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Environmental Impact of Magnetized Water: Evidence from Heavy Metals in the System Soil-Plant

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Abstract

Capacity for agriculture production needs to be increased to meet the demands of the increasing human population. Within alternatives for an improvement in technology of agriculture in arid and sub arid countries' irrigation with magnetized water (MH_2O). This study was carried out to investigate the nutrients taken up by plants irrigated with (MH_2O). During this study, we have grown Cucumis *sativus* in greenhouse for one month. The growth was carried on a sandy loamy soil type with two sets of pots 1) one set of pots without MH_2O, as reference and 2) another set of pots was irrigated with MH_2O. The results revealed that the plants' leaves irrigated with MH_2O were enriched in Zn, Cu and depleted in Ba, Ti and Sr relative to the plant grown in control conditions and unchanged in Fe, V, Ni; Mn and Cr. The roots of the same plants irrigated with MH_2O were depleted in Fe, Mn, Ti, Ba, V, Ni, Cr, Zn and Sr. Translocation of elements from roots to leaves irrigated with MH_2O seems more important than for plants irrigated with ordinary water. Based on the results of this study, irrigation with magnetized water may exhibit a positive effect on nutrition of plants. In addition to the effect of MH_2O on growth, content of nutrients, revealed the effect on the quality of plants. These results show that irrigation with MH_2O in arid countries with reduced water resources, may help to promote agriculture for an amelioration by increasing available elements.

Keywords

Magnetized Water, Leaves, Roots, Trace Elements, Translocation

1. Introduction

To meet the sustenance for anticipated increase of human population during this century, it is necessary that means be found for increasing capacity in agriculture production. Availability of water is an important limiting factor for the enhancement of agricultural productions and improvement in the use of water is important for increased agricultural growth.

Recent studies have shown that an enhancement in the growth of plants through the use of magnetized water in the irrigation process could potentially happen which shows that this mode of irrigation can be a way for an alleviation of the anticipated food crisis in the future. We have a long way to explore the full potential of this relatively novel means of agricultural enhancement to meet the future human needs.

The recent years, studies have shown that the use of magnetized water in the irrigation efforts has led to the increase in biomass production, enhanced root and shoot growth, increased number of leaves and rapid growth [1]-[7]. A few studies did not find support for this positive impact of magnetized water on irrigation projects [8] [9] [10] [11]. The disagreement suggests more studies be carried out on impact of use of magnetized water for announcement of agricultural growth.

Several experiments have shown that using magnetically activated water (MH_2O), plant growth improvement occurs in terms of mass increase of the foliage [12]-[23].

Published studies report antagonist conclusion about magnetic field effect on hydrogen bonds of water molecules. For example, according to [24] the magnetic field can cause the weakening of hydrogen bonds while [25] reported that magnetic field can enhance the bonding among water molecules.

Among studies which reported the effect of magnetic field on properties of water: [26] [27] [28] [29] [30]. According to [26], the magnetic field may change the conductivity and the surface tension of water [28] [31]. [28] concluded that the surface tension of water-air interfaces increased under the effect of magnetic field.

The experiment carried out by [30] showed that magnetic field treatment changed specific heat, evaporation amount and boiling point of water. [21] reported that magnetic field could accelerate the degradation of organic substances of pulp and paper wastewater, and the pH values of wastewater. [32] reported that the magnetic field affects the intercluster and intracluster hydrogen liaisons of water which can be explained based by the magnetic field effects on the hydrogen bonds of water molecules, possibly causing breakage of some of them. Within the highlighted properties of magnetized water is the memory of physicochemical parameters measured even for seven days [23].

However not all studies have confirmed similar results in the use of the MH_2O to improve the growth of plants. For example, [10] reported an inhibitory effect of static magnetic field on root dry weight of maize plants and [8] [9] observed that weak magnetic field had inhibitory effect on growth of primary roots during early growth.

These diverse observations clearly demonstrate that many different studies involving different conditions of the use of MH_2O in irrigation, are needed before the full potential of the use of MH_2O can be determined. Besides magnetic field variations in the process of magnetized water use, soil conditions and plant responses must be known in order to assess the dimension of this potential. The soil conditions that have been examined are few or many (pH, Eh, root and soil composition) and there are a lot of others to be considered. The use of the MH_2O in plant growth improvement is just beginning to develop and understanding of chemical aspect of plants grown under the influence of MH_2O has been very limited, but this knowledge is necessary to be able to optimize the growth factor if the use of the MH_2O becomes reality.

The metal uptake by a plant irrigated with magnetized water is a subject of investigation as yet remains nearly unexplored. The current study provides some information along this line through the study of growth enhancement of Cucumus *sativus* under a greenhouse environment using some ordinary water that was magnetized in comparison to the growth of the same plant using the same ordinary water that was not magnetized. Both above ground part and below ground part of the two sets of plants were analyzed for contents of the metals that included: K, Rb, Na, Mg, Ca, Sr, Ba, Al, Si, Ti, P, V, Cr, Mn, Fe, Co, Ni, Cu, Zn, Mo, REE (rare-earth elements), and Pb. The chemical comparisons of roots and shoot zones of the same plant grown in the same soil under the same physical conditions of light and temperature with availability of the same amount of moisture have been used to assess the nutrient uptake related to these particular conditions. An understanding of the distributions of metals in the two parts of the plant could be potentially valuable in the assessment of impact of using magnetized water in the growth of this plant. Similar investigations of metals involving growths of many other plants on different soil substrates could be useful to determine the scale of benefits to be gained from using magnetized water in the agricultural practices.

Magnetic field can be considered as a stress for living organisms [33] [34]. Therefore, it is important to maintain similar microorganism population in the root zone and the alteration of the population during the experiment process may yield the results that can be contrary to more common observations. This study made every effort to maintain nearly identical bio-environment in both sets of the experiment, as the entire experimental process was conducted in a highly clean laboratory with filter air flow. This study has observed a qualitative enhancement in the growth of Cucumus *sativus* using MH_2O.

The chemical data have been examined in light of qualitative improvement in the growth. This study looked at the metal contents in roots and shoots for the plants. Visibly it appeared there was a slight increase in the size of the leaves.

Water is a diamagnetic material which can be affected by magnetic field. Magnetic field (MF) can lead to several changes in water molecules which may persist in water after treatment. Such phenomena are qualified by magnetic memory of water and have been reported in previous studies [23] [35] [36]. Application of magnetic field on liquids leads to numerous bulk and surface phenomena, one of which is the deformation of the diamagnetic liquid/vapor interface by magnetic field, also called the "Moses Effect" [36] [37].

2. Material and Methods

Different sets of experiments have been conducted to determine the effect of magnetic field on chemical composition of plants. To generate a magnetic field, the material used during this study consisted in pairs of magnets aligned in opposite according to their poles. The strength of magnetic field has been controlled by regulating the distance between the adjacent magnets. During the experience carried by [38] to study the effect of MH_2O, the range of magnetic field strength 0.0035 - 0.136 Tesla (T) considered during irrigation did not significantly affect plants. However significant effect has been observed by [39] and by [40] with magnetic field of 0.1 T. Therefore, the strength of magnetic induction considered in the present study is 0.1 to 0.2 T.

For magnetizing, about 15 L of water were passed per hour through hole sandwiched between each two adjacent magnets having opposite magnetic poles facing each other. Previously to irrigation of plants, the exposure time of water to magnetic field was about 60 s.

Two sets of pots were prepared with soil substrate (about 1 kg of sandy loamy soil). Each pot had a height of 25 cm and a diameter of 15 cm. The two sets of pots include: 1) One set of pots was irrigated with MH_2O; 2) One set of pots for control and where soils have been irrigated with tap H_2O. In order to reduce errors on experiment, all experiments have been repeated 3 times.

Experiments have been carried in greenhouse under natural light at temperature of 30˚C - 35˚C with 50% of relative humidity. Before seeding of C. *sativus*, each sequence of pots was watered with 50 ml of demineralized water. No other chemical elements that could have interfered in plant growth or in transfer of elements from substrate to plant were added during the experiment. The pots were only watered periodically (every 3 days). Each pot received equal amounts of water during the growth period. No fertilizers have been added to the soil during this experiment. The N fertilizer has to be produced naturally from reduction of N_2 to NH_3 as it is commonly happening naturally in the absence of addition of fertilizers.

Thirty days after seeding, the grown plants were harvested for chemical analyses. About twenty individual plants from each pot were removed randomly and grouped in five separate batches. The plants of each batch were processed and analyzed separately, so that the chemical data for the plants grown in the individual pots represented an average of five sets of plant individuals in each case. In other words, instead of repeating the analyses for control of the analytical uncertainty, we managed the analytical reproducibility in analyzing systematically five batches of each plant at each step and averaged the data within a 2σ error. In summary, each plant data in **Table 1** represents an average measure of 100 - 125 individual plants splited into 5 independent batches.

Table 1. Average chemical composition of leaves and roots of plants. Concentrations are expressed in ($\mu g \cdot g^{-1}$).

	Above ground surface		Ratio MH_2O/Control	Below ground surface		Ratio MH_2O/Control	Ratios (Leaves/roots)	
(ppm)	Control	MH_2O		Control	MH_2O		Control	MH_2O
Si	55.86	44.16	0.79	183.85	106.36	0.58	0.3	0.42
Al	1265.68	1155.62	0.91	5419.23	2906.82	0.54	0.23	0.40
Mg	8857.17	8924.25	1.01	15261.47	11286.36	0.74	0.58	0.79
Ca	29230.77	27232.88	0.93	21769.23	16113.64	0.74	1.34	1.69
Fe	1308.28	1317.26	1.01	12707.69	3763.64	0.30	0.1	0.35
Mn	51.69	47.88	0.93	133.19	74.66	0.56	0.39	0.64
Ti	19.47	14.9	0.77	84.23	33.18	0.39	0.23	0.45
Na	3426.04	4372.6	1.28	6769.23	9590.91	1.42	0.51	0.46
K	20473.37	25397.26	1.24	36038.46	49204.55	1.37	0.57	0.52
P	1204.73	1967.12	1.63	1719.23	1909.09	1.11	0.7	1.03
Sr	211.24	179.73	0.85	132.85	117.2	0.88	1.59	1.53
Ba	39.53	29.27	0.74	55.81	40.73	0.73	0.71	0.72
V	1.78	1.92	1.08	10.38	5	0.48	0.17	0.38
Ni	23.96	23.45	0.98	126.92	66.14	0.52	0.19	0.35
Cr	11.72	12	1.02	112.69	37.05	0.33	0.10	0.32
Zn	37.46	43.18	1.15	366.54	100.45	0.27	0.10	0.43
Cu	5.92	8.38	1.42	23.08	17.27	0.75	0.26	0.49
Co	2.51	2.27	0.90	12.5	7.11	0.57	0.20	0.32
As	5.92	3.84	0.65	65.38	34.09	0.52	0.09	0.11
Rb	2.78	2.74	0.99	5.38	6.36	1.18	0.52	0.43
Mo	4.73	3.29	0.70	3.85	2.27	0.59	1.23	1.45
La	0.24	0.16	0.67	1.15	0.68	0.59	0.21	0.24
Ce	0.59	0.38	0.64	2.85	1.57	0.55	0.21	0.24
Pr	0.07	0.04	0.57	0.23	0.18	0.78	0.28	0.21
Nd	0.25	0.18	0.72	1.04	0.66	0.63	0.24	0.27
Sm	0.07	0.04	0.57	0.23	0.14	0.61	0.28	0.28
Dy	0.05	0.03	0.60	0.23	0.14	0.61	0.23	0.20
Pb	5.92	3.84	0.65	23.08	13.64	0.59	0.26	0.28
K/Rb	7364.52	9269.07	1.26	6698.6	7736.56	1.15	1.10	1.20
Sr/Ca	0.01	0.01	0.91	0.01	0.01	1.19	1.19	0.91

-MH_2O: magnetized water.

The collected plants were first washed five times with demineralized water. This washing was followed by a gentle ultrasonic treatment in a bath for about 2 minutes to remove any solid mineral particles that could have adhered at the surface of the plants, especially at the roots. After removing from ultrasonic bath, the plants were washed again with demineralized water.

As was followed by [41], the analytical procedure started with drying the plant batches at 60˚C for 24 hours and weighed them afterwards. Then each weighed plant amount was ashed in a Pt crucible at about 600˚C for 45 minutes. The ash was transferred into a Teflon beaker and digested in ultrapure concentrated HNO_3 at a temperature of about 70˚C for 24 hours and more if needed. The solution was then slowly evaporated to dryness by closing the beakers. Ten drops of $HClO_4$ were added afterwards to ensure dissolution of all remaining organic material, and the aliquot was evaporated again to dryness. The obtained solution was then prepared for analysis by dissolving the dried material with a known volume of 1N HNO_3.

The elemental contents of the plants were determined using an ICP-AES (Jobin Yvon JY 124) for analysis of major and trace elements (Sr and Ba), and an ICP-MS (Jobin Yvon JY 124) for analysis of V, Ni, Cr, Zn, Cu, Co, As, Rb, Mo, Ob, La, Ce, Pr, Nd, Sm and Dy with a Detection limit of 0.01 ppb. The equipment and accuracy controls of each ICP are available in [42]. Repeated analyses of standards were carried out during the course of the study on a regular weekly basis providing an analytical precision for the major and trace elements of respectively ±2% and ±5%, ±10% 2σ standard deviation of each analyzed element.

3. Results

During this study all plants have been grown in a sandy loamy soil. Its mineral composition determined by XRD consisted in quartz, calcite, dolomite, feldspar and palygorskite with some minor minerals.

The height of stems and leaves of grown Cucumis *sativus* reached about 15 cm and the width of the leaves was about 2 to 3 cm and the length was about 3 to 5 cm. Comparison of the growth density and the size of the plant in each pot showed that the application of magnetized water did not modify markedly the growth process of Cucumis *sativus* plant.

Chemical composition of leaves and roots collected from plants grown in different conditions is included in **Table 1**. Data are expressed as µg per g of dry plant.

MH_2O is supposed to affect paramagnetic elements. However, in this study we investigated both types of elements paramagnetic such as (Ni, Mn, Ba, Fe, Ti, Sr, Rb, Ce, Nd, Na, Mg, Ca, Al and Mo) and diamagnetic such as (Cu, Zn, Cr, V, As and Pb).

Silicon (Si), phosphorus (P) and aluminum (Al):

Data of the plant from substrate irrigated with magnetized water indicates that the average content of Si in leaves and roots water is 44 and 106 ppm respectively, the average content of P is about 1967 and 1909 ppm in leaves and roots respectively, the average content of Al is about 1156 and 2907 ppm in leaves and roots respectively.

Compared to the plant grown in control conditions, the leaves of plants irrigated with MH_2O have been depleted in Si, enriched in P and unchanged in Al (Table 1, Figure 1). The roots of the same plants irrigated with MH_2O have been depleted in Si and Al and unchanged in P.

First transition series of elements:

The elements investigated in this study among this group included titanium (Ti), vanadium (V), chromium (Cr), manganese (Mn), iron (Fe), cobalt (Co), nickel (Ni), copper (Cu) and zinc (Zn).

The average concentration of trace elements in leaves grown in control conditions from the highest to the lowest is as follows Fe > Mn > Zn > Ni > Ti > Cr > Cu > Co > V (Figure 2). The order of importance of elements in roots grown in control conditions is as follows: Fe > Zn > Mn > Ni > Cr > Ti > Cu > Co > V. Compared to order of these elements in the crust (Fe > Mn > V > Cr > Zn > Ni > Cu > Co), concentrations of transition elements in both leaves and roots differ only slightly.

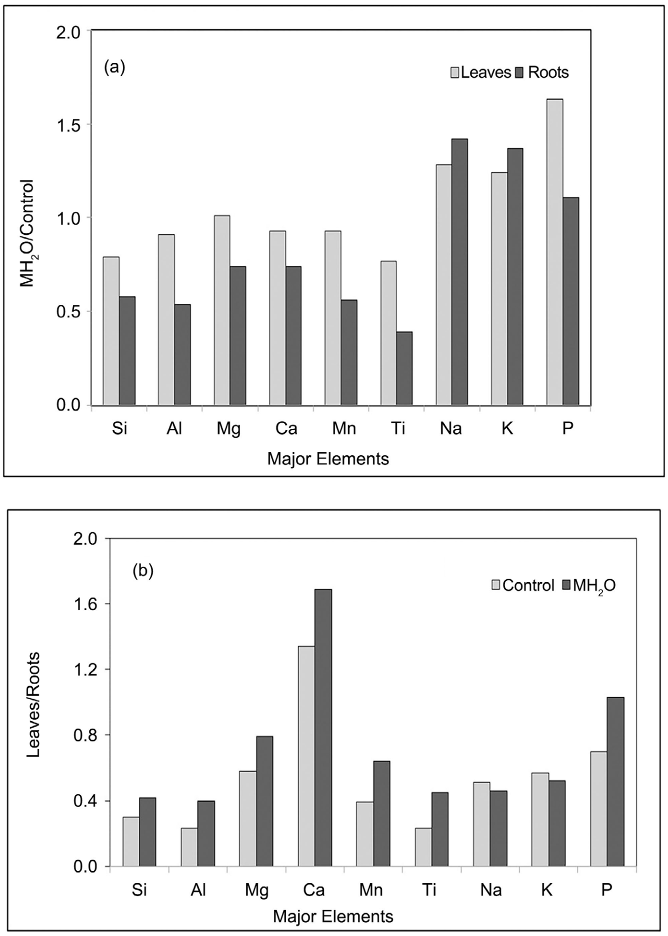

Figure 1. Content of major elements in leaves and roots irrigated with MH_2O relative to ordinary water (a) and the ratio between the content in leaves and roots in (b).

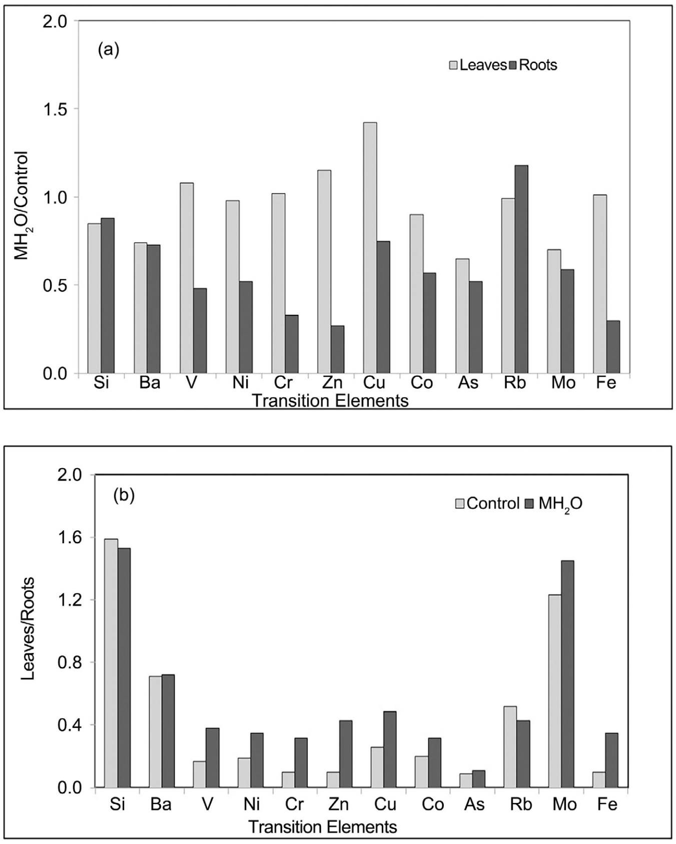

Figure 2. Content of transition elements in leaves and roots irrigated MH_2O relative to ordinary water (a) and the ratio between the content in leaves and roots in (b).

The order of importance of transition elements in plants irrigated with MH_2O in both leaves and roots remain similar to their order in plants grown in control conditions (**Table 1**, **Figure 2**).

Compared to plants grown in control conditions, the leaves of plants irrigated with MH_2O have been enriched in Zn and Cu and depleted in Ti and unchanged in Fe, V, Ni, Mn, Co and Cr (**Figure 2**). The roots of the same plants irrigated with MH_2O have been depleted in all transition elements relative to plants grown in control conditions.

Alkali and alkaline elements:

This group includes sodium (Na), calcium (Ca), magnesium (Mg), barium (Ba), potassium (K), rubidium (Rb) and strontium (Sr).

For the plant from irrigated soil with MH_2O, the average content of Na in leaves and roots is 4372.6 and 9590.9 ppm respectively, the average content of Ca in leaves and roots is 27232.9 and 16113.6 ppm respectively, the average content of Mg in leaves and roots is 8924.3 and 11286.4 ppm respectively, the average content of K in leaves and roots is 25397.3 and 49204.6 ppm respectively, the average content of Rb in leaves and roots is 2.74 and 6.36 ppm respectively, the average content of Ba in leaves and roots is 29.3 and 40.7 ppm respectively

Compared to the plant grown in control conditions, the leaves of plants irrigated with MH_2O have been enriched in Na and K and depleted in Ba and Sr and unchanged in Ca, Mg and Rb (**Table 1**). The roots of the same plants irrigated with MH_2O have been depleted in Ba, Ca, Sr and Mg, and enriched in Na, K and Rb relative to plants irrigated with ordinary water.

Rare earth elements (REEs):

Most of REEs especially the middle and heavy ones were too low, almost under detection limit. The explanation can be the low content of complexation agents to make easy the transfer of this group of elements from soil to roots. The discussion will include only La, Ce, Pr, Nd, Sm and Dy. Compared to the plant grown in control conditions, both leaves and roots of plants irrigated with MH_2O have been depleted in all REEs (**Table 1**).

Lead (Pb), arsenic (As) and molybdenum (Mo)

Data of the plant from substrate irrigated with magnetized water indicates that the average content of Pb in leaves and roots is 3.84 and 13.64 ppm respectively, the average content of As in leaves and roots is 3.84 and 34.09 ppm respectively and the average content of Mo in leaves and roots is 3.29 and 2.27 ppm respectively. Both leaves and roots of plants irrigated with MH_2O were depleted in Pb, As and Mo.

4. Discussion

Unlike the study of [43], the physical effect is not significant in the present study (about 10% of increase). Irrigation of Rhodes grass with magnetized slightly saline increased the grass yield by about 16% to 35.4% [43].

As it was stated above, irrigation with MH_2O induced a heterogeneous behaviour of elements in leaves and roots. Some elements have been enriched relative to plants grown in control conditions, such as Zn and Cu in leaves and some other elements such as Cr, As and Pb decreased while other elements such as Al and Ni were not affected by magnetism especially in leaves. The material considered in this study consists in the same species of plant (C. *sativus*) grown in the same conditions and the same substrate: a sandy loamy soil.

If we focus on the the metal contents for leaf which is the above ground, and we compare between the content of a metal in leaf for the plant irrigated with MH_2O with that irrigated with non-magnetized water, we come to the following conclusions:

Except for Na, K, P, Zn, and Cu, whose contents are higher in leaf from irrigation with magnetized water than that in leaf from irrigation with control or non-magnetized water, all other elements (Ca, Sr, Rb, Mg, Si, Al, Ti, V, Fe, Mn, Ni, Cr, Mo, Pb, LREE) have very similar contents between the two above ground sets.

This does not make sense, Fe plays a significant role in photosynthesis, Mg plays a significant role in photosynthesis, it is part of ATP-associated metal. Since we see a large P gain for leaf through the use of magnetized wate, there is no reason for us not to see an increase in Mg for leaf with magnetized water irrigation.

Hence current result presentation and accompanying discussion merit to a non-scientific approach, failing to consider the essential fundamental basis in the growth of a plant. Metals come from soils, which are largely degraded/decomposed by soil microorganisms (bacteria and virus) and some macroorganisms (earthworms, fungi etc.), and the metals released from the soil particles are then get distributed to plant root (below ground part) and leaf-stems or leaf (above ground part).

Based on this reasoning, for each metal, we had to calculate relative enrichment in leaf after normalizing to corresponding root. The following enrichments or depletions are seen in leaf from magnetized water, compared to non-magnetized water:

Si—37% gain, Al –70% gain, Mg—36% gain, Ca—26% gain, Sr—4% loss (or almost no change within the analytical error), Ba—1% gain (or no change), Fe—240% gain, Mn –65% gain, Ti –94% gain, Na—10% loss, K—10% loss, Rb—16% loss, P—47% gain, V—124% gain, Ni—88% gain, Cr—211% gain, Zn—321% gain, Cu—89% gain, Co—59% gain, As—24% gain, Mo—18% gain, Pb—10% gain, Total LREE—10% gain and K/Rb ratio—9% increase.

The differences between the control plants and plants grown in experiment conditions, have to be explained in terms of soil mineral chemistry, biological population and composition, decomposition of organic matter and metal-organic co-enzyme activated enzyme products in the root zone. In term of soil mineral chemistry, it will not be a big change between pots, but minor amounts of changes can have significant impact on plant chemistry. Any soil mineral chemistry change that can be induced by use of MH_2O has to rise from the presence of any colloidal material in the water which can be affected by magnetic field to which the water was subjected. Paramagnetic material can affect the microenvironment of soil mineral particles. The therein magnetic field strength increase can make the bonds between atoms of the minerals. This may promote some hydrolysis effect by which mineral solubility can be enhanced. The hydrolysis effect can be further enhanced by the presence of microorganisms. It has been well known that microorganisms have large kinetic effect on mineral dissolution through their enzymatic activities [44] [45] [46] [47].

It is known that application of MH_2O to soils increases the solubility of minerals in the soil and helps in easy penetration of nutrients in the plant cell [48]. Nevertheless, the study of [49] revealed that magnetic treatment of water slows down the movement of minerals probably because of crystallization and precipitation of minerals.

The response of paramagnetic elements to MH_2O consists in a depletion of Ba, Ce, Mo, Sr and Ti in leaves and no change for the others. The response of diamagnetic elements during this study to MH_2O consists in an increase of Zn and Cu, a depletion of As and Pb and no change for the other diamagnetic elements in leaves. Similar results were observed by [50] for N, P, K, Fe, Mn, Zn, and Cu which absorption by the cucumber plants increased due to soil treatment with magnetic water.

The response of elements in the roots consists in a depletion of most of elements either paramagnetic or diamagnetic. In term of spatial variations of elements, differences between the response of leaves and the response of roots to MH_2O must be correlated to their respective functions. Thus, the main function of leaves consists in the photosynthesis reactions while the main functions of roots consist in the adsorption of water and inorganic nutrients and their storage in the plant. The root related decrease, increase and no change in the elemental contents must be considered in terms of the root zone activity among the various natural components and the chemical environment in such zones. Several factors contribute to the dissociation of minerals. The most important of these factors consist in H_2O as agent of weathering, physico-chemical characteristics of the soil such as pH and Eh and temperature and microorganisms. Following dissociation of minerals, elements may form secondary minerals in the rhizosphere decreasing the mobility of elements and rendering the condition for their low availability to the roots. In the absence of any influence of secondary mineral formations, the low availability could be due to some complexation effect on elements, and which will not probably favour or promote the uptake of elements at the roots. Several previous studies reported the role of microorganisms in the mobilization and immobilization of metals in the rhizosphere [46] [51] [52] [53]. Bacteria excrete exudates which catalyze oxidation-reduction reactions in the rhizosphere which may affect mobility of elements.

Following their uptake by plants, metal elements are translocated from roots to leaves as complexed compounds. The movement is driven in the xylem by the gradient in hydrostatic pressure (root pressure) and the gradient in the water potential (transpiration). The rate of transpiration and the content of elements in the soil solution have a control on the movement of elements to roots.

Magnetization of water used for irrigation increased the contents of Zn and Cu only among all the first transition series elements in the leaves relative to leaves grown in control conditions. The contents of the other transition elements like V, Cr, Mn, Fe, Co and Ni remained unchanged while that of Ti was depleted. By comparison, all transition elements in the roots decreased.

It is common to find plants that requirements of Zn and Cu are high for their growth. It is also true that Fe requirement for plant growth is often very high. However, Fe content in the present study did not change in the leaves irrigated with MH_2O. It is then may be possible that magnetization effect induced a chemical environment that inhibited the transport of some elements that are required for the physiological function of the leaves. The relative transports of both Cu and Zn were high enough that these two elements took active roles in the absence of some of the other required elements.

The enzymes that can incorporate Zn have been already identified by several authors. [54] reported Zn as a co factor of a number of enzymes such as carbonic anhydrase, carboxypeptidase, alcohol dehydrogenase, glutamic dehydrogenase and lactic dehydrogenase. Carbonic anhydrase is an important enzyme for photosynthetic activity. The increase of Zn concentration in the leaves of the plants irrigated with MH_2O during this study may indicate an increase in carbonic anhydrase activity and thus an increase of photosynthetic activity.

Unlike Zn with an oxidation state of II in natural conditions, Cu has two oxidation states of I and II. Therefore, Cu has been used by plants for reactions that require oxidation-reduction processes [55] [56] [57]. Laccase ascorbic acid oxidase polyphenol oxidase, cytochrome oxidase and ferroxidase are plant enzymes which have been known to contain Cu as a co factor.

Unlike Cu and Zn, the content of the other elements such as Fe, Ni, Cr, Co, V, Mn and Ba did not change in the leaves but exhibit an important depletion in the roots compared to the roots of plants irrigated with ordinary water. Among these elements which experienced a depletion, Fe is one of them that is always known as essential element and it is generally present in high concentrations in living materials, nearly paralleling its abundance in crustal materials. The decrease in Fe content is therefore a reflection may be of some forms of precipitation of Fe compounds at the root zone, causing a low concentration of Fe in the solution from which the roots take up the metals. Iron uptake is inhibited by $FeOH_3$ formation, but plants have found ways to take up FeIII to overcome the precipitation effect in the root zone. Siderophores, which are microbially produced compounds [58] [59] [60] are among the strongest Fe-chelating agents that can increase and regulate the availability of oxidized form of Fe in microbial and plant cells. The Mn^{3+} can also act to some degree as replacement for Fe^{3+}. The MH_2O caused a depletion in Fe content in the root zone, may be a suggestive that siderophore production was inhibited or reduced. The same explanation can be used to explain the depletion of the content of Mn in the root zone irrigated with MH_2O. However, precipitation of Fe-Mn in the root zone will not explain the very large reduction in Zn which was more depleted than Fe in roots irrigated with MH_2O. Another explanation could be the increase in the root mass. This increase of root mass should require enzymes which have Zn, Fe and Cr as co factors since there are bacterial populations growing and utilizing more Zn, Fe and Cr than in the root zone of plants irrigated with ordinary water. These bacterial populations may have influenced both the growth of the plant and their chemical environment.

Among Alkali elements, only Na and K were enriched in leaves irrigated with MH_2O which could be due to the increase in stomata activity [61] [62] [63]. Unlike the increases in Na, and K, no change happened for Rb in leaves. The stomata openings are structural functions directed by proteins. Perhaps the same proteinaceous compounds acted to control the Rb contents in the leaf structures. The alkali elements in the roots all increased in their contents as a result of irrigation with MH_2O. The content of these elements in the roots were higher than those in the leaves. This relative increase in the roots, compare to that in the leaves for these elements may suggest that irrigation with MH_2O may have induced more vigorous growth of secondary roots. The K/Rb ratios of the roots were about 16% lower than those of the leaves. The higher ratios for the leaves may indicate an effect of more selectivity in uptake of K over Rb by the proteinaceous compound or compounds that control the stomata activity.

Of the four of Alkaline earth elements (Mg, Ca, Sr and Ba), the first two are essential nutrients for growth of plants and the other two are non-essential. Magnesium plays a role in the stability of all polyphosphatase enzymes in the cells [64] [65], including those associated with DNA, and RNA synthesis. The ATP (adenosine triphosphate), the main source of energy in cells, must be bound to a magnesium ion in order to be biologically active. In plants, Mg is necessary for synthesis of chlorophyll and photosynthesis. It is very involved in enzyme reactions.

Calcium is an essential plant nutrient. It is required for various structural roles in the cell wall and membranes, it is a counter-cation for inorganic and organic anions in the vacuole, and the cytosolic Ca^{2+}. Calcium is also important in root development and for cell division.

As it was stated above, the contents of Mg and Ca were depleted in the roots, but their contents were not significantly changed in the leaves. The depletion of these two elements in the root zone may indicate a precipitation of carbonate minerals from the rhizosphere solution. This precipitation might be possible by having a relatively more alkaline solution in the rhizosphere by irrigation with MH_2O. The percent of translocation of Mg and Ca to the leaves were higher for irrigation with MH_2O and this may suggest that Mg and Ca requirements were higher for the leaves which in term may be suggestive of higher structural development and higher energy efficiency conversion.

By comparison to plants irrigated with no MH_2O, the content of Sr and Ba were depleted in both leaves and roots irrigated with MH_2O.

Unlike the results of [66] who observed a depletion of P in leaves of Date Palm, the content of P in the leaves irrigated with MH_2O during this study showed an increase (slightly more than 63%) relative to leaves from plant control while the P contents differed by a very small amount between roots irrigated with MH_2O and roots from control plants (**Table 1**). The content of P in roots of control plant is higher than P contents in the leaves of control plant but for plants from MH_2O irrigated soil, roots and leaves have nearly the same content of P.

Having roots with similar P contents but different in leaves suggest that the higher need of P for leaves to grow under irrigation with MH_2O than P content of leaves grown in control conditions might indicate an important dephosphorylation in leaves due to MH_2O.

The total REE contents of all natural materials are determined very largely by the contents of the light REEs (LREEs), namely La to Sm. Leaves of plants irrigated with MH_2O (about 0.83 ppm) were lower in total REES than leaves of control plant (about 1.27 ppm). The same trend holds true for the roots between the two plants (3.37 ppm in plants irrigated with MH_2O versus 5.73 ppm in roots from plants grown in control conditions). The distribution patterns for the leaves of plants irrigated with MH_2O relative to leaves of control plant indicated an enrichment in Nd, while the roots for the MH_2O were found to be depleted in Ce and enriched in Pr with a depletion in Nd, Sm and Dy (**Figure 3**). The enrichment in Pr in roots is indicating that there is an enzyme accepting REEs and which structural configuration fits better for Pr than for the others. Another explanation could be that the negative anomaly in Ce between La and Pr and the rest of the other REEs could be an oxidation-reduction effect and the decrease in Nd, Sm and Dy could be an effect of phosphate precipitation. The enrichment in Nd in leaves irrigated with MH_2O is an indication of enzyme effect. It is also quite possible that Pr enzyme in roots is different from Nd enzyme of leaves.

Either for Pb or As, there is a decrease in their content (about 35% for both elements) in leaves irrigated with MH_2O (**Table 1**). The same trend concerns the roots irrigated with MH_2O where Pb and As were depleted (about 40%). These results show that both As and Pb don't represent any threat to leaves when the plants are irrigated with MH_2O.

Both Pb and As have no known biological function in plants. The depletion of both elements in roots is more important than in leaves relative to plants irrigated with ordinary water. Their depletion in leaves, may be due to either an increase of leaf mass during their growth or to an inactivation of complexation of As for its transport from roots to leaves. However, the irrigation with MH_2O induced more loss of As from roots than from leaves relative to plants irrigated with ordinary water. Such depletion may indicate on one hand that the soil solution might be depleted in As and on the other hand that a relatively small amount of As remained in the roots and larger amount was transported to the leaves.

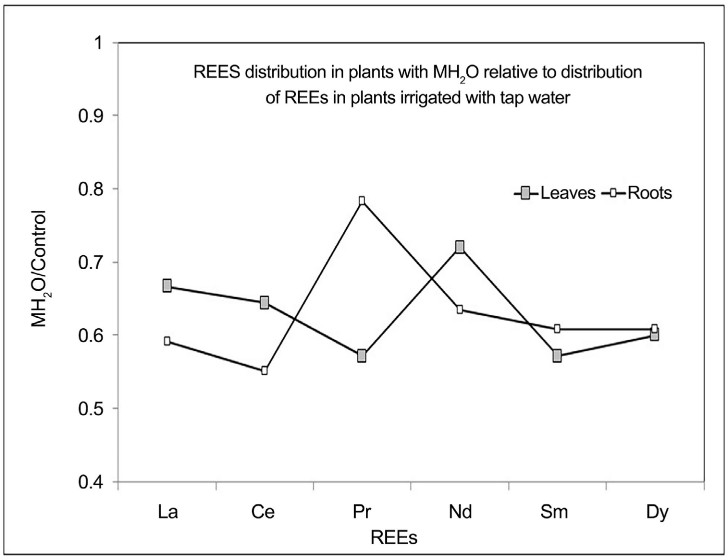

Figure 3. REEs distribution in plants irrigated with MH_2O relative to distribution of REEs in plant grown in control conditions.

Since oxyhydroxides carry several trace elements, the depletion of Fe and other heavy metals in the roots of plants irrigated with MH_2O may indicate a precipitation of such minerals in lack of siderophore. As it is known, the behaviour of Fe is often related to its valency (Fe^{2+} and Fe^{3+}) and may reflect oxidation-reduction effect. Apparently, irrigation with MH_2O created a reductive environment which helped either Fe or Mn to be mobile and washed from the rhizosphere and depleted in the root zone. Cerium which can exist as Ce^{3+} or Ce^{4+} according to the oxidation reduction conditions in the environment shows behaviours similar to Fe and Mn (**Table 1**) and supports such effect of MH_2O in rhizosphere.

As it was stated above, transfer of P and Al based on the ratio (leaf/Root) show the same behavior as Fe reflecting a gain in the leaves which are irrigated with MH_2O. Such interconnectivity between the three elements may indicate the association of these elements with Fe oxyhydroxides in the soil.

In summary, this study revealed that Pb, As, Ti, Sr, Ba and REEs decreased in both leaves and roots when plant is irrigated with MH_2O relative to the same plant with controlled irrigation (ie without magnetization). The content of Zn, Cu, K, and Na has been relatively increased in leaves while they decreased in the roots. The contents of Fe, Mn, Ni, V, Co, Rb, Al, Mg and Cr were not affected by MH_2O in leaves.

Effect of MH_2O on Selectivity of elements that are chemically similar

To determine the impact of MH_2O on plant selectivity in uptake of elements, causing element fractionations we compared elements that are chemically similar such as Sr with Ca, and K with Rb. We also evaluate the elemental selectivity with P and REEs.

The irrigation of soils with MH_2O induced a depletion in Sr in leave tissues relative to the control plant but did not affect the uptake of Ca which results in a depletion of Sr/Ca ratio (**Table 1**). In the opposite to Ca in the leaves irrigated with MH_2O, Ca in roots is more affected than Sr, which generated an increase in Sr/Ca ratio relative to roots of control conditions.

The irrigation of plants with MH_2O induced a selectivity in the uptake of K by leaves compared to Rb which remain similar to the leaves of control conditions. This selectivity results in an increase of K/Rb ratio in leaves (**Table 1**). In roots of plants irrigated with MH_2O mobility of K increased relative to that of K in control conditions and relative to Rb which mobility also increased because of MH_2O. The resulting K/Rb ratio is higher than K/Rb of plants in control conditions.

5. Conclusions

A major conclusion from this data is that magnetization not only enhances growth, but also:

- Causes relative enrichments in transition metals, P, Ca, Mg, Si and Al.
- Creates a reductive environment in the soil.

- Increases the mobility of Zn and Cu in plants collected from the soil irrigated with MH_2O.
- Activates enzymes with Zn or Cu as co factor more than the other enzymes.
- Reduces the translocation of Pb and As from roots to leaves in the soil irrigated with MH_2O.
- Affects microorganisms in soils which seems to inhibit creation of siderophore.

These results show that MH_2O application in irrigation of soils in arid and sub arid countries where water resources are reduced, may help to promote agriculture for an amelioration by increasing available elements.

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Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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