THE ABSORPTION OF MINERAL NUTRIENTS BY SWEET CORN SEEDLINGS (*Zea mays* L.) AS AFFECTED BY NITROGEN FERTILIZATION AND WATER STRESS[1]/

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Resumen

Se estudió la absorción de N, P, K y Mg por plántulas de maiz sembradas en potes con diferentes niveles de H y cantidades de agua. En adición, se estudió la resistencia de los estomas, el potencial hidrico de las hojas y el contenido de humedad relativo.

Cuando los resultados se expresan como porcentaje de peso seco, los contenidos de N, P y K decrecieron con el aumento del déficit de humedad; sin embargo, el porcentaje de Mg aumentó significativamente. Si los datos se expresan como mg planta^{-1}, *todos los nutrimentos estudiados menos el P aumentaron con el déficit de agua.*

La adición de N tendió a incrementar la resistencia de los estomas en la superficie adaxial de las hojas y a disminuirla en la superficie abaxial. Así mismo, la fertilización con N disminuyó el potencial hidrico de la hoja y el contenido de humedad relativo en las plántulas bajo deficiencia de agua.

Introduction

The interaction between water utilization and mineral nutrition has been studied by various researchers, often with different results. It has been observed, for instance, that increasing transpiration also increases mineral absorption (10). It has also been suggested (14) that plants that have very low transpiration also have low photosynthesis and slow growth rate. Arnon (2) however, has cautioned against the notion that one cannot reduce transpiration without adversely affecting plant growth. All these workers tend to agree that there is a correlation between water use, nutrient uptake, and growth.

Radin and Parker (20) found that nitrogen deficient cotton plants (*Gossypium hirsutum* L.) had greater drought resistance than nitrogen-supplied plants. Their results did not support those of Holt and Fisher (12) who reported that high levels of N helped Bermuda grass (*Cynodon dactylon*) to avoid water stress, partly by having deep roots. It has been shown that N-fertilization could be of great advantage in coffee seedlings (*Coffea arabica* L.) grown under water stress conditions (23) and that the absorption of nitrogen fertilizer is not affected adversely by water stress until the soil moisture is less than 50% field capacity (24).

In the present work the absorption of nitrogen, potassium, phosphorus and magnesium by sweet corn seedlings was studied in relation to different levels of fertilizer nitrogen and water stress conditions. In addition the stomatal resistance, the leaf water potential and the relative water content of the seedlings were studied.

Materials and methods

Seedling growth:

Seeds were grown in acid-washed sand in pots in the greenhouse. Each pot contained 1.5 kg of air-dry sand. Irrigation using tap water on alternate days was continued for 26 days. At this stage the seedlings had four leaves. Three levels of N were then applied

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as: $N_1 = 56$ ppm, $N_2 = 140$ ppm and $N_3 = 252$ ppm The other essential nutrients were added in the following amounts: K= 4 mM, P = 1mM, Ca = 2 mM, Mg = 2 mM, S = 4 mM, $FeSO_4 \cdot 7H_2O = 5\ 98$ mg/l, $H_3BO_3 = 0.572$ mg/l, $MnCl_2 \cdot 4H_2O = 0.901$ mg/l, $ZnSO_4 \cdot 7H_2O = 0\ 440$ mg/l, $CuSO_4 \cdot 5H_2O = 0\ 0393$ mg/l, and $Na_2MoO_4 \cdot 2H_2O = 0\ 252$ mg/l Randomized complete block design was used, with each treatment replicated 3 times Six sets of this kind were carried out simultaneously. Plant heights at this stage were found to be 4 9 ± 0 7 cm.

The nutrients were applied on alternate days at a rate of 100 ml kg^{-1} of air-dry sand, and continued for 20 days. By this time the seedlings were at the 8 – 9 – leaf stage One set of plants was harvested for dry weight determination. The remaining sets of plants were thoroughly irrigated with four volumes of - 5 bar polyethylene glycol 6 000 (PEG) in order to bring the osmotic potential to a relatively low value, and then the plants were left without further irrigation One set of plants was left as a control and continued to receive normal irrigation with N_1, N_2, N_3 on alternate days.

At 2–days intervals stomatal diffusive resistance and plant tissue analysis for N, P, K, and Mg were measured on individual sets as water stress developed. After 8 days of stress, the final set was used for leaf water potential.

Leaf water potential

The leaf water potential was measured on either the third or fourth leaf (counting from top) using the pressure chamber method Measurements were normally taken between 1 400 hours and 1 500 hours in order to limit the influence on water stress due to diurnal variations commonly observed in corn and other plants (1).

Relative water content (RWC)

The RWC was always measured around 1 500 hours Small leaf segments were cut from the middle portion of the 3rd leaf, immediately its area was measured and fresh weight (FW) taken. The segments were then floated on distilled water in covered Petri dishes arranged on a well illuminated table for at least 5 hours They were then removed, wiped dry with soft tissue paper and weighed to obtain their saturated weight (SW). Then they were dried in an oven at 80°C and weighed again to obtain the dry weight (DW). The RWC was then calculate using the following formula (4).

$$\%\ RWC = \frac{(FW - DW)}{(SW - DW)} \times 100$$

Stomatal diffusive resistance

Resistance to water vapour diffusion (stomatal diffusive resistance) was measured with a Li-Cor Autoporometer (Lambda Instruments Corporation, Lincoln, Nebraska) This was measured both on the upper (adaxial) and the lower (abaxial) and the lower (abaxial) sides of the leaf. The total leaf resistances were then calculated from the parallel resistances of the two sides. Measurements were always taken between 1 400 hours and 1 500 hours, the time when the temperature and light conditions are assumed to be maximum and the water potential minimum (20).

Results

The data in Figure 1 show the effects of N on leaf stomatal resistance measured before water stress was imposed. Here, high-N significantly ($P = 0.05$) increased stomatal resistance on the adaxial (upper) leaf surface but it lowered the resistance on the abaxial (lower) side somewhat. The overall resistance was found to be higher at high-N than at the other two levels.

Water stress lowered both the leaf water potential (Figure 2) and the relative water content (Figure 3). It can be seen that the water stressed plants and the controls were affected differently by N. In the control plants the lowest water potential was recorded in medium N while water stressed plants had the lowest values in high-N plants. The data for leaf water potential and RWC do not seem to suggest that the two are closely related. For example, medium – N plants in the control (without water stress) had relatively low leaf water potential (Figure 2) but had relatively high RWC (Figure 3).

Absorption of nutrients

At 2-days intervals as water stress developed, plant material was harvested for tissue analysis. All the aboveground portions of the plants were used (in subsequent sections this will be referred to simply as "plant").

Phosphorus (P), potassium (K) and magnesium (Mg) were determined as detailed by Steckel and Flannery (22) and the total nitrogen was determined by Kjeldahl's method as described by Bremner (5).

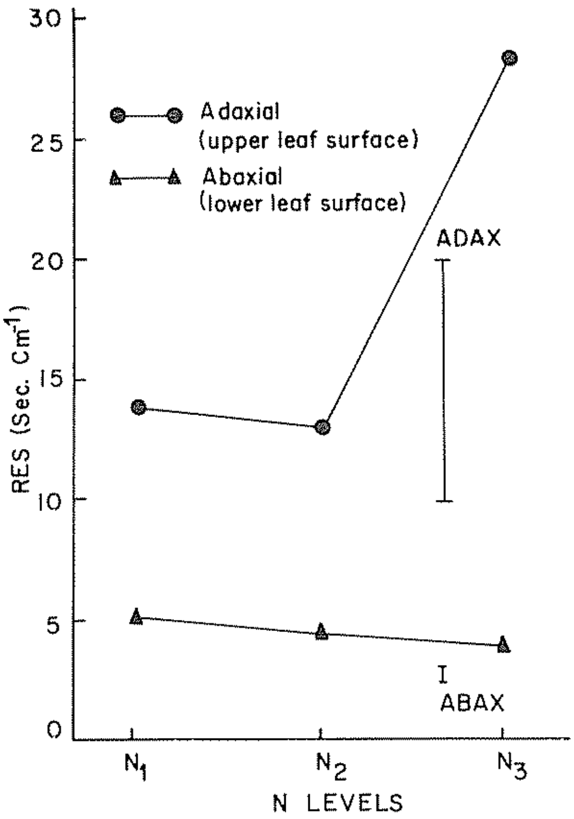

Fig. 1. Leaf stomatal resistance (Res) as affected by N fertilization. Measurements were taken for both the abaxial and the adaxial surfaces. Vertical line indicates the LSD at P = 0.05

The data in Tables 1, 2, 3 and 4 compare the values of tissue nutrients (N, P, K, Mg respectively) when expressed as % dry weight and when expressed as total amounts per plant. It can be seen (Table 1) that N fertilization increased N accumulation in plant tissuee, both when expressed as % dry weight and when expressed as mg/plant. Water stress in this case reduced N accumulation in the plants in all the 3 levels of N applied. However, whereas water stress reduced tissue N as % dry weight, it increased the total N in the plant. This might be accounted for in terms of "dilution" caused by better growth where there was no water stress. The same trend was observed in the case of K (Table 3), but not for P (Table 2). The data for Mg (Table 4) show that water stress significantly increased tissue content both in terms of % dry weight and as total Mg per plant.

Discussion

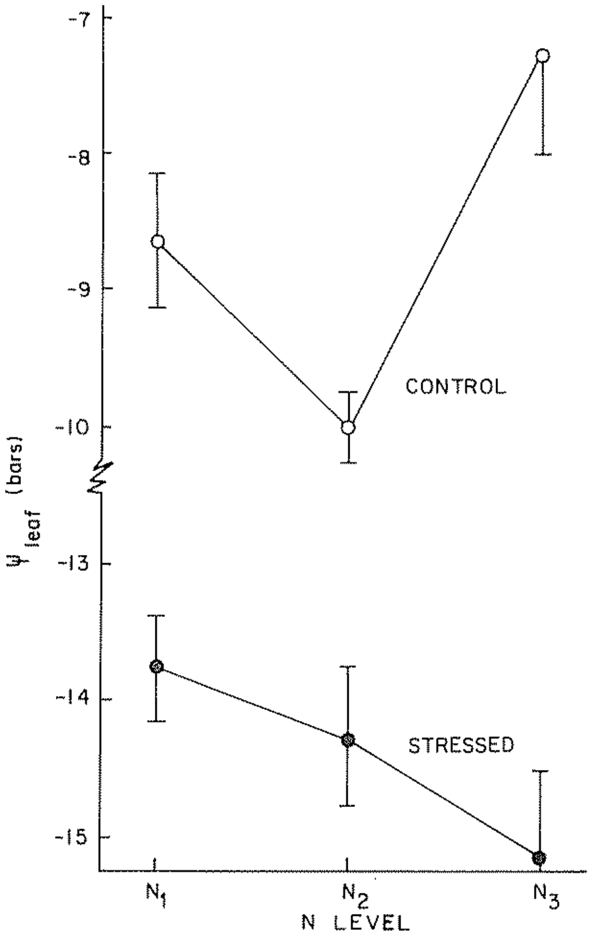

Fig. 2. The leaf water potential as affected by N fertilization. Vertical lines indicate the standard errors (SE) of the means

The relationship between the major plant nutrients and water economy in plants has been studied for a long time (3), usually with varied results and/or interpretations. Brown (6), for instance, reported that N increased the water use efficiency of dryland wheat by an average of 56%. Other results (15), however, suggested that N fertilization accentuates the effects of dry summers. The variabilities reported might be attributed to such factors as the plant species (or even cultivars) used, the parameters measured, the age of the plants, and the actual amounts of the nutrients applied.

The results presented in Figure 1 show that the leaf diffusive resistance was not the same for the abaxial and the adaxial leaf surfaces. Whereas high N plants had high resistance on the adaxial surface they had a slightly reduced resistance on the abaxial surface. This behaviour could be of advantage in conserving water since it is known that high stomatal diffusive resistance reduces transpiration much more than it reduce CO_2 transfer (8, 18). Low water potential in plants is generally considered a sign of

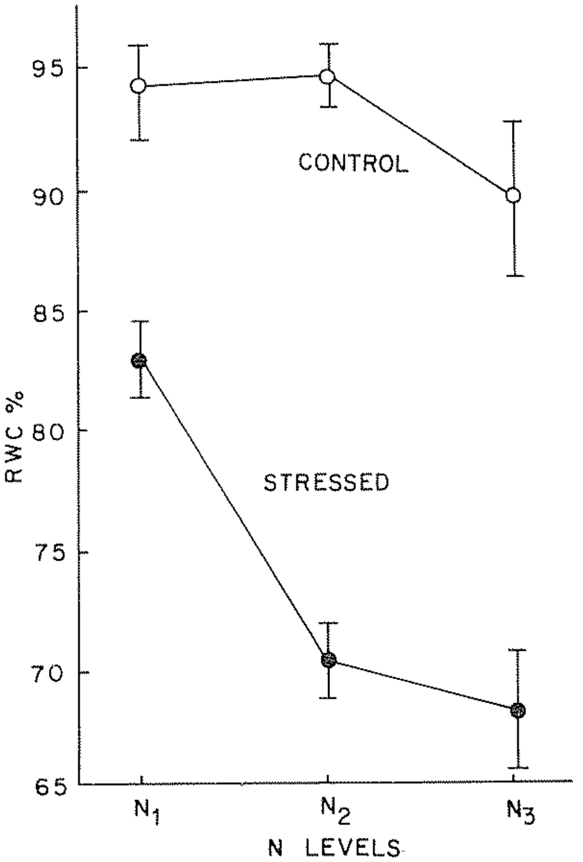

Fig 3 The relative water content (RWC) as affected by N fertilization and by water stress The vertical lines indicate the standard errors (SE) of the means).

Table 1. Effects of N and water stress on tissue N as percentage (%) dry weight, and as mg plant^{-1}.

Treatment	N (%)	N (mg plant^{-1})
No Water Stress		
N_1	3.54 ± 0 51	69 2 ± 13.9
N_2	4.31 ± 0.73	114 8 ± 21.8
N_3	4 79 ± 0 06	125 1 ± 43.1
6 days of water stress	6 days of water	
N_1	1 97 ± 0.17	88.9 ± 1 1
N_2	2 82 ± 0.17	126 0 ± 9.5
N_3	3.83 ± 0 11	194,0 ± 10 3

LSD$_{.05}$ for N (%) = 0 9

LSD$_{.05}$ for N (mg plant^{-1}) = 38.46

Table 2. Effects of N and water stress on tissue P as percentage (%) dry weight, and as mg plant^{-1}.

Treatment	P (%)	P (mg plant^{-1})
No Water Stress		
N_1	0.35 ± 0 09	6.68 ± 1 30
N_2	0.39 ± 0 14	10.00 ± 0.21
N_{33}	0 32 ± 0.17	10 93 ± 4 31
6 days of water stress		
N_1	0.22 ± 0 02	10.11 ± 0.52
N_2	0.20 ± 0.05	9 07 ± 2.19
N_3	0 29 ± 0 03	14 86 ± 1 96

LSD$_{.05}$ for P (%) means = 0.23

LSD$_{.05}$ for P (mg plant^{-1}) means = 5.45

Table 3. Effects of N and water stress on tissue K as percentage (%) dry weight and as mg plant^{-1}.

Treatment	K (%)	K (mg plant^{-1})
No water stress		
N_1	6 21 ± 0.53	123.30 ± 32.44
N_2	5 67 ± 1.26	148.78 ± 18.34
N_3	5.72 ± 0 78	145 13 ± 34.32
6 days of water stress		
N_1	4 40 ± 0.34	199.13 ± 2.81
N_2	4 40 ± 0.34	196.76 ± 21.23
N_3	4.29 ± 0.00	217.07 ± 6.90

LSD$_{.05}$ for K (%) means = 1 2

LSD$_{.05}$ for K (mg plant^{-1}) means = 10 27

drought tolerance. This is, at least partly, due to the increased ability of low water potential plants to absorb water from low solute potential media (13). This was found to be the case in sweet corn seedlings (Figure 2).

In the experiments reported here (Table 1) it was clearly shown that as N was increased in the growing medium it also increased in the plant tissue, provided water supply remained the same. Similar results have been reported (7, 17) At the same time, water stress significantly reduced tissue N (Table 1) and K (Table 3) and increased tissue Mg (Table 4), but it had variable effects on P (Table 2). These results differ in some respects from those reported by Richards and Wadleigh, as cited by Jenne (16). These authors reported that some evidence existed showing that decreasing soil moisture supply is associated with an increase in N percentage, a decrease in K percentage and a variable effect upon P. This descrepancy might be attributed to the differences in plant species used.

The data in Table 3 also shows that although water stress significantly reduced K uptake, N did not have any significant effect on K uptake. This is in contrast to the results reported by other workers (9) that high N may bring about K deficiency in some fruit plants. It has been suggested that the low levels of K, Ca, Mg often observed in high-N plants could be attributed to growth dilution. However, Palaniyandi and Smith (19) found that applied N did not depress leaf K concentration in snap beans although the vine weight more than doubled. Smith (21) found that applied N increased Mg concentration in snap beans and that K applications resulted in a reduction in the concentration of both Ca and Mg. These results were not confirmed in the present work (see Table 4). Here it was shown that water stress increased the percentage Mg in the tissue, but applied N did not increase tissue Mg significantly.

The total amounts of the nutrients (mg · plant^{-1}) as affected by N and by water stress were also interesting. It can be seen (Table 1) that although water stress reduced % N in the tissue, the absolute amount per plant actually increased. This shows that dilution due to growth must be taken into account. The same picture was observed for K (Table 3) but not for P. Mg increased about four fold with water stress when expressed at % dry weight, but it increased almost ten fold when expressed as total content per plant. This again shows the effect of growth dilution. Gates (11) working on tomato plants reported that N decrease in water stressed plants both when expressed as mg plant^{-1} and as % dry weight, but the relative decreases were different. Here again species variability may account for the differences.

Table 4. Effects of N and water stress on tissue Mg as percentage (%) dry weight and as mg plant^{-1}.

Treatment	Mg (%)	Mg (mg plant^{-1})
No water stress		
N_1	0.06 ± 0.08	1.04 ± 0.97
N_2	0.06 ± 0.03	1.70 ± 0.70
N_3	0.03 ± 0.03	0.95 ± 0.99
6 days of water stress		
N_1	0.20 ± 0.06	8.96 ± 2.33
N_2	0.25 ± 0.04	11.47 ± 3.15
N_3	0.19 ± 0.01	9.44 ± 0.36

$LSD_{.05}$ for Mg (%) means = 0.10.

$LSD_{.05}$ for Mg (mg plant^{-1}) means = 7.53.

Summary

The absorption of N, P, K and Mg by potted sweet corn seedlings was studied at different levels of applied fertilizer N and in relation to water stress. Stomatal resistance, leaf water potential and the relative water content were also studied.

When expressed as percentage dry weight the amounts of N, P, and K significantly decreased as water stress increased. However, tissue Mg (%) significantly increased with increasing water stress. On the other hand, when expressed as mg · plant^{-1}, all the mineral nutrients analysed except P increased with increasing water stress.

Nitrogen tended to increase the stomatal resistance on the adaxial surfaces of the leaves while it decreased the resistance slightly on the abaxial leaf surfaces. At the same time nitrogen fertilization decreased the leaf water potential and the relative water content of water-stressed seedlings.

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