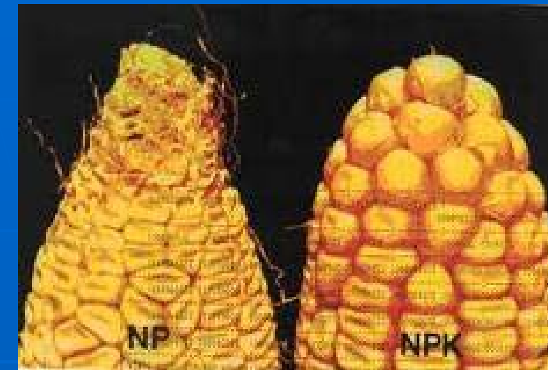
# Potassium (K)-Iron (Fe) Interactions in Maize Growth

**Hakan ÇELİK, Ali Vahap KATKAT, Barış Bülent AŞIK and Serhat GÜREL**

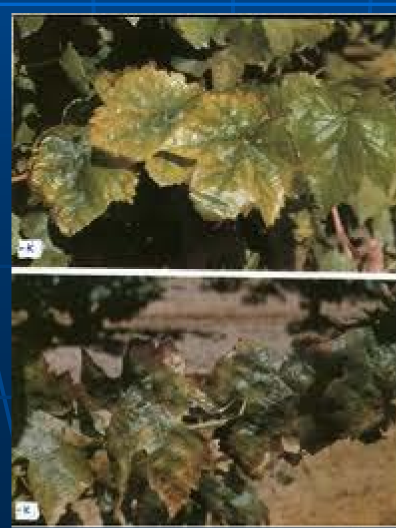
Uludag University, Faculty of Agriculture,
Department of Soil Science and Plant Nutrition, Bursa, 16059, TURKEY
Fax:+90 224 2941402, e-mail: hcelik@uludag.edu.tr

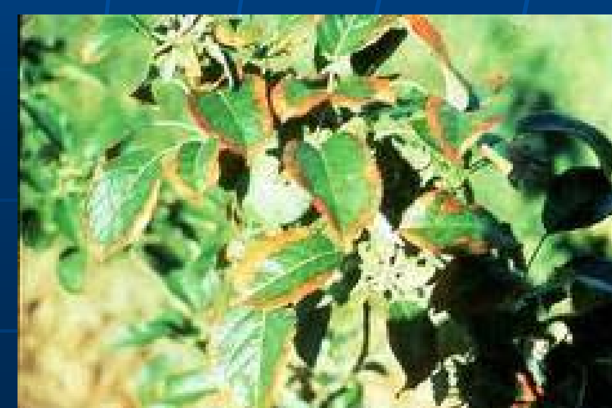


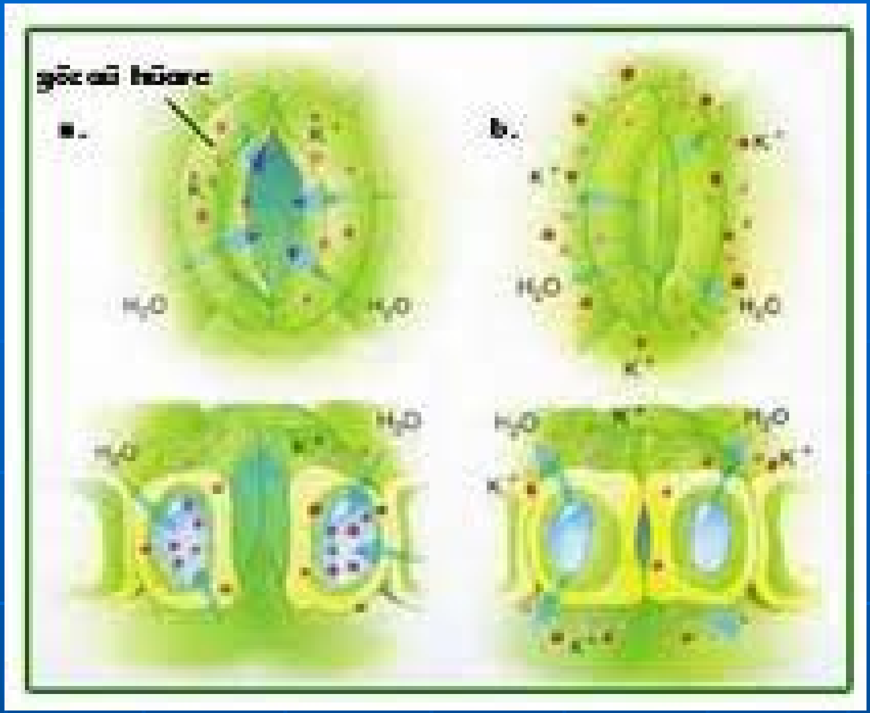

Potassium (K) is essential for plant and animal life wherein it has many vital nutritional roles.

While in animals and humans, potassium is the third most abundant element after calcium and phosphorus,
in plants, potassium and nitrogen are the two elements required in greatest amounts.

Without sufficient plant and animal intake of potassium, life as we know it would cease.






This nutrient plays an essential role in plant growth and metabolism.
It activates enzymes,
serves as an osmoticum to maintain tissue turgor pressure,
regulates the opening and closing of stomata
balances the charge of anions (Marchner, 1995; Mengel, 2007) .

All plants require potassium, especially crops high in carbohydrates.

Studies have shown that adequate amounts of potassium may promote the growth of long, strong cotton fibres;

increase the size and quality of fruits, grains, and vegetables;

Increases the shelf life of fruits;
Increases the stem length and quantity of roses;
Enhances the green colour and growth of turf grass;

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 and Aly, 2004).

Although most soils contain adequate total iron, amounts that are available to plants might be inadequate dependent on various soil factors.

very high or low soil temperature,
high humidity,
poor soil aeration and compaction,
high pH, $HCO_3^-$ and $CaCO_3$ contents.

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 other heavy metals such as Zn, Cu, Mn, Co, Ni and Cd (Lucena, 2000; Köseoğlu, 1995).

Excess applications of K or increasing amounts of K release under suitable soil conditions can inhibit the Fe uptake and may affect the degree of Fe chlorosis.

Some recent studies showed that when the chlorosis symptoms occurred, K contents of the plant were found high at this chlorotic plant samples (Abadia et al., 1985; Dong, 1987; Köseoğlu, 1995; Belkhodja et al., 1998; Saatçi and Yağmur, 2000; Torres et al., 2006; Çelik and Katkat, 2007).

On the other hand Fe toxicity occurs in various rice-growing areas most frequently. This type of toxicity is especially frequent in heavy soils and is often associated with K deficiency (Tanaka et al., 1973).

When the K nutrition is inadequate, the capability of rice roots to oxidise $Fe^{+2}$ to $Fe^{+3}$ is impaired (Trolldenier 1973).

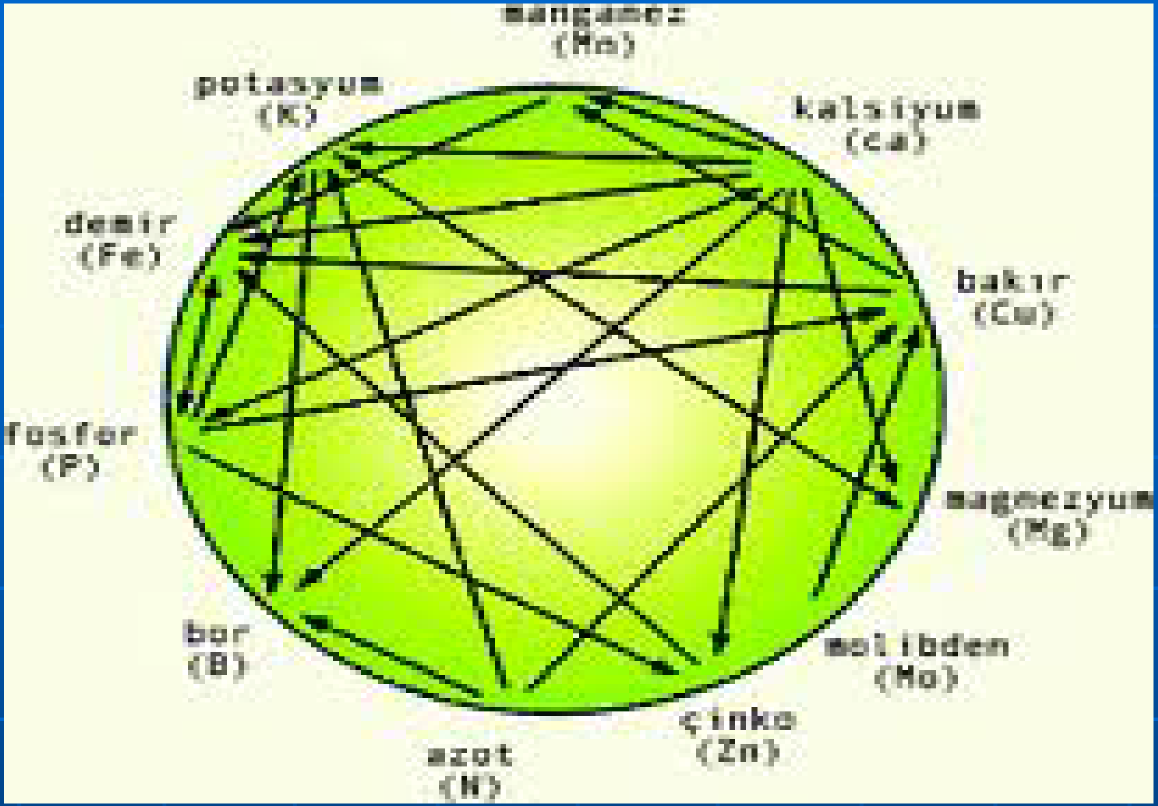
Increasing amounts of K reduce the Fe concentration in the leaves at least 2-fold and improve the plant growth (Li et al. 2001).

A large body of literature supports the ameliorative effects of phosphorus, potassium and zinc fertiliser application under Fe toxic conditions (Becker and Asch, 2005).

Toxicity effects can be ameliorated or eliminated using excess K dressings that reduce the uptake of $Fe^{+2}$ (Trolldenier, 1973; Tanaka et al., 1973; Li et al., 2001; Çakmak, 2005; Becker and 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).

Plants take 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 (Urrestarazu et al. (1994).




This study was aimed 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.

Maize (*Zea Mays* L. cv. BSC 6661) seeds were germinated in a perlite medium that was moistened with half strength nutrient solution modified from Römheld and Marschner (1981), containing the following nutrients (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,

three channels parallel to each other. Each channel contained four plants.

Twenty different nutrient solutions composed of five K doses (1, 2, 4, 6 and 8 mM) and four Fe doses (30, 60, 90 and 120 μM) were administered to the plants in twenty hydroponic systems during the vegetation period.

Table 1. Nutrient elements, concentrations and their resources used in the experiment.

| 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 | 60µM Fe | 90µM Fe | 120µM Fe | |

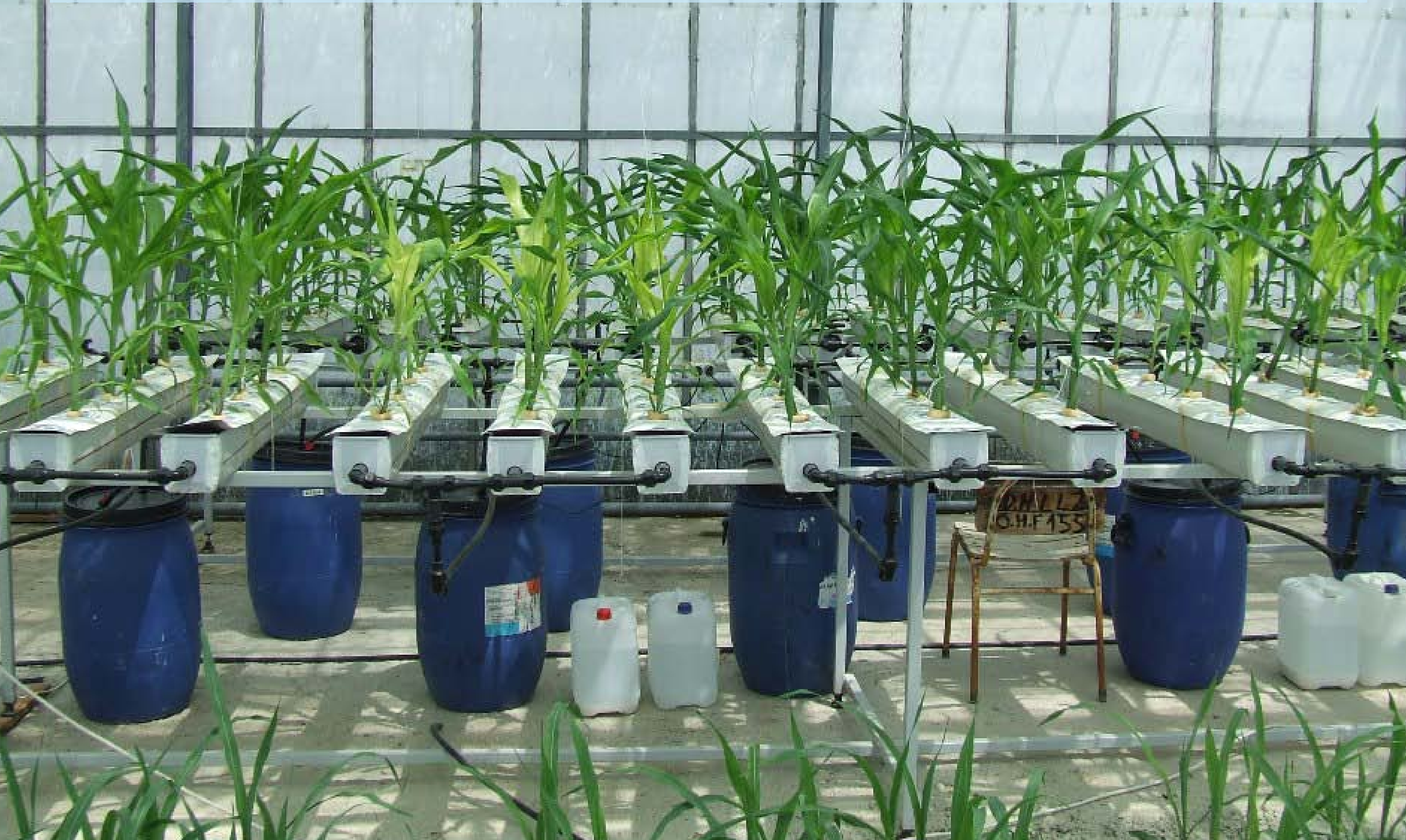
pH of the nutrient solutions ranged between 6.93-8.06 and the E.C. values ranged between 982-1407$\mu$S $cm^{-1}$ due to their nutrient contents. The nutrient solutions were renewed every 4-5 days.

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 effected the development. The plants became taller and greener with the addition of increasing amounts of K and Fe.

As a result, the potassium deficiency symptoms 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.

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 41st day.



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 hours 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).

Table 2: Effects of increasing amounts of potassium and iron on dry weight of maize leaves (g $pot^{-1}$).

| Potassium (K) Doses, mM | Iron Doses, (Fe) | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Fe1, 30µM | | | Fe2, 60µM | | | Fe3, 90µM | | | Fe4, 120µM | | | Means | |
| | Dry Weight, (g $pot^{-1}$) | | | | | | | | | | | | | |
| K1, 1mM | 16.79 | b | C | 50.64 | b | B | 81.70 | b | AB | 86.49 | c | A | 58.91 | b |
| K2, 2mM | 30.89 | b | C | 55.06 | b | BC | 78.95 | b | B | 121.18 | ab | A | 71.52 | b |
| K3, 4mM | 46.60 | b | C | 95.53 | a | B | 116.82 | a | AB | **145.46** | a | A | 101.08 | a |
| K4, 6mM | 48.50 | b | C | 93.40 | a | B | 127.04 | a | A | 143.67 | a | A | 103.15 | a |
| K5, 8mM | 83.10 | a | A | 95.42 | a | A | 83.77 | b | A | **93.45** | bc | A | 88.93 | a |
| 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 | | | | |

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

Table 3: Effects of increasing amounts of potassium and iron on dry weight of maize roots (g $pot^{-1}$).

| Potassium (K) Doses. mM | Iron Doses. (Fe) | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Fe1, 30µM | | | Fe2, 60µM | | | Fe3, 90µM | | | Fe4, 120µM | | | Means | |
| | Dry Weight, (g $pot^{-1}$) | | | | | | | | | | | | | |
| K1, 1mM | 5.59 | c | B | 11.75 | b | AB | 19.86 | c | A | 19.18 | b | A | 14.10 | b |
| K2, 2mM | 9.61 | bc | B | 12.04 | b | B | 24.85 | bc | A | 30.24 | a | A | 19.19 | b |
| K3, 4mM | 15.77 | b | C | 27.54 | a | B | 32.14 | ab | AB | 40.21 | a | A | 28.91 | a |
| K4, 6mM | 12.53 | bc | C | 26.98 | a | B | 38.82 | a | A | **40.74** | a | A | 29.77 | a |
| K5, 8mM | 25.15 | a | B | 29.05 | a | AB | 29.02 | b | AB | 35.65 | a | A | 29.72 | 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 | | | | |

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

## 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.

Table 4: Effects of increasing amounts of potassium and iron on SPAD readings of maize leaves.

| Potassium (K) Doses, mM | Iron Doses, (Fe) | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Fe1, 30µM | | | Fe2, 60µM | | | Fe3, 90µM | | | Fe4, 120µM | | | Means | |
| | SPAD Values | | | | | | | | | | | | | |
| K1, 1mM | 8.43 | b | C | 18.60 | c | B | 29.83 | bc | A | 32.53 | ab | A | 22.50 | c |
| K2, 2mM | 9.53 | ab | C | 19.20 | bc | B | 31.57 | b | A | 33.83 | a | A | 23.53 | c |
| K3, 4mM | 12.53 | a | C | 24.27 | ab | B | 31.43 | b | A | 33.73 | a | A | 25.49 | b |
| K4, 6mM | 12.67 | a | C | 25.50 | a | B | **35.80** | a | A | **35.47** | a | A | 27.36 | a |
| K5, 8mM | 11.43 | ab | C | 21.97 | bc | B | 27.53 | c | A | 30.27 | b | A | 22.80 | c |
| 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.

| | |
|---|---|
| Fe, | ICP-OES (PerkinElmer Optima 2100 DV) (Isaac and Johnson, 1998). |
| Active Fe | In the dry plant parts by incubating for 24 h in 1 N HCl extraction solution (1:10) using the method of Oserkowsky (1933), modified by Llorente et al. (1976). The resultant amounts were measured by ICP-OES. |
| K | Flame emission (Eppendorf Elex 6361) (Horneck and Hanson 1998). |

Table 5: Effects of increasing amounts of potassium and iron on potassium concentrations of maize shoots.

| Potassium (K) Doses, mM | Iron Doses, (Fe) | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Fe1, 30µM | | | Fe2, 60µM | | | Fe3, 90µM | | | Fe4, 120µM | | | Means | |
| | **Potassium Concentrations, %** | | | | | | | | | | | | | |
| K1, 1mM | 5.82 | c | A | 3.01 | d | B | 1.78 | d | C | 1.77 | d | C | 3.10 | e |
| K2, 2mM | 7.88 | b | A | 4.16 | c | B | 3.41 | c | B | 2.58 | c | C | 4.51 | d |
| K3, 4mM | **8.90** | a | A | 5.12 | b | B | 3.94 | c | C | 3.92 | b | C | 5.47 | c |
| K4, 6mM | 8.23 | ab | A | 6.27 | a | B | 5.66 | b | B | 4.51 | b | C | 6.17 | b |
| K5, 8mM | 7.51 | b | A | 6.96 | a | AB | 7.39 | a | AB | 6.67 | a | B | 7.13 | 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

Table 6: Effects of increasing amounts of potassium and iron on potassium concentrations of maize roots.

| Potassium (K) Doses, mM | Iron Doses, (Fe) | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Fe1, 30µM | | | Fe2, 60µM | | | Fe3, 90µM | | | Fe4, 120µM | | | Means | |
| | **Potassium Concentrations, %** | | | | | | | | | | | | | |
| K1, 1mM | 2.79 | d | A | 1.46 | d | B | 1.10 | e | B | 1.09 | d | B | 1.61 | e |
| K2, 2mM | 4.41 | c | A | 2.38 | c | B | 1.91 | d | BC | 1.41 | d | C | 2.53 | d |
| K3, 4mM | 5.80 | b | A | 3.58 | b | B | 3.54 | c | B | 2.43 | c | C | 3.84 | c |
| K4, 6mM | 6.82 | a | A | 5.73 | a | B | 4.25 | b | C | 4.08 | b | C | 5.22 | b |
| K5, 8mM | **7.08** | a | A | 5.59 | a | B | 6.99 | a | A | 6.69 | a | A | 6.59 | 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

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

Table 7: Effects of increasing amounts of potassium and iron on potassium uptake by maize shoots (mg $tdw^{-1}$).

| Potassium (K) Doses, mM | Iron Doses, (Fe) | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Fe1, 30µM | | | Fe2, 60µM | | | Fe3, 90µM | | | Fe4, 120µM | | | Means | |
| | **Potassium Uptake, mg $tdw^{-1}$** | | | | | | | | | | | | | |
| K1, 1mM | 974.63 | d | A | 1524.66 | c | A | 1476.46 | d | A | 1670.72 | c | A | 1411.62 | d |
| K2, 2mM | 2423.91 | c | A | 2285.73 | c | A | 2669.98 | c | A | 3115.75 | b | A | 2623.84 | c |
| K3, 4mM | 4100.45 | b | B | 4892.27 | b | AB | 4600.06 | b | AB | 5687.70 | a | A | 4820.12 | b |
| K4, 6mM | 3983.82 | b | C | 5837.39 | ab | B | **7123.46** | a | A | 6488.24 | a | AB | 5858.23 | a |
| K5, 8mM | 6252.97 | a | A | 6636.34 | a | A | 6197.07 | a | A | 6119.18 | a | A | 6301.39 | 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 | | | | |

Table 8: Effects of increasing amounts of potassium and iron on potassium uptake by maize roots (mg $tdw^{-1}$).

| Potassium (K) Doses, mM | Iron Doses, (Fe) | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Fe1, 30µM | | | Fe2, 60µM | | | Fe3, 90µM | | | Fe4, 120µM | | | Means | |
| | **Potassium Uptake, mg $tdw^{-1}$** | | | | | | | | | | | | | |
| K1, 1mM | 156.61 | c | A | 172.41 | c | A | 220.63 | c | A | 209.30 | d | A | 189.74 | d |
| K2, 2mM | 420.58 | c | A | 286.62 | c | A | 476.38 | c | A | 429.72 | d | A | 403.33 | d |
| K3, 4mM | 919.06 | b | A | 985.15 | b | A | 1140.73 | b | A | 978.78 | c | A | 1005.93 | c |
| K4, 6mM | 860.07 | b | B | 1532.25 | a | A | 1641.08 | a | A | 1659.83 | b | A | 1423.31 | b |
| K5, 8mM | 1771.81 | a | BC | 1619.67 | a | C | 2033.23 | a | AB | **2385.37** | a | A | 1952.52 | 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 | | | | |

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

Table 9: Effects of increasing amounts of potassium and iron on iron concentrations of maize shoots.

| Potassium (K) Doses, mM | Iron Doses, (Fe) | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Fe1, 30µM | | | Fe2, 60µM | | | Fe3, 90µM | | | Fe4, 120µM | | | Means | |
| | **Iron Concentrations, mg kg$^{-1}$** | | | | | | | | | | | | | |
| K1, 1mM | 33.39 | a | B | 37.73 | ab | AB | 33.13 | b | B | 44.95 | a | A | 37.30 | b |
| K2, 2mM | 27.22 | ab | A | 27.23 | c | A | 30.59 | b | A | 33.41 | b | A | 29.61 | c |
| K3, 4mM | 24.07 | b | B | 32.13 | bc | A | 34.38 | b | A | 34.68 | b | A | 31.32 | c |
| K4, 6mM | 21.34 | b | C | 30.39 | bc | B | 33.78 | b | B | **47.31** | a | A | 33.21 | c |
| K5, 8mM | 32.73 | a | B | 44.22 | a | A | 44.26 | a | A | 44.71 | a | A | 41.48 | 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 | | | | |

Table 10: Effects of increasing amounts of potassium and iron on iron concentrations of maize roots.

| Potassium (K) Doses, mM | Iron Doses, (Fe) | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | Fe1, 30µM | | Fe2, 60µM | | Fe3, 90µM | | Fe4, 120µM | | Means | |
| | **Iron Concentrations, mg kg$^{-1}$** | | | | | | | | | |
| K1, 1mM | 933.77 | | 1334.33 | | 1831.33 | | 1724.33 | | 1455.94 | a |
| K2, 2mM | 830.07 | | 1086.73 | | 1212.33 | | 1180.03 | | 1077.29 | b |
| K3, 4mM | 593.47 | | 626.10 | | 1086.97 | | **1353.67** | | 915.05 | bc |
| K4, 6mM | 451.03 | | 794.13 | | 1268.13 | | 1180.73 | | 923.51 | bc |
| K5, 8mM | 435.10 | | 888.63 | | 907.03 | | 896.03 | | 781.70 | c |
| 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.

Table 11: Effects of increasing amounts of potassium and iron on iron uptake by shoots (mg $tdw^{-1}$).

| Potassium (K) Doses, mM | Iron Doses, (Fe) | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Fe1, 30µM | | | Fe2, 60µM | | | Fe3, 90µM | | | Fe4, 120µM | | | Means | |
| | **Iron Uptake, mg $tdw^{-1}$** | | | | | | | | | | | | | |
| K1, 1mM | 0.56 | b | C | 1.91 | bc | BC | 2.70 | bc | AB | 3.89 | b | A | 2.27 | b |
| K2, 2mM | 0.84 | b | C | 1.49 | c | BC | 2.42 | c | B | 4.05 | b | A | 2.20 | b |
| K3, 4mM | 1.13 | b | C | 3.07 | ab | B | 4.00 | ab | AB | 5.05 | b | A | 3.31 | a |
| K4, 6mM | 1.04 | b | D | 2.83 | abc | C | 4.28 | a | B | **6.80** | a | A | 3.74 | a |
| K5, 8mM | 2.73 | a | B | 4.22 | a | A | 3.77 | abc | AB | 4.16 | b | A | 3.72 | a |
| 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 | | | | |

Table 12: Effects of increasing amounts of potassium and iron on iron uptake of maize roots (mg $tdw^{-1}$).

| Potassium (K) Doses, mM | Iron Doses, (Fe) | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Fe1, 30µM | | | Fe2, 60µM | | | Fe3, 90µM | | | Fe4, 120µM | | | Means | |
| | **Iron Uptake, mg $tdw^{-1}$** | | | | | | | | | | | | | |
| K1, 1mM | 5.22 | a | B | 15.54 | ab | B | 35.98 | ab | A | 33.04 | c | A | 22.45 | c |
| K2, 2mM | 7.93 | a | B | 12.92 | b | B | 29.69 | b | A | 35.71 | bc | A | 21.56 | c |
| K3, 4mM | 9.94 | a | C | 17.31 | ab | C | 35.25 | ab | B | **53.88** | a | A | 29.10 | ab |
| K4, 6mM | 5.75 | a | C | 20.99 | ab | B | 48.33 | a | A | 48.48 | ab | A | 30.89 | a |
| K5, 8mM | 11.23 | a | B | 26.01 | a | A | 26.41 | b | A | 32.35 | c | A | 24.00 | bc |
| 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

Table 13: Effects of increasing amounts of potassium and iron on active iron concentrations of maize shoots.

| Potassium (K) Doses, mM | Iron Doses, (Fe) | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Fe1, 30µM | | | Fe2, 60µM | | | Fe3, 90µM | | | Fe4, 120µM | | | Means | |
| | **Active Iron Concentrations, mg kg$^{-1}$** | | | | | | | | | | | | | |
| K1, 1mM | 13.30 | ab | B | 22.52 | ab | B | 24.68 | c | B | 27.12 | b | A | 21.91 | b |
| K2, 2mM | 20.06 | a | A | 24.37 | ab | A | 26.11 | bc | A | 24.41 | b | A | 23.74 | b |
| K3, 4mM | 11.64 | b | C | 20.29 | b | B | 34.38 | a | A | 27.30 | b | AB | 23.40 | b |
| K4, 6mM | 18.76 | a | C | 22.47 | ab | C | 32.97 | ab | B | **42.01** | a | A | 29.05 | a |
| K5, 8mM | 18.28 | ab | B | 28.65 | a | AB | 22.06 | c | B | 29.01 | b | A | 24.50 | b |
| Means | 16.41 | C | | 23.66 | B | | 28.04 | A | | 29.97 | A | | | |
| $Fe_{LSD<0.01}$: 3.180 | | | | $K_{LSD<0.01}$: 3.555 | | | | | | $Fe*K_{LSD<0.01}$: 7.110 | | | | |

Table 14: Effects of increasing amounts of potassium and iron on active iron uptake by shoots (mg tdw$^{-1}$).

| Potassium (K) Doses, mM | Iron Doses, (Fe) | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Fe1, 30µM | | | Fe2, 60µM | | | Fe3, 90µM | | | Fe4, 120µM | | | Means | |
| | **Active Iron Uptake, mg tdw$^{-1}$** | | | | | | | | | | | | | |
| K1, 1mM | 0.23 | a | B | 1.14 | b | AB | 2.01 | b | A | 2.35 | c | A | 1.43 | d |
| K2, 2mM | 0.62 | a | C | 1.34 | b | BC | 2.07 | b | AB | 2.96 | bc | A | 1.75 | cd |
| K3, 4mM | 0.55 | a | C | 1.93 | ab | B | 4.11 | a | A | 3.97 | b | A | 2.64 | ab |
| K4, 6mM | 0.91 | a | C | 2.10 | ab | C | 4.20 | a | B | **6.02** | a | A | 3.31 | a |
| K5, 8mM | 1.53 | a | A | 2.73 | a | A | 1.85 | b | A | 2.73 | bc | A | 2.21 | bc |
| Means | 0.77 | D | | 1.85 | C | | 2.85 | B | | 3.61 | A | | | |
| $Fe_{LSD<0.01}$: 0.602 | | | | $K_{LSD<0.01}$: 0.673 | | | | | | $Fe*K_{LSD<0.01}$: 1.346 | | | | |

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

tdw: total dry weight

# 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 potassium reserves of the seed are 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 plants growth, dry matter yield, SPAD values and Fe amounts of maize.

Various researchers have 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.

Potassium 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. Potassium is absorbed rapidly, and this causes competition for the uptake of other cations (Demiral and Köseoğlu, 2005).

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.

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 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.

Table 9: Effects of increasing amounts of potassium and iron on iron concentrations of maize shoots.

| Potassium (K) Doses, mM | Iron Doses, (Fe) | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Fe1, 30µM | | | Fe2, 60µM | | | Fe3, 90µM | | | Fe4, 120µM | | | Means | |
| | Iron Concentrations, mg kg$^{-1}$ | | | | | | | | | | | | | |
| K1, 1mM | 33.39 | a | B | 37.73 | ab | AB | 33.13 | b | B | 44.95 | a | A | 37.30 | b |
| K2, 2mM | 27.22 | ab | A | 27.23 | c | A | 30.59 | b | A | 33.41 | b | A | 29.61 | c |
| K3, 4mM | 24.07 | b | B | 32.13 | bc | A | 34.38 | b | A | 34.68 | b | A | 31.32 | c |
| K4, 6mM | 21.34 | b | C | 30.39 | bc | B | 33.78 | b | B | **47.31** | a | A | 33.21 | c |
| K5, 8mM | 32.73 | a | B | 44.22 | a | A | 44.26 | a | A | 44.71 | a | A | 41.48 | 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 | | | | |

Table 10: Effects of increasing amounts of potassium and iron on iron concentrations of maize roots.

| Potassium (K) Doses, mM | Iron Doses, (Fe) | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Fe1, 30µM | | Fe2, 60µM | | Fe3, 90µM | | Fe4, 120µM | | Means | |
| | Iron Concentrations, mg kg$^{-1}$ | | | | | | | | | |
| K1, 1mM | 933.77 | | 1334.33 | | 1831.33 | | 1724.33 | | 1455.94 | a |
| K2, 2mM | 830.07 | | 1086.73 | | 1212.33 | | 1180.03 | | 1077.29 | b |
| K3, 4mM | 593.47 | | 626.10 | | 1086.97 | | **1353.67** | | 915.05 | bc |
| K4, 6mM | 451.03 | | 794.13 | | 1268.13 | | 1180.73 | | 923.51 | bc |
| K5, 8mM | 435.10 | | 888.63 | | 907.03 | | 896.03 | | 781.70 | c |
| 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.

## CONCLUSIONS

1. Deficiency of K and Fe caused poor development and chlorosis symptoms in the maize plant,
2. Their increased amounts stimulated the plant growth and enhanced dry matter yield.
3. The highest doses had a negative effect and decreased the plant growth and other parameters.
4. The highest dose of potassium not only lowered the potassium amounts in the plant but also decreased the total and active iron concentrations in the leaves and roots of maize.
5. 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.
6. To observe the competition between these nutrients and show their effects on yield, further researches should be done on various field conditions.

Thank You