Influence of Iron, Potassium, Magnesium, and Nitrogen Deficiencies on the Growth and Development of Sorghum (*Sorghum bicolor* L.) and Sunflower (*Helianthus annuus* L.) Seedlings

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Plant mineral nutrition is a vital area of research to understand the mineral needs of plants, especially crops, and increase crop yields. The objective of this study was to investigate the impact of iron (Fe), potassium (K), magnesium (Mg), and nitrogen (N) deficiencies on the growth and development of sorghum and sunflower. Fe-deficient sorghum and sunflower plants had slightly reduced plant height, root length, and leaf numbers. Leaf chlorosis and necrosis is extreme in sorghum leaves compared to sunflower leaves which exhibited slight leaf chlorosis and necrosis limited to their edges. K-deficient sorghum and sunflower plants exhibited slightly reduced plant height and leaf number but highly reduced root length. Mg-deficient sorghum plants had similar plant heights, leaf number, and root length; however, their leaves were chlorotic with necrotic spots. In contrast, Mg-deficient sunflower plants had highly reduced plant height, leaf number, and root length, and had stunted growth, brown, necrotic, and chlorotic leaves. N-deficient sorghum and sunflower plants had severely reduced plant height, leaf number, and root length. These plants exhibited extreme stunted growth and leaf chlorosis. The symptoms obtained here are in agreement with characteristic symptoms of plant mineral nutrition deficiencies for Fe, K, Mg, and N reported in the previous studies. The results presented here are very important to a better understanding of the impact of mineral deficiency on sunflower and sorghum plants.

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Abbreviations: Fe: Iron; K: Potassium; Mg: Magnesium; N: Nitrogen; C: Carbon; H: Hydrogen; O: Oxygen; P: Phosphorus; S: Sulfur; Ca: Calcium; Mn: Manganese; Zn: Zinc; Cu: Copper; B: Boron; Mo: Molybdenum; Cl: Chlorine; Ni: Nickel.

Introduction

Plants require both macronutrients (C, H, O, N, P, S, K, Mg, and Ca), and micronutrients (Fe, Mn, Zn, Cu, B, Mo, Cl, and Ni) in specific concentrations for their growth and development (1, 2). These essential elements are components of important molecules and the plant cannot complete its life cycle without them. These nutrients have different functions within the plant body including ionic, enzymatic, structural, and regulatory roles. For example, carbon, hydrogen, and oxygen are important components of carbohydrates, lipids, proteins, and nucleic acids. Nitrogen and sulfur is found in proteins and coenzymes. Magnesium is an important part of chlorophyll molecules, and most micronutrients are enzyme cofactors (3).

When the quantities of these mineral nutrients are reduced or deficient, the plants begin to exhibit characteristic symptoms of deficiency (4). Each of the essential element's deficiency exhibit specific physical symptoms some of which overlap with the symptoms of other elements (2). The most studied of these deficiencies are associated with the shoot systems; however, there is an increase in recent studies dealing with symptoms affecting the root systems (2, 4, 5). The symptoms depend both on the mobility and the role of the essential element. These symptoms include stunted stems and leaves, leaf chlorosis, general chlorosis, root leaf necrosis, educed plant height and leaf size, among other symptoms (3, 4, 5).

For example, nitrogen deficient plants exhibit general chlorosis, necrosis, and die. In certain plants, anthocyanins accumulate and cause stunting and purple coloration (4, 6, 7). Potassium deficient plants exhibit symptoms of mottled or chlorotic leaves, weak and narrow stems, and necrotic leaf tips and margins (4, 8). Magnesium deficient plants exhibit symptoms of mottles or chlorotic leaves with necrotic spots, slender stems, and their leaf tips and margins turn upward (3, 4). Iron deficient plants also exhibit symptoms of leaf chlorosis, interveinal leaf chlorosis, and slender and short stems (4, 7, 9).

Understanding the basics of plant mineral nutrition and deficiencies is very important for agriculture. Therefore, plant breeders and nutritionists develop crop cultivars better adapted to grow in nutrient deficient farmlands and environments using the knowledge gained from these plant mineral nutrition studies (3, 4).

The objective of this study was to investigate the influence of iron, potassium, magnesium, and nitrogen deficiencies on the growth and development of monocotyledon (sorghum) and dicotyledon (sunflower) seedlings.

Materials and Methods

Sorghum (*Sorghum bicolor* L.) and sunflower (*Helianthus annuus* L.) seeds, a complete mineral solution, and 4 mineral deficient solutions (Fe-, N-, K-, and Mg-deficient) were purchased from Carolina Biological Supply Company (http://www.carolina.com). The stock solutions were purchased as kits and their composition is shown in Table 1. Five liters of the complete (control) and deficient (Fe-, N-, K-, and Mg-deficient) mineral solutions were prepared according to Table 1 and used during the experiments period.

Five seeds of each plant (sorghum and sunflower) were grown on each of the five mineral nutrition solutions [one complete solution, the controls; and 4 deficient solutions, Table 1] using a hydroponic system as described previously (5). The system was well aerated and covered with aluminum foil to prevent light from reaching the root systems of plants. The solutions were replaced three times a week during the whole period of the experiment (two months). Observations were made daily and pictures were taken to show symptoms of mineral nutrition deficiency when observed. After two months, all plants were removed from the hydroponic growth system and measurements of maximum root length (MRL), plant height (PH), and leaf number (LN) were recorded.

Data analysis was done by using the computer software STATISTIX 8.1 (Analytical Software, FL) and running a Student's t test to see if there

Table 1. Composition of complete and mineral deficient solutions used in this study. Iron (Fe-), Nitrogen (N-), Potassium (K-), and Magnesium (Mg-) deficient. Five liters of each solution were prepared and used during the experiments.

	Milliliter (mL) of Stock Solution										
Type	$CaCl_2$ 0.5M	$Ca(NO_3)_2$ 0.5M	KNO_3 0.5M	KCl 0.5M	KH_2PO_4 0.1M	Mg SO_4 0.2M	FeEDTA 10g/L	Trace	$NaNO_3$ 0.5M	NaH_2PO_4 0.1M	$NaSO_4$ 0.23M
Complete	-	10	10	-	10	10	10	10	-	-	-
Fe-Def.	-	10	10	-	10	10	-	10	-	-	-
N-Def.	10	-	-	10	10	10	10	10	-	-	-
K-Def.	-	10	-	-	-	10	10	10	10	10	-
Mg-Def.	-	10	10	-	10	-	10	10	-	-	10

are significant differences between control groups (complete solutions) and experimental groups (mineral deficient groups: Mg, Fe, K, and N deficient) for all the traits measured: MRL, PH, and LN.

Results and Discussion

Fe-deficient sorghum plants exhibited extreme chlorosis and necrosis at the base of their leaves compared to the controls (Figure 1A–B). These plants also had reduced plant height (14 cm in experimental plants compared to 17 cm in control plants), root length (9.9 cm in experimental plants compared to 14 cm in control plants), and leaf numbers (3 in experimental plants compared to 5 in control plants) (Figure 2). In Fe-deficient sunflower plants, leaf chlorosis and necrosis is slight and limited to the leaf edges (Figure 3A); however, they also exhibited reduced plant height (20 cm in experimental plants compared to 23 cm in control plants), root length (7.5 cm in experimental plants compared to 10 cm in control plants), and leaf numbers (8 in experimental plants compared to 10 in control plants) (Figure 4). Iron is an essential element for plant growth and development. It is an important component of heme proteins, iron-sulfur proteins, lipoxygenases (10), and many other ezymes. Iron also is involved in chlorophyll biosynthesis, chloroplast development, and photosynthesis (1, 3, 4, 11). Therefore, symptoms of chlorosis and necrosis observed here are typical of iron deficiency (1, 2, 3, 4, 12, 13, 14).

K-deficient sorghum plants had several lesions and necrotic spots at their leaf tips compared to the control plants (Figure 1C). These plants also had reduced plant height (14 cm in experimental plants compared to 17 cm in control plants), root length (7 cm in experimental plants compared to 14 cm in control plants), and leaf number (3 in experimental plants compared to 5 in control plants) (Figure 2). K-deficient sunflower plants also had reduced plant height (15 cm in experimental plants compared to 23 cm in control plants), leaf number (8 in experimental plants compared to 10 cm in control plants), and highly reduced root length (5 cm in experimental plants compared to 10 cm in control plants) and died just after the end of the experiment (Figure 4). Potassium ions (K^+) contribute significantly to osmotic adjustment (15, 16). In K-deficient plants, soluble carbohydrates and nitrogen compounds are accumulated, and starch content is decreased

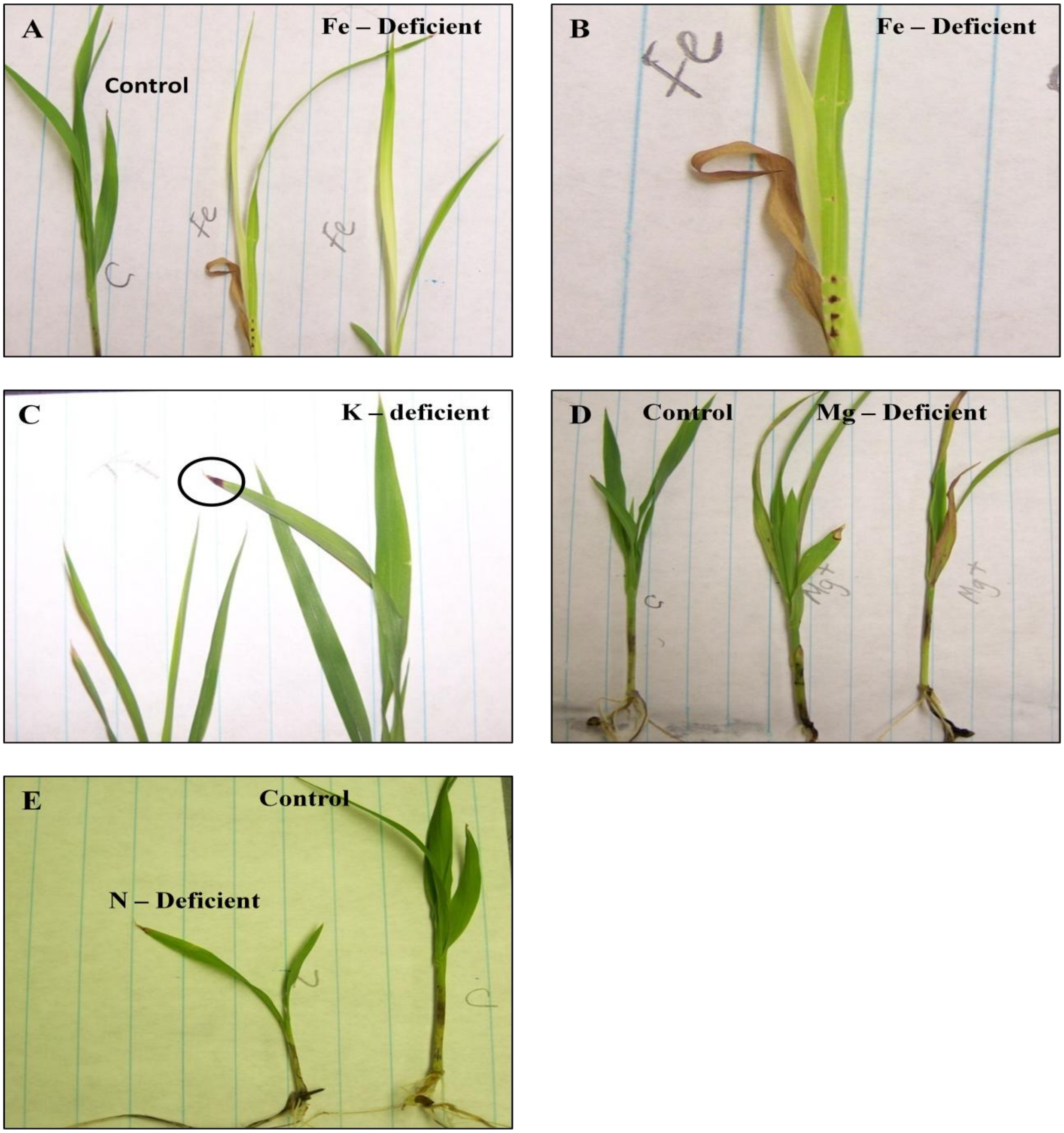

Figure 1. Control and mineral nutrition deficient sorghum plants. (A–B). Fe – deficient plants with symptoms of general leaf chlorosis, necrosis, and bending; (C). K–Deficient plants with symptoms of necrotic leaf tips; (D). Mg–Deficient plants with symptoms of leaf necrosis and necrotic leaf tips; and (E). N–Deficient plants with symptoms of reduced plant height and root system, and necrotic leaf tips.

(1). These changes are due to the fact that many enzymes involved in carbohydrate metabolism require high concentrations of K^+ (1). K^+ ions are also involved in the activation of proton-pump ATPases, photosynthesis, osmoregulation, cell expansion, and stomatal movement (1). These various roles explain the symptoms of lesions and necrotic spots in leaves as well as reduction of plant growth.

Mg-deficient sorghum plants had slightly reduced plant height (13 cm in experimental

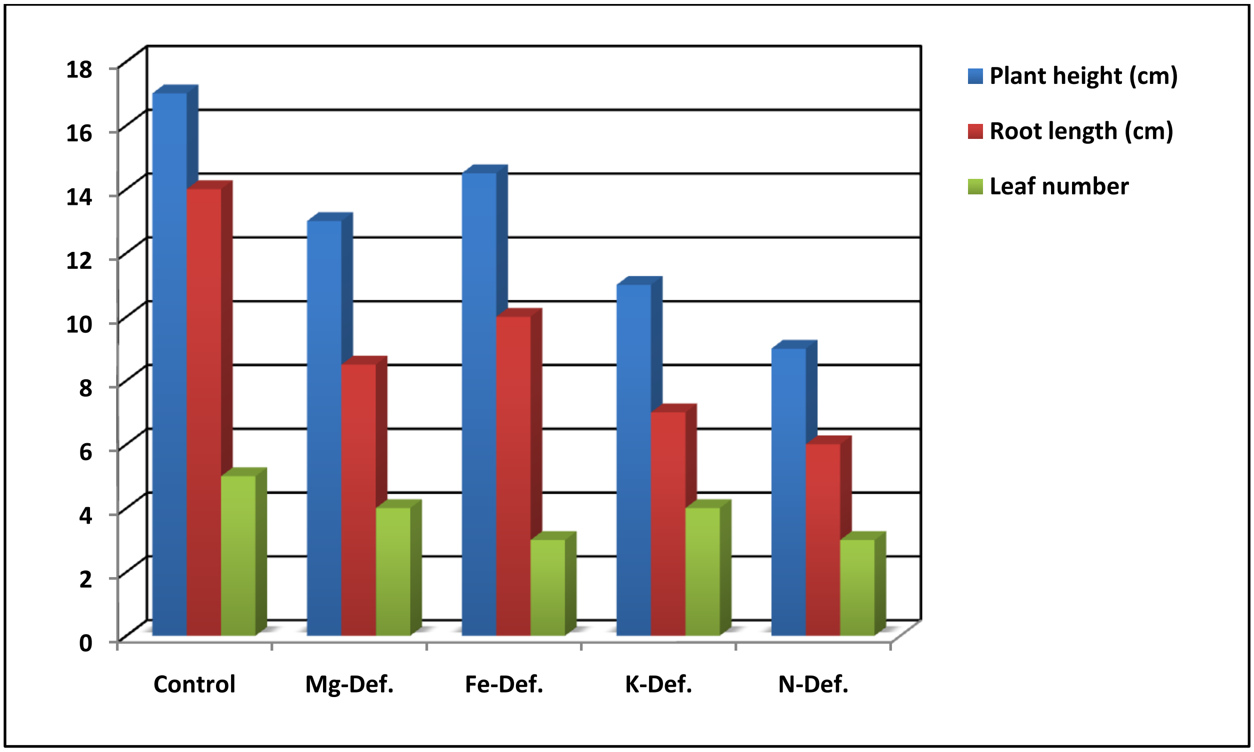

Figure 2. Plant height, root length, and leaf numbers in control (complete solution), Mg–Deficient, Fe–Deficient, K–Deficient, and N–Deficient sorghum plants.

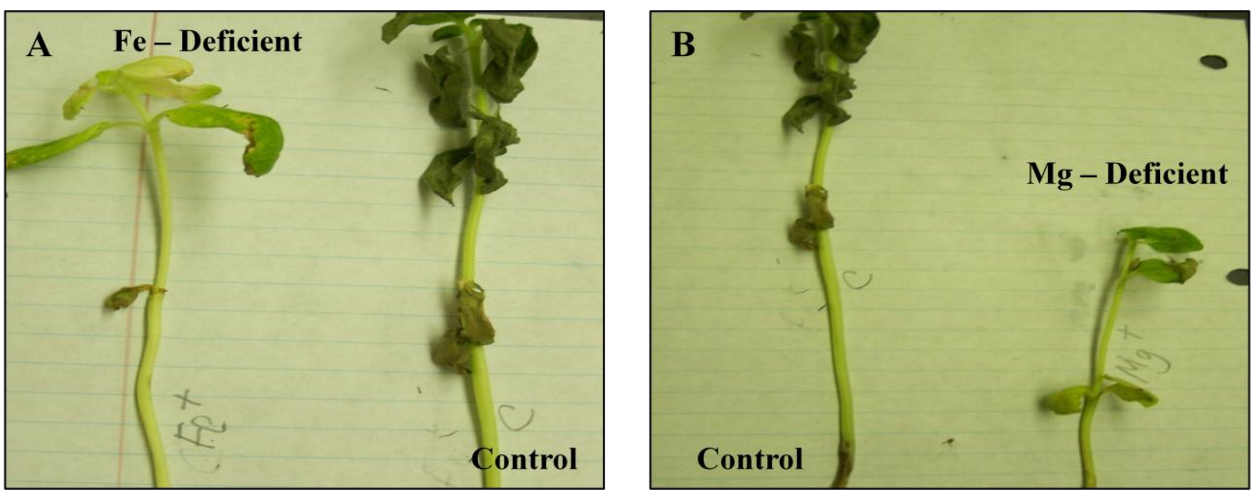

Figure 3. Control and mineral nutrition deficient sunflower plants. (A). Fe–deficient plants with symptoms of leaf chlorosis, necrosis, and reduced plant height (dwarfism); and (B). Mg–Deficient plants with symptoms of leaf necrosis and reduced plant height (dwarfism). K–deficient and N–deficient plants died and their photos were not taken.

plants compared to 17 cm in control plants), root length (8 cm in experimental plants compared to 14 cm in control plants), and leaf number (4 in experimental plants compared to 5 in control plants) (Figure 2). Their leaves were brown and chlorotic (Figure 1D). In contrast, Mg-deficient sunflower plants had highly reduced plant height (12 cm in experimental

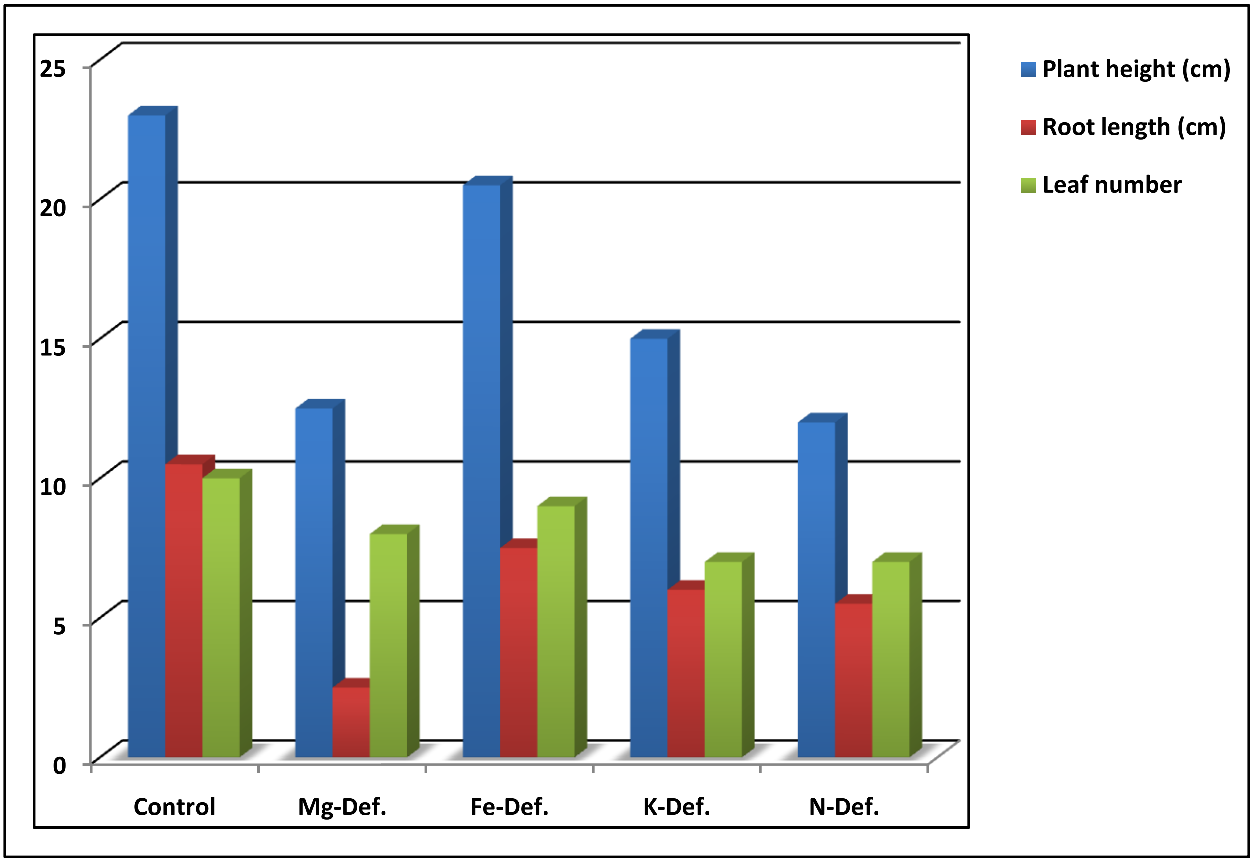

Figure 4. Plant height, root length, and leaf numbers in control (complete solution), Mg–Deficient, Fe–Deficient, K–Deficient, and N–Deficient sunflower plants.

Table 2. The probability values showing significant differences between control groups (complete solutions) and experimental groups (mineral deficient groups: Mg, Fe, K, and N deficient) for all the traits measured: maximum root length (MRL), plant height (PH), and leaf numbers (LN) for sorghum and sunflower plants. The values were obtained from the Standard Student t test using the statistical software STATISTICS 8.1.

	Sorghum Plant Height	Sorghum Root Length	Sorghum Leaf Number
Mg Deficient	0.004	0.030	0.180
Fe Deficient	0.080	0.006	0.080
K Deficient	0.080	0.001	0.040
N Deficient	0.005	0.004	0.070
	Sunflower Plant Height	**Sunflower Root Length**	**Sunflower Leaf Number**
Mg Deficient	0.004	0.0003	0.080
Fe Deficient	0.090	0.120	0.120
K Deficient	0.020	0.006	0.120
N Deficient	0.008	0.040	0.030

plants compared to 23 cm in control plants), root length (1.8 cm in experimental plants compared to 10 cm in control plants), and slightly reduced leaf number (8 in experimental plants compared to 10 in control plants). These plants had stunted growth, brown, necrotic, and chlorotic leaves (Figures 3B and 4). Magnesium occupies a central part in the chlorophyll molecules (1, 3, 4). Therefore, its deficiency decreases growth (17) and photosynthetic rate. Hence, stunted growth, brown, necrotic and chlorotic leaves were obtained here.

N-deficient sorghum plants exhibited extreme stunted growth and leaf chlorosis before most of them died (Figure 1E). These plants also had severely reduced plant height (9 cm in experimental plants compared to 17 cm in control plants), reduced leaf number (3 in experimental plants compared to 5 in control plants), and reduced root length (5.8 cm in experimental plants compared to 14 cm in control plants) (Figure 2). N-deficient sunflower plants also had reduced plant height (13 cm compared to 23 cm in control plants), leaf number (6 in experimental plants compared to 10 in control plants), and root length (5 cm in experimental plants compared to 10 cm in control plants) before they died (Figure 4). These are in accordance with the retardation of the overall growth and the mobilization of nitrogen to areas of new growth whith symptoms of N-deficiency (1). Nitrogen is a component of many organic compounds such as nucleic acids (DNA and RNA) and proteins. Consequently, higher plants require large amounts of nitrogen (1, 3, 4, 18, 19, 20). Nitrogen is abundant in the atmosphere (78%); however, most plants cannot uptake atmospheric nitrogen and only certain bacteria can convert it into ammonium that is assimilated rapidly in root cells (1, 19, 21). These bacteria are known to form symbiotic associations with the roots of legume plants (1, 3, 4, 19, 22). N-deficiency affects strongly these symbiotic associations quantitatively and qualitatively (3, 4, 19, 22).

Statistical data analysis showed in general a significant difference between control groups (complete solutions) and experimental groups (mineral deficient groups: Mg, Fe, K, and N deficient) for all the traits measured: MRL, PH, and LN. The probability values were 0.004, 0.03, and 0.18 for plant height, root length, and leaf numbers respectively for Mg-deficient sorghum plants vs. control plants (Table 2). The probability values were 0.08, 0.006, and 0.08 for plant height, root length, and leaf numbers respectively for Fe-deficient sorghum plants vs. control plants (Table 2). The probability values were 0.08, 0.001, and 0.04 for plant height, root length, and leaf numbers respectively for K-deficient sorghum plants vs. control plants (Table 2). The probability values were 0.005, 0.004, and 0.07 for plant height, root length, and leaf numbers respectively for N-deficient sorghum plants vs. control plants (Table 2).

In the other hand, the probability values were 0.004, 0.0003, and 0.08 for plant height, root length, and leaf numbers respectively for Mg-deficient sunflower plants vs. control plants (Table 2). The probability values were 0.09, 0.12, and 0.12 for plant height, root length, and leaf numbers respectively for Fe-deficient sunflower plants vs. control plants (Table 2). The probability values were 0.02, 0.006, and 0.12 for plant height, root length, and leaf numbers respectively for K-deficient sunflower plants vs. control plants (Table 2). The probability values were 0.008, 0.04, and 0.03 for plant height, root length, and leaf numbers respectively for N-deficient sunflower plants vs. control plants (Table 2).

Our findings will add significant knowledge for a better understanding of the impact of mineral deficiency on sunflower and sorghum plants.

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