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Full Length Article

Potassium as an Intensifying Factor for Iron Chlorosis

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ABSTRACT

This research was conducted to determine the interactive effect of different potassium (K) and iron (Fe) rates on the growth and nutrient uptake of maize. The work also investigated the effects of high amounts of K on Fe uptake and on the occurrence of Fe chlorosis. For this purpose, five K (1, 2, 4, 6 & 8 mM) and four Fe (30, 60, 90 & 120 µM) doses were applied to maize (*Zea Mays* L. cv. BSC 6661) plants in a re-circulated hydroponic system. Increasing K and Fe levels had positive effects on the dry weight of the maize leaves and roots. Total Fe concentrations and their uptake increased with the increasing levels of Fe and K, but decreased with the highest K dose. This response was similar to dry weight and the SPAD values with increasing Fe. We conclude that adequate K may also be required for the efficient use of Fe. However too high a concentration of K will cause competition with Fe. © 2010 Friends Science Publishers

Key Words: Hydroponic system; Iron; Iron chlorosis; Maize; Potassium

INTRODUCTION

Balanced nutrition in plants is one of the main factors affecting yield and quality. Although potassium (K) is regarded as one of the major nutrient elements that influence the yield and quality, iron (Fe) chlorosis is an important factor that is responsible for significant decreases in the yield and quality of plants (Mahmood *et al.*, 1999; Mohamed & Aly, 2004).

Total high (0.5-5.0%), forms available for plants are extremely low. This is related to the poor physical properties in the soil, such as very high or low soil temperature, high humidity, poor soil aeration and compaction, high pH, the HCO_3^- content and the $CaCO_3$ content (Köseoğlu, 1995; Başar, 2000; Lucena, 2000). In addition to the physical properties of the soils and the physiological effectiveness of Fe in the plant tissues, Fe chlorosis is also related to the PO_4^- and NO_3^- anions and to the concentration of heavy metals such as Zn, Cu, Mn, Co, Ni and Cd.

Fe toxicity occurs in various rice-growing areas. This type of toxicity is especially frequent in heavy soils and is often associated with K deficiency (Tanaka *et al*., 1973). Trolldenier (1973) reported that when the K nutrition is inadequate, the capability of rice roots to oxidise Fe^{+2} to Fe^{+3} is impaired. We know that Fe toxicity effects can be ameliorated or eliminated using excess K dressings that reduce the uptake of Fe (Trolldenier, 1973; Tanaka *et al.*, 1973; Li *et al.*, 2001; Becker & Asch, 2005; Çakmak, 2005). Li *et al.* (2001) showed that increasing amounts of K reduced the Fe concentration in the leaves at least 2-fold and improved the plant growth. A large body of literature supports the ameliorative effects of P, K and Zn fertiliser application under Fe toxic conditions (Becker & Asch, 2005). The ameliorating effects of K may be attributed to the antagonistic effect of K on Fe absorption and translocation into the shoots (Li *et al.*, 2001). Urrestarazu *et al.* (1994) also pointed out that plants uptake K much more readily than Fe and that excess amounts of K inhibit the uptake and translocation of Fe in plants, leading to Fe deficiency. Similar to Fe toxicity, excessive applications of K or increasing amounts of K released under suitable soil conditions can inhibit the Fe uptake ability of plants and may affect the degree of Fe chlorosis. Some recent studies have shown that when the chlorosis symptoms occurred, the K contents of the chlorotic plants were high (Köseoğlu, 1995; Saatçi & Yağmur, 2000; Torres et al., 2006; Çelik & Katkat, 2007). However it is not clear if this situation is related to the antagonistic effect between K and Fe or a dilution effect.

This study was conducted to determine the interaction between K and Fe, examine the effects of high amounts of K on the Fe uptake and to show if there is a response in the occurrence of Fe chlorosis.

MATERIALS AND METHODS

Nutrient solution experiment: Maize (*Zea Mays* L. cv. BSC 6661) seeds were germinated in a perlite medium that was moistened with half strength nutrient solution containing the following (in mM): Ca $(NO_3)_2$, 2; K_2SO_4, 0.75; $MgSO_4$, 0.65; KH_2PO_4, 0.5 and (in µM): KCl, 25; H_3BO_3, 10; FeEDDHA 10; $MnSO_4$, 1; $CuSO_4$, 0.5; $ZnSO_4$, 0.5; $(NH_4)_6Mo_7O_{24}$, 0.05 (Çelik *et al.*, 2006). The maize plants were transferred into re-circulated hydroponic systems after ten days of preculture. A hydroponic system consists of a solution tank that contains a 50-L volume of nutrient solution, a pump and three channels parallel to each other. Each channel contained four plants. Twenty different nutrient solutions composed of five K doses (1, 2, 4, 6 & 8 mM) and four Fe doses (30, 60, 90 & 120 µM) were administered to the plants in twenty hydroponic systems during the vegetation period. The nutrient solution pH ranged between 6.93-8.06 and the EC values ranged between 982-1407µS cm^{-1} due to nutrient contents. Information about the composition of the nutrient solutions is given at Table I. The nutrient solutions were renewed every 4-5 days.

Maize plants were kept for 41 days, which was long enough for the appearance of the effects of the treatments. The aerial parts of the plants were harvested on day 41. The leaf and root samples were immediately transported to the laboratory in closed polyethylene bags. For the evaluation of nutrient uptake of the plants, the plant materials were washed once in tap water and then twice with deionised water. After washing, the plant material was dried in a forced air oven at 70°C for 72 h and ground. The ground plant samples were digested using a mixture of 2 mL of HNO_3 and 3 mL of H_2O_2 in a microwave oven (Berghof MWS 2) (Wu *et al.*, 1997). The Fe contents in the digest were determined by ICP-OES (PerkinElmer Optima 2100 DV) (Isaac & Johnson, 1998). The K was determined by flame emission (Eppendorf Elex 6361) (Horneck & Hanson, 1998). The active Fe^{2+} contents were determined in the dry plant parts by incubating for 24 h in 1 N HCl extraction solution (1:10) using the method of Oserkowsky (1933) that was modified by Llorente *et al.* (1976). The resultant amounts were measured by ICP-OES.

All of the analyses were conducted in triplicate. The mean values were compared using the LSD (Least Significant Differences) multiple range test and simple correlations were measured with the computer program TARIST (1994).

SPAD value measurements: A portable chlorophyll meter (SPAD-502, Minolta Camera Co., Osaka, Japan) was used to measure the leaf chlorophyll content at 20, 27, 34 days after the transfer and at the time of harvest (Cordeiro *et al.*, 1995). The upper most fully expanded leaf was selected from each plant to measure and record the SPAD values. Three SPAD readings were taken around the midpoint of each leaf. Twelve SPAD readings were averaged to give the mean SPAD value of each channel.

RESULTS

According to the general appearance of the plant in the experiment, the development of the maize plants was poor at the time of the first dose of K and Fe. The plants were small and showed both K deficiency and Fe chlorosis symptoms. The increasing amounts of K and Fe further affected the development. The plants became taller and greener than at the first doses K deficiency symptoms also disappeared. The iron chlorosis symptoms were also fading due to the increasing amounts of Fe, but they did not completely vanish with the subsequent K doses.

Table I: Nutrient element concentrations and their resources used in the experiment for each treatment

Nutrient Resources	K1 (1 mM K)	K2 (2 mM K)	K3 (4 mM K)	K4 (6 mM K)	K5 (8 mM K)
KH_2PO_4	1 mM	-	-	-	-
K_2HPO_4	-	1 mM	1 mM	1 mM	1 mM
KNO_3	-	-	2 mM	4 mM	6 mM
$Ca(NO_3)_2$	2 mM	2 mM	2 mM	1mM	-
$Ca(OH)_2$	-	-	-	1 mM	2 mM
$CaSO_4.2H_2O$	1 mM	1 mM	1 mM	1 mM	1 mM
$MgSO_4.7H_2O$	1 mM	1 mM	1 mM	1 mM	1 mM
MgO	1 mM	1 mM	1 mM	1 mM	1 mM
NH_4NO_3	1mM	1mM	-	-	-
H_3BO_3	10 µM	10 µM	10 µM	10 µM	10 µM
$MnSO_4.4H_2O$	2 µM	2 µM	2 µM	2 µM	2 µM
$ZnSO_4.7H_2O$	2 µM	2 µM	2 µM	2 µM	2 µM
$CuSO_4.5H_2O$	1 µM	1 µM	1 µM	1 µM	1 µM
NaCl	0.1 µM	0.1 µM	0.1 µM	0.1 µM	0.1 µM
$(NH_4)_6Mo_7O_{24}$	0.05 µM	0.05 µM	0.05 µM	0.05 µM	0.05 µM
	Fe1	**Fe2**	**Fe3**	**Fe4**	
FeEDDHA% 6 Fe	30 µM Fe	60 µM Fe	90 µM Fe	120 µM Fe	

The effects of increasing amounts of K and Fe on the dry weight of the maize leaves and the roots are shown in Table II. Increasing the K levels had positive effects on the dry weight of the maize leaves and roots. The elevated amounts of Fe also affected this increase, but the application of the highest K and Fe doses decreased the growth. While the highest dry weight amount in the leaves (145.46 g) was taken from the K3Fe4 application, increasing the K decreased the weight that was measured as 93.45 g at K5Fe4 application. The dry weight of the maize roots was also positively affected by the application of K and Fe. Neither the highest dose of K nor the third and forth dose of Fe were enough to reach the maximum weight. The highest weight (40.74 g) was taken from the K4Fe4 application.

Visual chlorotic symptoms were also supported by the SPAD readings. Iron applications affected the SPAD readings positively. The SPAD values were increased due to the increasing amounts of Fe. The maize leaves with high concentrations of Fe had higher SPAD readings than those with a low concentration of Fe. While the SPAD value for treatment Fe1 was 8.43-12.67, this value was 30.27-35.47 for treatment Fe4. In addition to the Fe concentrations, the K doses also had a positive effect. The fourth dose of K had the highest SPAD values compared with those with low concentrations of potassium (K1, K2 & K3). Although there was a positive effect of increasing amounts of K, the highest dose (K5) lowered the SPAD values (Table III).

The effects of increasing amounts of K and Fe on their concentrations in both the leaves and the roots of maize and their uptake are shown in Tables IV-V. The addition of increasing levels of K enhanced the concentrations and the uptake of K into the leaves and roots. While the highest

Table II: Effects of increasing amounts of potassium and iron on dry weight of maize leaves and roots (g pot^{-1})

Potassium (K) doses, mM	Iron Doses, (Fe)							
	Fe[1], 30 µM		Fe2, 60 µM		Fe3, 90 µM		Fe4, 120 µM	
	Dry weight of leaves, (g pot^{-1})							
K1, 1mM	16.79	b	50.64	b	81.70	b	86.49	c
K2, 2mM	30.89	b	55.06	b	78.95	b	121.18	ab
K3, 4mM	46.60	b	95.53	a	116.82	a	145.46	a
K4, 6mM	48.50	b	93.40	a	127.04	a	143.67	a
K5, 8mM	83.10	a	95.42	a	83.77	b	93.45	bc
Means	45.16	D	78.01	C	97.66	B	118.05	A
$Fe_{LSD<0.01}$: 14.754				$K_{LSD<0.01}$: 16.495			$Fe*K_{LSD<0.01}$: 32.991	
	Dry weight of roots, (g pot^{-1})							
K1, 1mM	5.59	c	11.75	b	19.86	c	19.18	b
K2, 2mM	9.61	bc	12.04	b	24.85	bc	30.24	a
K3, 4mM	15.77	b	27.54	a	32.14	ab	40.21	a
K4, 6mM	12.53	bc	26.98	a	38.82	a	40.74	a
K5, 8mM	25.15	a	29.05	a	29.02	b	35.65	a
Means	13.73	C	21.47	B	28.94	A	33.20	A
$Fe_{LSD<0.01}$: 4.901				$K_{LSD<0.01}$: 5.479			$Fe*K_{LSD<0.05}$: 8.188	

Table III: Effects of increasing amounts of potassium and iron on SPAD readings of maize leaves

Potassium (K) doses, (mM)	Iron Doses, (Fe)							
	Fe1, 30 µM		Fe2, 60 µM		Fe3, 90 µM		Fe4, 120 µM	
	SPAD Values							
K1, 1mM	8.43	b	18.60	c	29.83	bc	32.53	ab
K2, 2mM	9.53	ab	19.20	bc	31.57	b	33.83	a
K3, 4mM	12.53	a	24.27	ab	31.43	b	33.73	a
K4, 6mM	12.67	a	25.50	a	35.80	a	35.47	a
K5, 8mM	11.43	ab	21.97	bc	27.53	c	30.27	b
Means	10.92	D	21.91	C	31.23	B	33.17	A
	$Fe_{LSD<0.01}$: 1.467			$K_{LSD<0.01}$: 1.640			$Fe*K_{LSD<0.01}$: 3.280	

The differences between values indicated by different letters are significant
Capital letters indicate rows and small letters indicate columns

concentrations (8.90%) in leaves and (7.08%) in roots were measured at the K3Fe1 and K5Fe1 applications, the highest uptakes (7123.46 mg tdw^{-1}) (2385.37 mg tdw^{-1}) were found at K4Fe3 and K5Fe4, respectively. Although the increasing amounts of Fe lowered the concentrations of K, it enhanced their uptake both in the leaves and in the roots.

Similar to the dry weight and SPAD values, the total Fe concentrations as well as their uptakes increased with the increasing levels of Fe and K, but the amounts decreased with the highest K dose, especially in the K5Fe4 application. Total Fe concentrations of the leaves were 47.31 mg kg^{-1} in the K4Fe4 application. This value decreased to 44.71 mg kg^{-1} with the K5Fe4 application (Table IV). High concentrations of K affected the uptake of total Fe. The highest uptake (6.80 mg tdw^{-1}) occurred with K4Fe4 application and decreased to 4.16 mg tdw^{-1} with the K5Fe4 application (Table V).

The response mentioned above was much more evident at the roots. The highest total Fe concentration (1353.67 mg kg^{-1}) was measured with the K3Fe4 application and tended to decrease with increasing amounts of K. This value was measured as 1180.73 mg kg^{-1} with K4Fe4 and 896.03 mg kg^{-1} with K5Fe4 applications (Table IV). High concentrations of K also lowered the total Fe uptake of the roots. The highest uptake (53.88 mg tdw^{-1}) was with the K3Fe4 treatment and it decreased to 48.48 mg tdw^{-1} with the K4Fe4 application and 32.35 mg tdw^{-1} with the K5Fe4 application (Table V).

DISCUSSION

Potassium (K) is unique among the essential nutrients, given the diversity of roles it plays in plant metabolic processes (Pervez *et al*., 2006). Numerous solution culture methods and pot experiments with K-free substrates have shown that plants do not grow without K. As soon as the K reserve in the seed is exhausted, the plants die away (Mengel, 2007). According to the physical appearance of the plants in our research, neither the first dose of K, nor the application of additive Fe was sufficient for the healthy development of the maize plants and confirms the findings of Mengel (2007). We observed that the elevated concentrations of K had positive effects on the plant growth, however excess amounts of K at K5 level, depressed the plant growth, dry matter yield, SPAD values and Fe amounts of maize. Various researchers have also confirmed the direct effect of K on plant growth and development. In a pot experiment comprising graded doses of K and Fe, Sahu and Mitra (1992) reported that the dry matter yield of rice increased with increasing doses of K. Cheema *et al.* (1999) also reported that K application improved maize yield but the highest level found uneconomical.

Table IV: Effects of increasing amounts of potassium and iron on potassium and iron contents of maize leaves and roots

Potassium (K) doses, mM	Iron Doses, (Fe)							
	Fe1, 30µM		Fe2, 60µM		Fe3, 90µM		Fe4, 120µM	
	Potassium contents of leaves, %							
K1, 1mM	5.82	c	3.01	d	1.78	d	1.77	d
K2, 2mM	7.88	b	4.16	c	3.41	c	2.58	c
K3, 4mM	8.90	a	5.12	b	3.94	c	3.92	b
K4, 6mM	8.23	ab	6.27	a	5.66	b	4.51	b
K5, 8mM	7.51	b	6.96	a	7.39	a	6.67	a
Means	7.67	A	5.11	B	4.44	C	3.89	D
$Fe_{LSD<0.01}$: 0.336			$K_{LSD<0.01}$: 0.376				$Fe*K_{LSD<0.01}$: 0.752	
	Potassium contents of roots, %							
K1, 1mM	2.79	d	1.46	d	1.10	e	1.09	d
K2, 2mM	4.41	c	2.38	c	1.91	d	1.41	d
K3, 4mM	5.80	b	3.58	b	3.54	c	2.43	c
K4, 6mM	6.82	a	5.73	a	4.25	b	4.08	b
K5, 8mM	7.08	a	5.59	a	6.99	a	6.69	a
Means	5.38	A	3.75	B	3.56	B	3.14	C
$Fe_{LSD<0.01}$: 0.272			$K_{LSD<0.01}$: 0.304				$Fe*K_{LSD<0.01}$: 0.607	
	Iron contents of leaves, mg kg^{-1}							
K1, 1mM	33.39	a	37.73	ab	33.13	b	44.95	a
K2, 2mM	27.22	ab	27.23	c	30.59	b	33.41	b
K3, 4mM	24.07	b	32.13	bc	34.38	b	34.68	b
K4, 6mM	21.34	b	30.39	bc	33.78	b	47.31	a
K5, 8mM	32.73	a	44.22	a	44.26	a	44.71	a
Means	27.75	C	34.34	B	35.23	B	41.01	A
$Fe_{LSD<0.01}$: 3.604			$K_{LSD<0.01}$: 4.030				$Fe*K_{LSD<0.01}$: 8.059	
	Iron contents of roots, mg kg^{-1}							
K1, 1mM	933.77		1334.33		1831.33		1724.33	
K2, 2mM	830.07		1086.73		1212.33		1180.03	
K3, 4mM	593.47		626.10		1086.97		1353.67	
K4, 6mM	451.03		794.13		1268.13		1180.73	
K5, 8mM	435.10		888.63		907.03		896.03	
Means	648.69	C	945.99	B	1261.16	A	1266.96	A
$Fe_{LSD<0.01}$: 212.273			$K_{LSD<0.01}$: 237.328				Fe*K: ns	

The differences between values indicated by different letters are significant
Capital letters indicate rows and small letters indicate columns

K has an impact on the uptake of other cationic species and thus may affect the crop yield and the crop quality (Mengel, 2007). K interacts with almost all of the essential macronutrients, the secondary nutrients and the micronutrients (Pervez *et al*., 2006). Our results also confirm this interaction with Fe. Sahu and Mitra (1992) observed that although the uptake of K increased with increasing K doses, the ratio of Fe/K continued to decrease indicating that K has an antagonistic effect on Fe uptake. K is absorbed rapidly and this causes competition for the uptake of other cations, thus acting as a strong competitor (Demiral & Köseoğlu, 2005). If K is present in a relatively high concentration, it affects the uptake of other cations such as Na^+, Mg^{2+} and Ca^{2+}. If K is not present in the nutrient solution, the other cationic species are taken up at higher rates (Mengel, 2007). This situation clarifies the high contents of Fe at K1 level in both leaves and roots of maize. The response mentioned above was much more evident at the roots. The concentration of Fe was found high in the roots and tend to decrease with increasing amounts of K dealing with the antagonistic effect. High amounts of Fe in the roots are also the evidence that Fe may accumulate in the roots. Tanaka *et al.* (1973) also associated Fe toxicity with K deficiency, especially in heavy soil. Fe toxicity can be ameliorated or eliminated by K fertilizer applications (Trolldenier, 1973; Tanaka *et al*., 1973; Li *et al*., 2001; Çakmak, 2005; Becker & Asch, 2005). The ameliorating effects of K may be attributed to the antagonistic effect of K on Fe absorption and translocation into the shoots (Li *et al*., 2001). Apart from its high activity, K has lethal action on microorganisms that are responsible for the depletion of O_2 and the production of electrons. As shown using manganese and copper, K can serve as an oxidising agent that converts Fe^{2+} ions into the less soluble Fe^{3+} (Troeh & Thompson, 2005). Urrestarazu *et al.* (1994) also pointed out that plants absorb K much more than Fe and that excess amounts of K inhibit the uptake and translocation of Fe in plants, leading to Fe deficiency. Some recent studies have shown that when the chlorosis symptoms occurred, the K contents of the plant were high in the chlorotic plant samples (Köseoğlu, 1995; Belkhodja *et al*., 1998; Saatçi & Yağmur, 2000; Torres *et al.,* 2006; Çelik & Katkat, 2007). Demiral and Köseoğlu (2005) also reported that the application of increasing amounts of K lowered the Fe content of the Galia melon from that of a control.

Table V: Effects of increasing amounts of potassium and iron on potassium and iron uptake of maize leaves and roots (mg tdw^{-1})

Potassium (K) Doses, mM	Iron Doses, (Fe)							
	Fe1, 30µM		Fe2, 60µM		Fe3, 90µM		Fe4, 120µM	
	Potassium uptake by leaves, mg tdw^{-1}							
K1, 1mM	974.63	d	1524.66	c	1476.46	d	1670.72	c
K2, 2mM	2423.91	c	2285.73	c	2669.98	c	3115.75	b
K3, 4mM	4100.45	b	4892.27	b	4600.06	b	5687.70	a
K4, 6mM	3983.82	b	5837.39	ab	7123.46	a	6488.24	a
K5, 8mM	6252.97	a	6636.34	a	6197.07	a	6119.18	a
Means	3547.16	B	4235.28	AB	4413.41	A	4616.32	A
$Fe_{LSD<0.01}$: 712.575			$K_{LSD<0.01}$: 796.684			$Fe*K_{LSD<0.05}$: 1190.593		
	Potassium uptake by roots, mg tdw^{-1}							
K1, 1mM	156.61	c	172.41	c	220.63	c	209.30	d
K2, 2mM	420.58	c	286.62	c	476.38	c	429.72	d
K3, 4mM	919.06	b	985.15	b	1140.73	b	978.78	c
K4, 6mM	860.07	b	1532.25	a	1641.08	a	1659.83	b
K5, 8mM	1771.81	a	1619.67	a	2033.23	a	2385.37	a
Means	825.63	B	919.22	AB	1102.41	A	1132.60	A
$Fe_{LSD<0.01}$: 239.922			$K_{LSD<0.01}$: 268.241			$Fe*K_{LSD<0.05}$:400.869		
	Iron Uptake of leaves, mg tdw^{-1}							
K1, 1mM	0.56	b	1.91	bc	2.70	bc	3.89	b
K2, 2mM	0.84	b	1.49	c	2.42	c	4.05	b
K3, 4mM	1.13	b	3.07	ab	4.00	ab	5.05	b
K4, 6mM	1.04	b	2.83	abc	4.28	a	6.80	a
K5, 8mM	2.73	a	4.22	a	3.77	abc	4.16	b
Means	1.26	D	2.70	C	3.43	B	4.79	A
$Fe_{LSD<0.01}$: 0.638			$K_{LSD<0.01}$: 0.713			$Fe*K_{LSD<0.01}$: 1.426		
	Iron uptake by roots, mg tdw^{-1}							
K1, 1mM	5.22	a	15.54	ab	35.98	ab	33.04	c
K2, 2mM	7.93	a	12.92	b	29.69	b	35.71	bc
K3, 4mM	9.94	a	17.31	ab	35.25	ab	53.88	a
K4, 6mM	5.75	a	20.99	ab	48.33	a	48.48	ab
K5, 8mM	11.23	a	26.01	a	26.41	b	32.35	c
Means	8.02	C	18.55	B	35.13	A	40.69	A
$Fe_{LSD<0.01}$: 7.829			$K_{LSD<0.01}$: 6.541			$Fe*K_{LSD<0.01}$: 13.081		

The differences between values indicated by different letters are significant, Capital letters indicate rows and small letters indicate columns
tdw: total dry weight

CONCLUSION

Deficiency of K and Fe caused poor development and chlorosis symptoms in the maize plant, while their increased amounts stimulated growth and enhanced dry matter yield. However the highest doses had a negative effect and decreased the plant growth and other parameters. The highest dose of K not only lowered the K amounts in the plant but also decreased the total iron contents in the leaves and roots of the maize. Thus adequate K is also required for the efficient use of Fe. However, too high a concentration of K will cause competition with iron and other cations.

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