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MAGNESIUM DEFICIENCY INDUCED CHANGES IN YIELD AND METABOLISM OF MAIZE

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Maize (*Zea mays* L.) cv. K 280 plants were grown in refined sand at three levels of magnesium viz. 0.02 (acute deficiency), 0.2 (sub-normal) and 2.0 mM (normal) supplied as magnesium chloride. Plants were maintained in nutrient culture medium till maturity (102 DAS) to obtain economic yield of maize. After 21 DAS, the visible symptoms of magnesium deficiency as depression in growth and interveinal chlorosis on old leaves were observed at 0.02 mM Mg. Leaves turned severely chlorotic and formed chlorotic stripes, later the affected lower leaves developed interveinal necrotic areas at leaf margins, became dry and withered. Magnesium deficiency effects were less pronounced at sub-normal level (0.2 mM) of magnesium. The deficiency of magnesium reduced biomass, concentration of chlorophylls (a and b), carotene and specific activities of catalase, acid phosphatase and ATPase and increased the activities of peroxidase and RNAse in leaves. The concentration of Mg, S and P increased in all parts of maize with an increase in Mg supply from 0.02 to 2 mM. In acute Mg deficiency (0.02 mM), the cobs of maize plants failed to produce any seed whereas compared to control the formation of cobs and seed was poor at sub-normal (0.2 mM) Mg supply. The results indicate that the adequate magnesium is required to obtain higher economic yield of maize.

Key words : Magnesium ; maize ; deficiency ; yield ; concentration.

The beneficial effect of adding mineral elements to soils to improve plant growth and productivity has long been recognized in agriculture. In recent years, the importance of magnesium as a nutrient has increased. Earlier magnesium was applied unwittingly as an impurity along with other fertilizers (Mengel and Kirkby,2001). Magnesium in plants is mainly related to its capacity to interact with strongly nucleophilic ligands (e.g. phosphoryl groups) through ionic bonding, and to act as a bridging element or form complexes of different stabilities (Marschner, 1995).

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The significance of magnesium as a secondary nutrient is well established in higher plants. Magnesium functions as a constituent of many organic molecules (Langmeier *et al.*, 1995), enzyme activator (Wedding and Black, 1998) or as a charge carrier (Pei *et al.*, 1999). Magnesium is indispensable for the formation of chlorophyll since it is the one and only mineral constituent of the chlorophyll molecule (Walker and Weinstein, 1991). It is intimately associated with the phosphorus metabolism and is particularly essential for the enzymes involved in the phosphate transfer reactions. It plays a vital role in synthesis of ATP from ADP and inorganic phosphorus (Marschner, 1995). Magnesium also functions as a bridging element for the aggregation of ribosome subunits (Cammarano *et al.*, 1972), a process that is necessary for protein synthesis.

Despite the higher concentration of Mg^{2+} in soils, the uptake rate of Mg^{2+} by root cells of the plants is much lower (Mengel and Kirkby, 2001). The deficiency of magnesium usually appears on the old / mature parts of the plant because of its high mobility in plants. Deficiency of magnesium enhances the formation of superoxide radicals (O_2) and hydrogen peroxide (H_2O_2), and in response increases the activity of anti oxidants and H_2O_2 scavenging enzymes (Marschner, 1995).

Despite the fact that essentiality of Mg as a secondary nutrient has been proved long back, the role of Mg in the metabolism and uptake of other macronutrients in cereals is still not clearly understood. Therefore the present study has been

made to find out the changes in growth, yield and metabolism of maize, 'an important cereal crop', due to deficiency of Mg when grown in refined sand.

MATERIALS AND METHODS

To induce Mg deficiency, maize (*Zea mays* L.) var. K 280 was raised in purified sand (Agarwala & Chatterjee, 1996) amended with three levels of magnesium viz., 0.02 (acute deficiency), 0.2 (sub-normal) and 2.0 mM (normal) in polyethylene containers of 10 L capacity in a glass house at an ambient temperature (25-30° C). The plants were grown till maturity (102 DAS) with three replicates for each treatment. The seedlings after emergence were supplied daily with the nutrient solution. Initially there were four plants, later periodically the number of plants were reduced to one plant in each pot. On week ends, pots were flushed with glass distilled water to remove accumulated salts from the surface of roots as well as that of sand in pots.

The composition of nutrient solution excluding magnesium was : 4 mM KNO_3 ; 4 mM $Ca(NO_3)_2$; 2 mM Na_2SO_4 ; 1.5 mM NaH_2PO_4 ; 100 iM Fe-EDTA ; 10 iM $MnSO_4$; 30 iM H_3BO_3 ; 1 iM $CuSO_4$; 1 iM $ZnSO_4$; 0.2 iM Na_2MoO_4 ; 0.1 iM $NiSO_4$; 0.1 iM $CoSO_4$ and 0.1 mM NaCl. Magnesium was supplied as magnesium chloride.

The biomass and cob yield of maize were determined at 102 DAS. The visible effects of magnesium deficiency was noted periodically. The oven dried plant parts were digested with HNO_3 : $HClO_4$ (10 : 1). In clear digest, concentration of magnesium (Mason, 1950), phosphorus (Wallace, 1951) and sulphur (Chesnin and Yien, 1951) were estimated. On 46 JHS the concentration of chlororphylls (a and b), carotene and activities of peroxidase, catalase, RNAse, acid phosphatase and ATPase were measured in fresh affected leaves described elsewhere (Mitra *et al.*, 1998) at 46 DAS. All determinations were made in triplicate and data have been analyzed statistically and mean values are given in table and figures along with ± SE.

RESULTS AND DISCUSSION

The symptoms of magnesium deficiency were observed on 21 DAS as growth retarding due to condensed internodes than the normal (2 mM Mg) plants. On 30 DAS, interveinal chlorosis was exhibited in the old leaves of these plants. Gradually the affected leaves turned severely chlorotic and formed chlorotic stripes. Leaves were stiff and brittle. Persistent magnesium deficiency showed that chlorotic lower leaves developed interveinal necrotic areas at leaf margins which later spread to the base of lamina with age. These leaves became dry and withered. Symptoms of magnesium deficiency in maize appeared on older leaves as Mg^{2+} is phloem mobile in plant and easily translocated from older to younger leaves (Mengel and Kikrby, 2001). In lower levels (0.02 and 0.2 mM) a reduction in leaf number and area was observed. Cob formation and seed yield were also poor owing to Mg deficiency (< 0.2 mM). At sub-normal (0.2 mM) level of magnesium, the intensity of symptoms was comparatively mild. The observed symptoms appearing in maize were in accordance with the earlier observations on wheat, oat and rye (Bergmann, 1993 ; Fischer *et al.*, 1998 ; Huguet and Coppenet, 1994).

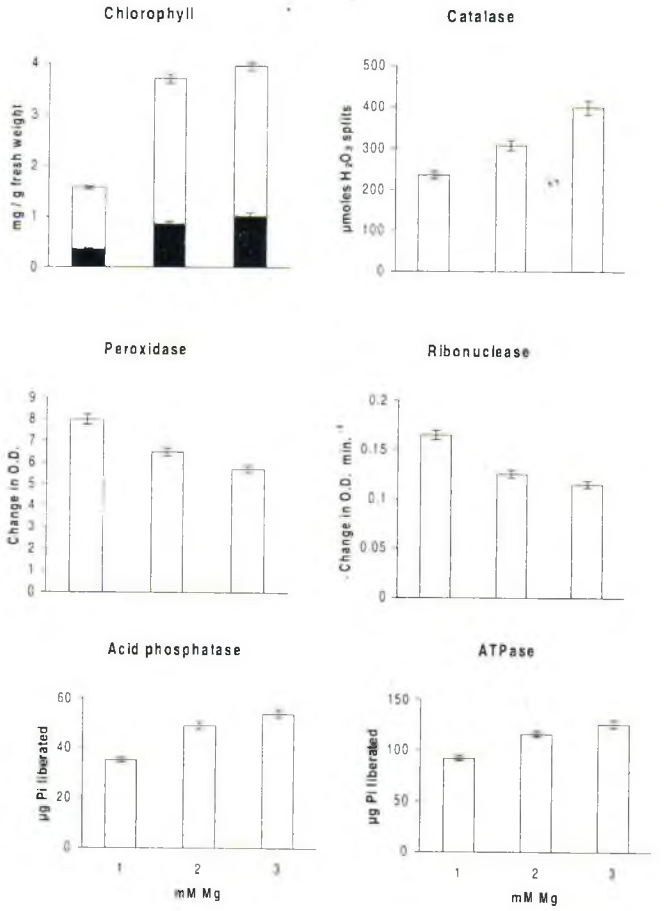
In maize, at both low levels of Mg deficiency (0.02 and 0.2 mM), the biomass was decreased significantly. The decreased biomass in response to Mg deficiency might be due to low photosynthesis as deficiency of Mg hampers the activity of RuBP carboxylase which mediates the CO_2 incorporation in stroma of chloroplast (Pierce, 16), or might be an expression of enhanced rate of protein degradation, including structural proteins of the thylakoids (Marschner, 1995). In acute deficiency of Mg (0.02 mM), cobs failed to produce seeds whereas the number and weight of seed were less at subnormal (0.2 mM) Mg compared to control. The results are in consonance with that on the cereals other than maize (Forster, 1980).

With increase in Mg supply from low (0.02 mM) to adequate (2.0 mM) magnesium, the concentration of Mg increased concomitantly in all parts of maize. The concentration of Mg was 0.07 to

0.10% in acute deficiency (0.02 mM) whereas at adequate supply (2.0 mM) the Mg concentration ranges from 0.11 to 0.19% and is in consonance with the results observed by earlier workers (Marschner, 1995 ; Mitra *et al.*, 1998). Magnesium deficiency has considerable impact on the acquisition of other mineral nutrients. There was a marked decrease in concentration of sulphur and phosphorus in all the parts of plant. The concentration of P and S was more in the roots than in the leaves.

In maize, owing to Mg deficiency, the concentration of both the chlorophyll spieces (a and b) (Fig.1) and carotene decreased significantly as the deficiency of magnesium affects the size, structure and function of chloroplast including electron transfer in PS II

Fig.1 Influence of magnesium deficiency on chlorophyll concentration and specific activities of catalase, peroxidase, acid phosphatase, ribonuclease and ATPase in leaves of maize. Vertical lines in each bar represents ± SE. 1= 0.02 ; 2 = 0.2; 3 = 2.0 mM Mg.



(McSwaine *et al.*, 1976). The decrease in chlorophyll content in magnesium deficiency might be due to its role in chlorophyll synthesis as magnesium is strongly bound to the chlorophyll molecules. The first step of chlorophyll synthesis requires the insertion of Mg into the porphyrin structure which is catalysed by the magnesium chelatase (Walker and Weinstein, 6).

The deficiency of Mg decreased the activities of catalase, acid phosphatase and ATPase and increased the activities of peroxidase and ribonuclease in maize leaves (Fig.1). The decreased activity of catalase in Mg deficiency might be due to enhanced formation of H_2O_2 creating oxidative stress enhancing the inactivation of catalase by preventing synthesis of the enzyme (Marschner, 1995). In Mg deficiency, the activity of acid phosphatase decreased significantly and the low supply of Mg suppressed phosphorus metabolism by lowering the content of inorganic phosphorus which is important for incorporation in inorganic and organic compounds (Beringer and Forster, 1981). This might suggest a positive co-relation between magnesium and phosphorus (Marschner, 1995).

Table 1 : Influence of magnesium deficiency on biomass, economic yield, carotene content and concentration of magnesium, sulphur and phosphorus in different parts of maize (± SE).

Parameters	mM Mg 0.02	0.2	2.0
Dry matter (g plant^{-1})	20.4±0.10	40.9±0.03	58.8±0.14
Cob weight (g plant^{-1})	5.52±0.78	13.6±0.88	22.6±1.12
Length of cob (cm)	7±0.00	10±0.01	14±0.05
Number of seeds (number cob^{-1})	--	11±0.002	41±0.05
Seed weight (g plant^{-1})	--	1.9±0.001	13.6±0.06
100 seed weight (g plant^{-1})	--	14.4±0.03	25.4±0.05
Carotene (mg g^{-1} fresh weight)	0.261±0.001	0.664±0.001	0.679±0.003
Mg concentration (% in dry matter)			
Leaves	0.07±0.001	0.12±0.005	0.19±0.02
Stem	0.06±0.00	0.08±0.01	0.15±0.01
Root	0.10±0.01	0.11±0.00	0.17±0.01
S concentration (% in dry matter)			
Leaves	0.28±0.02	0.48±0.01	0.98±0.06
Stem	0.12±0.00	0.22±0.00	0.37±0.005
Root	0.57±0.08	0.96±0.02	1.50±0.02
P concentration (% in dry matter)			
Leaves	0.66±0.00	0.66±0.00	0.69±0.005
Stem	0.95±0.005	0.97±0.005	1.03±0.005
Root	0.87±0.01	0.91±0.03	0.99±0.02

The decreased activity of ATPase in Mg deficient maize leaves might be the result of low concentration of Mg-ATP, the substrate for ATPases as well as inorganic phosphatases (Rea and Sanders, 1987). The Mg-ATP is utilized by the active sites of ATPases for the transfer of the energy rich phosphoryl group (Balke and Hodges, 1975).

Consequent to Magnesium deficiency, increased activity of peroxidase was observed. This may be due to enhanced production of H_2O_2 in the Mg deficient leaves as magnesium deficiency leads to reductive O_2 activation favouring superoxide radicals which in turn enhance production of H_2O_2. The stimulated activity of RNAse might be an expression of low availability of Mg which results in low concentration of RNA or also the low protein formation in such conditions. As reported previously (Ahsen and Noller, 1995), inadequate supply of Mg^{2+} have detrimental impact on polypeptide synthesis and thus on protein formation.

Magnesium being involved in various metabolic processes, its deficiency disturbed the growth and development of plant. These results revealed that adequate Mg is required for the development of seeds in maize leading to higher yield.

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