvation, I_{max} increased (about 2 times) while the K_m remained at the same low value.

The results showed that NIBGE-2 was more K efficient since it was able to produce maximum dry matter yield at deficient K+Na (0.3+2.7 mM) than that MNH-786. The higher K efficiency of NIBGE-2 can be explained by the higher K uptake rate of the root system with the passage of time. There was significant negative relationship (R^2= -0.89, -0.90, n=3 i.e. mean of 4 replicates) between uptake rate and time (hr) (Fig. 3). Both varieties varied significantly for its K uptake rate at the deficient K+Na level. Significant negative relationship (R^2= -0.93, -0.87, n=3 i.e. mean of 4 replicates) for K uptake rate and time at deficient K as shown in Fig. 4. The uptake efficiency comprises both the root dry weight and the uptake rate per unit root dry weight and time i.e., the influx.

K_m value decreased in the plants when grown at deficient K. Similar unchanged K_m values of 12.82 ppm and 12.82 ppm (Table 5) for both varieties at deficient K+Na concentration, indicated that half I_{max} values of 1.0 and 0.60 mg K g rdw^{-1} h^{-1} were reached at the same K_m value which was greater for NIBGE-2. Wrona & Epstein (1985) explained that pre-treatment with K caused a decrease in rates of K uptake in two tomato species. K-starved roots of tomato cv. *Lycopersicon cheesmanni* absorbed Na at a greater rate than those of other tomato cv. Walter, whereas K pre-treated roots of Walter absorbed Na at a greater rate than those of *Lycopersicon cheesmanii*. Closely related varieties exhibited widely different responses to K and Na.

Conclusion

Both varieties had significantly different I_{max} values for K uptake rate. NIBGE-2 had about 2-fold higher I_{max} value for K uptake rate at deficient K+Na than that for MNH-786. Maximum K influx in NIBGE-2 at deficient K and deficient K +Na was attributed to

enhanced growth response as compared to that in MNH-786. Verification of the results of solution culture experiments, regarding K, Na rates on growth and yield response of cotton varieties is warranted in soil culture.

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