*Journal of Applied and Natural Science* 7 (2): 903 - 906 (2015)

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# Deficiency of magnesium in maize (*Zea mays* L.) induced by high potassium level in a micaceous soil of Kumaon region of Uttarakhand, India

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*Received: April 20,2015; Revised received:August 3, 2015 Accepted: November 5, 2015*

**Abstract:** A field observation was undertaken in a farmer's field sown with maize at Mukteshwar, Uttarakhand to record whether K rich micaceous soil can cause Mg deficiency. The crop was fertilized with nitrogen and phosphorus only. The visible effect of Mg-deficiency initiated after 20-25 days of maize sowing as interveinal chlorosis in older leaves along the margins running the full length of the leaves parallel to the veins. In later stage, necrosis of older leaves occurred particularly at the tip of the leaves. The leaf and soil sample collected at 45 days after sowing (DAS) revealed an extremely low content of Mg in soil (4.32 mg $kg^{-1}$) and plant (0.11%). The soil analysis also revealed that the soil was acidic in nature (pH 5.07) with low cation exchange capacity (9.7 cmol $kg^{-1}$). However, the soil was having a very high level of water soluble (18.2 mg $kg^{-1}$), exchangeable (262.3 mg $kg^{-1}$) and available K (280.5 mg $kg^{-1}$), which has resulted in an imbalanced exchangeable K: Mg ratio (60.7:1) rendering reduced uptake of Mg by maize. Therefore, it was concluded from the study that magnesium deficiency can occur in maize in conditions like acidic, sandy, mica rich soils with high level of K combined with low Mg content, even without K fertilization. Hence, the farmers may use dolomitic lime and/or Mg-containing fertilizers to correct Mg deficiency under such conditions for sustainable agricultural production systems.

**Keywords:** Magnesium deficiency, Maize, Micaceous soil, Potassium

## INTRODUCTION

Magnesium (Mg) is considered as secondary essential nutrient required by the crops and, is absorbed by crops as $Mg^{+2}$ from the soil solution. The functions of Mg in crops are 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, and/or form complexes of different stabilities (Marschner, 1995). Most reactions involving phosphate transfer from adenosine tri-phosphate (ATP) require Mg. Magnesium concentration in crops varies between 0.1 to 0.4% and, is a primary constituent of chlorophyll. Magnesium also serves as a structural component of ribosomes, stabilizing them in the configuration necessary for protein synthesis. Since the fundamental process of energy transfer occurs in photosynthesis, glycolysis, the citric acid cycle, and respiration, is important throughout crop metabolism (Havlin *et al*., 2009).

Magnesium deficiency in plants is a widespread problem, affecting productivity and quality in agriculture (Aitken *et al*., 1999). $Mg^{+2}$ ions are more easily leached from the upper soil layers than $Ca^{+2}$ because of less adsorption by soil colloids (Mengel *et al*., 2006). In addition, Mg is not specifically bound to clay minerals as in the case of K. Therefore, it is highly prone to leaching, which is considered as one of the major factors in decreasing Mg availability for roots (Hermans *et al*., 2004). In many crops, Mg deficiency causes interveinal chlorosis in leaves, where only leaf veins remain green. Under severe Mg deficiency, leaf tissue becomes uniformly chlorotic to necrotic. Because of the mobility of $Mg^{+2}$ in plants and its readily translocation from older to younger plant parts, deficiency symptoms often appear first on the lower leaves (Havlin *et al*., 2009).

Conditions in which Mg is likely to be deficient include acid, sandy, highly leached soil with low cation exchange capapcity (CEC), soils inherently low in Mg and, soils receiving high rates of K fertilization (Marschner, 1995; Havlin *et al*., 2009). Mg deficiency is also quite common in micaceous soils rich in K and consequently, Mg deficiency might be aggravated, particularly when K fertilizers are heavily applied as a result of antagonistic effect between K and Mg (Ding *et al*., 2006). This antagonism depends on soil type, physical properties, pH, ambient temperature and moreover, proportion of the participating nutrients. Generally, the binding strengths of K and Ca to the exchange sites of clay minerals are much stronger than Mg and they easily out-compete Mg at exchange sites. Therefore, application of potassium fertilizers may reduce a plant's ability to absorb Mg (Ranade-Malvi, 2011). Non-judicious and imbalanced application of NPK fertilizers without Mg in high intensive agricul-

ISSN : 0974-9411 (Print), 2231-5209 (Online) 

tural cropping system has lead to a widespread deficiency of Mg, especially in the light sandy acid soils of the world. Many researchers have reported deficiency of Mg in numerous crops caused by high K levels under K fertilization and/or combined application of K and Mg. Nonetheless, there are very few developments in reporting the deficiency of Mg in maize grown without K fertilization in K rich micaceous soil of Kumaon region of Uttarakhand. Therefore, the objective of this study was to elucidate the effect of high level of soil K on the occurrence of Mg deficiency in maize grown in a mica rich soil of Kumaon region, Uttarakhand. It is assumed that information generated from this study would help us in understanding the conditions conducive for the occurrence of Mg deficiency in this region.

## MATERIALS AND METHODS

**Study site, climate and soil:** A field observation was undertaken in a farmer's field sown with maize at Mukteshwar, Nainital, Uttarakhand (latitude: 29° 28' N, longitude: 79° 39' E; altitude: 2280 m above mean sea level). This site is located on a ridge at the southern edge of the Kumaon Hills of the Himalayan range. This area falls under temperate region, having hot and dry summer between May to June and cold and chilly conditions from November to February, with an average annual rainfall ranges from 1300–1600 mm, three-fourth of which is received during July–September and the remaining one-fourth between October and June. Frequent snowfall occurs between December to February resulting in drop of minimum air temperature below freezing point. Annual maximum and minimum air temperature usually ranges between 25 to -3 °C, respectively. The soil of the site belongs to order Entisol (USDA Classification). The soil is loamy sand in texture, rich in mica, gravelly, deep and well drained with moderate permeability in the upper layer and rapid in the lower part. The soil is formed in a loamy mantle and sandy or gravelly sediments.

**Agronomic management practices:** Agricultural operations in this area are generally practiced under terrace condition with land slope greater than 30%. The size of the terrace at the farmer's field was 100 × 6 m with net plot area of 10 × 5 m. Hybrid maize (cv. Vivek 33) seeds were sown in mid June of 2014 with a spacing of 15 cm (intra-plant) × 30 cm (between-row). Soil was irrigated once before sowing to ensure adequate soil water for establishment of plants. A dose of 60 kg N $ha^{-1}$ and 40 kg $P_2O_5$ $ha^{-1}$ as basal was applied through urea and di-ammonium phosphate (DAP), respectively. No potassium fertilizer was added in the soil. Other recommended agronomic practices were also followed throughout experiment for raising the crop.

**Leaf and soil sampling:** About 25 days after sowing (DAS), older leaves of maize plants started showing stripped chlorosis symptom. About 45 DAS, older and younger leaves of the affected maize plants were

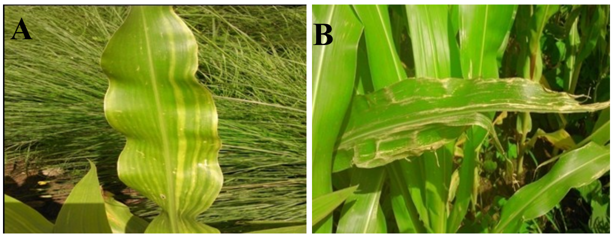


**Fig. 1.** *Visual deficiency symptom of Mg in maize at (A) 30 days after sowing (yellow strips can be seen parallel to the veins) and (B) 45 days after sowing (older leaves with necrotic tip).*

collected from those plots. The collected leaves were washed thoroughly with phosphate-free soap to remove waxes followed by rinsing with 0.1 N HCl to remove possible contaminants and, finally rinsed with double distilled water to remove excess acid and, then dried at 70°C to constant weight. The nitrogen content in leaves was determined by micro-kjeldahl method (Singh *et al*., 2005). The leaves were also analyzed for phosphorus, potassium, calcium and magnesium contents by digestion with $HNO_3$:$HClO_4$ (4:1) mixture and, subsequent determination by vanadomolybdophosphoric acid, flame photometric method and versanate method, respectively (Bhargava and Raghupathi, 2001).

At the time of leaf sampling, soil samples were also collected randomly from the plots with the help of a screw auger from 0-15 cm depth. Soil samples were air dried, processed and sieved through 2 mm sieve and stored for further analytical purpose. The soil was analyzed for pH (1:2 soil to water suspension; Jackson, 1973), electrical conductivity (1:2 soil to water suspension; Bower and Wilcox, 1965), organic carbon (Walkley and Black, 1934), cation exchange capacity through NaOAc method (Jackson, 1973), available N (Subbiah and Asija, 1956), available P (Olsen *et al*., 1954) and exchangeable Ca and Mg (Jackson, 1973). The available K was extracted with $NH_4OAc$, pH 7.0 (Schollenberger and Simon, 1945) and water soluble K was determined in the soil extracted with water (1:5:: soil: water) shaken for 5 min. Exchangeable K was calculated by subtracting water soluble K from available K.

## RESULTS AND DISCUSSION

The present study indicated the visible effect of interveinal chlorosis which initiated 20-25 days after sowing of maize. The effect was seen first in the old leaves, initiated in the interveinal areas particularly along the margins, progressed towards the midribs and from the old towards the young leaves (Fig. 1A). Dead, round spots followed, which gave the impression of beaded streaking. Older leaves became reddish-purple, and the tips and edges became necrotic when the deficiency was severe (Fig. 1B). $Mg^{+2}$ ions are mobile in the plant and deficiency always begins in the older leaves and the moves to the younger leaves as $Mg^{+2}$ in phloem mobile and, translocated from older to younger leaves when supply is insufficient (Sawyer, 2004;

**Table 1.** Physico-chemical properties of soil grown with maize.

| Soil Parameter (s) | Value |
|---|---|
| pH (1:2 (w/v) soil to water suspension) | 5.07 |
| Electrical conductivity (dS $m^{-1}$) (1:2 (w/v) soil to water suspension) | 0.08 |
| Organic C (g $kg^{-1}$) | 7.10 |
| Organic matter (g $kg^{-1}$)* | 12.20 |
| Cation exchange capacity (cmol $P^+$ $kg^{-1}$) | 9.72 |
| Available N (mg $kg^{-1}$) | 87.40 |
| Available P (mg $kg^{-1}$) | 7.85 |
| Available K (mg $kg^{-1}$) | 280.50 |
| Water soluble K (mg $kg^{-1}$) | 18.20 |
| Exchangeable K (mg $kg^{-1}$) | 262.30 |
| Exchangeable Ca (mg $kg^{-1}$) | 14.00 |
| Exchangeable Mg (mg $kg^{-1}$) | 4.32 |

*Organic C (OC) data were converted to organic matter (OM) using the conventional conversion OM = OC×1.724.

Mengel *et al.*, 2006). Under Mg deficiency, necrosis of older leaves occurs particularly at the tips of the leaf, which was the case in this study also. Sawyer (2004) observed magnesium deficiency first seen as yellow to white interveinal striping of the lower corn leaves and eventually, the older leaves became reddish-purple with necrotic tips. Magnesium deficiency symptoms differ between plant species although some general characteristics like interveinal yellowing or chlorosis are apparent and necrosis occurs, particularly at the tip of the leaf (Marschner, 1995; Mengel *et al.*, 2006; Havlin *et al.*, 2009). Recently, Bing *et al.* (2011) also reported that the deficiency of magnesium appears as yellow or white strips in lower leaves of maize plants, running the full length of the leaves parallel to the veins. In later stage, the stripping turned into dead and round spots appearing as beaded streaks. Similar kind of observation was also made in this study and therefore, it confirms the deficiency symptom of magnesium in maize as described by these authors. The older leaves eventually dried and withered leading to stunted growth of the crop.

The soil analysis revealed that it was acidic in nature (pH 5.07) with low cation exchange capacity (9.7 cmol $kg^{-1}$), low in Mg content (4.32 mg $kg^{-1}$) and high in K (280.5 mg $kg^{-1}$) availability (Table 1). The water soluble K content of soil was also quite high (18.2 mg $kg^{-1}$). Generally, the water soluble K content for optimum plant growth varies between 1 to 10 mg $kg^{-1}$ (Havlin *et al.*, 2009). The exchangeable Mg level (4.32 mg $kg^{-1}$) of the soil was in extremely deficient range. Generally, soils are likely to be deficient in Mg when they contain less than 25 mg $kg^{-1}$ exchangeable Mg (MAAF, 1979; Havlin *et al.*, 2009). In this study, exchangeable soil Mg level was extremely low as compared to the critical level. Low cation exchange capacity of the soil has led to the reduced adsorption of exchangeable Mg to the exchange sites resulting leaching of $Mg^{+2}$ ions to subsoil. Loss of Mg by leaching predominates frequently on sandy soils. In such soils the subsoil often contains higher levels of Mg than in the upper layer of the soil profile. This was perhaps one of the major reasons for Mg deficiency in maize. Cation competitions in soil may play a crucial role and the uptake of Mg can be greatly depressed by an excess of other cation species, especially of K which are absorbed at high rates and, may compete with Mg for the negatively charged cytosol (Mengel *et al.*, 2006). This competition can lead to Mg deficiency in plants. Generally, the recommended exchangeable K: Mg ratio for field crops is 5:1 (Havlin *et al.*, 2009) however, the observed ratio was 60.7:1 in this study (Table 2). Therefore, it is clear from the results that the soil physico-chemical conditions were extremely conducive for Mg deficiency to occur.

The imbalanced K and Mg levels of the soil have also disrupted the uptake of Mg by maize as indicated by leaf Mg concentrations. The Mg concentrations in younger and older leaves (0.14 and 0.11%, respectively) were also low (Table 2), which is categorized as deficient range (Marschner, 1995). A decrease in the older leaves compared to the younger leaves in the concentration of Mg corroborates the relative severity of Mg-deficiency effects in the older leaves. Generally, maize is considered as an exhaustive crop and the demand for nutrients remains higher for this crop. With the level of Mg in soil, the uptake of Mg was probably suboptimal and moreover, increased uptake of K also led an antagonistic effect on Mg uptake by plant roots. Not only the uptake but also the physiological translocation of Mg from the roots to the upper plant parts can be restricted by high level of soil K (Marschner, 1995). Antagonism between two mineral nutrients becomes even more important when the content of one of the elements is near in deficiency range (Ranade-Malvi, 2011). In this case, it was Mg which was in deficient range, whereas, K was present in excessive range. The plants became stunted and have an overall yellow appearance in the later stage of growth. Although the data regarding yield was not recorded in this particular study, the farmers have

**Table 2.** Nutrient content in leaves and ratio of exchangeable K, Ca and Mg in soil and leaves of maize.

| Nutrient Content | Younger leaves | Older leaves | Ratio of nutrient | Soil | Leaves* |
|---|---|---|---|---|---|
| N (%) | 3.97 | 3.83 | K:Mg | 60.70 | 24.13 |
| P (%) | 0.38 | 0.31 | K:Ca | 18.60 | 13.47 |
| K (%) | 3.00 | 2.95 | Ca:Mg | 3.25 | 1.85 |
| Ca (%) | 0.20 | 0.25 | | | |
| Mg (%) | 0.14 | 0.11 | | | |

*Average of younger and older leaves

observed 50-60% yield decline compared to his expectation. According to the farmers, the grains formed were also shriveled, malformed and not suitable for consumption.

## Conclusion

It was seen that when uptake of nutrients is concerned, the crops could preferentially exclude or absorb nutrients based on the concentration of nutrients provided to them and, any odd combination of nutrients is unable to provide the essential nutrients in the appropriate ratios required by the crop. It was observed that high K (280.5 mg $kg^{-1}$) and low Mg content (4.32 mg $kg^{-1}$) of soil has resulted an imbalanced ratio (60.7:1) which rendered reduced uptake and translocation of Mg causing its deficiency in maize. Therefore, conditions like acidic, sandy, mica rich soils with high level of K and low CEC could lead to Mg deficiency in crops like maize, even without K fertilization. The condition may further aggravate when soils are heavily fertilized with NPK without Mg. Periodical soil tests can help detect Mg deficiency in crops. Thus, the farmers are urged to use dolomitic lime and/or Mg- containing fertilizers to alleviate the conditions causing Mg deficiency for sustainable agricultural production systems in this area.

## ACKNOWLEDGEMENTS

We want to thank Prof. Nazeer Ahmed, Director, ICAR-CITH for providing the facilities to conduct this research. Thanks to the anonymous reviewer for his critical remarks and valuable suggestions regarding improvement of the manuscript.

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