

RESPONSES OF PLANTS TO HYDRIC STRESS AND IRON OXIDE NANOPARTICLES

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Abstract

The tolerance of plants to hydric stress has become a global problem for sustainable agriculture. Nanotechnology is an emerging strategy designed to eliminate the awful effects of food shortage, heavy metal contamination and other abiotic stresses. Some studies show that iron oxide nanoparticles play a proficient role in stimulation of the growth, development, and enhancement of the stress tolerance of plants and the provision of nutrients. But there are studies that show the toxic effect of artificial nanoparticles on plants or ingested by animals. This study aims to provide new experimental data for clarifying the question of the positive or harmful impacts of magnetic iron oxide solution on plant growth in relationship with hydric stress. Our results have shown that the effect of iron oxide solutions on crop plants depends on how they are applied. In the case of ground application, there was a negative effect on the plant height and the leaf area meanwhile the sprays directly on the leaves (foliar application) had a positive effect on height of plants and leaf area. Under water stress conditions, the concentrated iron oxide solution had a negative effect on the leaf area, but dilute solutions had a positive effect on this trait. In both cases (ground and foliar applications), iron oxide treatments have diminished the negative effect of hydric stress. On the basis of these results it is highly recommended that the influence of low dose of iron nanoparticles (foliar applications) be used in order to stimulate seedling growth and increasing the water stress tolerance.

Key words: maize, iron oxide nanoparticles, hydric stress, height of plants, leaf area, length of root, dry matter

1. INTRODUCTION

Plants are an essential component in ecological systems and may serve as a potential pathway for nanoparticles transport into the food chain and a route for bioaccumulation in higher organisms. Many of the reported studies in the literature are focused on silver (Ag) and titanium oxide (TiO₂) nanoparticles because of their extensive use in food packing and cosmetics (Bombin et al., 2015). Iron oxide nanoparticles are widely used in biomedicine for drug delivery and in magnetic resonance imaging (Carredor et al., 2009). These nanoparticles are also widely used for a variety of other applications, such as soil and ground water treatments (Namedo et al., 2008) and photocatalytic reactions (Shipley et al., 2011).

Iron oxide nanoparticles are also generated from the oxidation of zero-valence iron nanoparticles, which have been used for environmental remediations (Chen et al., 2008), with more than 50 commercial sites in the United States (Zhang W. X., 2003). To reduce the negative (toxic) impact of iron oxide nanoparticles and to increase the positive effect on plant development (Wang et al., 2011), the magnetic solutions and the iron concentration in these solutions should be optimized.

Most of the current published studies regarding nanoparticles and plants are centered around the effects of this on seed germination and vegetative plant growth.

Depending on the types of nanoparticles and the plant species under study, both positive and negative effects have been reported (Bondarenko et al., 2013, Nair et al., 2012).

In this study we have investigated the effects of iron oxide nanoparticles on vegetative growth in maize plants under optimal and hydric stress conditions.

2. MATERIAL AND METHODS

2.1. Material

Seeds of maize were shown in pots filled with a soil-sand mixture (3:1). In this study we used a magnetic solution obtained by National Institute of Materials Physics in order to be used as a fertilizer for plants. The precursors used to obtain the magnetic solution were ferric chloride and ferrous chloride. A solution of ferrous chloride tetrahydrate was mixed with a solution of ferric chloride hexahydrate at 90°C. The ratio of the iron ions of the final solution was $\text{Fe}^{2+}/\text{Fe}^{3+} = 1/2$. The attainment of the iron oxide nanoparticles based on the co-precipitation method was performed starting from Massart's method.

2.2. Stress induction

The optimal soil volumetric water content, corresponding to 70% from field water capacity of soil, was maintained by daily irrigation (watering). Hydric stress treatment were imposed at two leave stage of maize by maintaining soil moisture at 40% from field water capacity of soil (the soil used was chambic cernozem).

2.3. Experimental treatments

The treated variants were: pots which were watering with tap water (water), pots watering with concentrated solution of iron oxides (T1), pots watering with 1% iron oxides solution (T2) and pots watering with 1‰ iron oxides solution (T3).

The treatments were applied at soil and on the plants by spaying.

2.4. Analyses

The height of plant (mm), leaf area (cm²), main root length (mm) and dry matter (g) were determined.

3. RESULTS

3.1. Treatments with iron oxide solution applied to the soil (ground applications)

The analyses of variance for the height of plants indicated a significant effect of treatments, level of soil moisture and interaction of these factors at the 0.1% level of significance, (Table 1).

Table 1. Analyses of variance for height of plants

Source of variance	DF	Sum of squares	Mean square	<i>F value and significance</i>
Factor A (treatments)	3	17512	5737	40.40***
Error A	6	851.91	141.9	
Factor B (soil moisture)	1	84728.17	84728	358.82***
Interaction AxB	3	12124.8	4041.6	17.11***
Error B	8	1889	236.12	

In the case of plants grown under optimum soil moisture (control), the height of plant was 672 mm, while for the fertilized plants with iron oxide concentrated solution was 540 mm respectively 570 mm and 600 mm for iron oxide diluted solutions (T2 and T3).

What is noteworthy is that differences registered under hydric stress conditions are not as obvious as in the case of the optimum moisture of soil, (Figure 1).

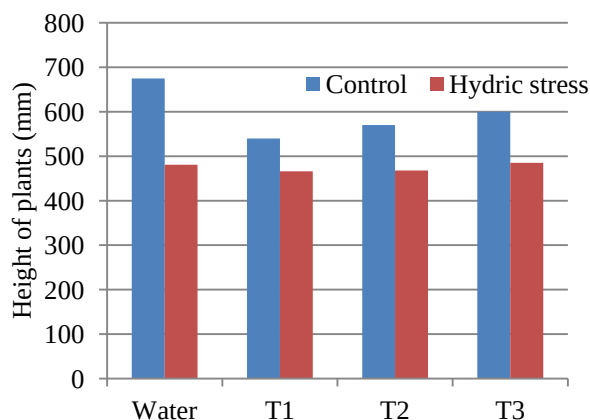


Fig. 1. The effect of iron oxide solutions and soil moisture on height of maize plants. Ground treatments (T1 = concentrated iron oxide solution, T2 = dilution 1% and T3 = dilution 1 ‰)

The results of the analysis of variance showed that the leaf area of maize plants was affected by the iron oxide solutions, soil moisture, as well as by interactions between these factors and these influences were statistically very significant (Table 2).

Table 2. Analyses of variance for leaf area

Source of variance	DF	Sum of squares	Mean square	<i>F value and significance</i>
Factor A (treatments)	3	56474.13	18824.71	57.16***
Error A	6	1976	329.33	
Factor B (soil moisture)	1	1275587	1275587	2650***
Interaction AxB	3	42052.46	14017.49	29.12***
Error B	8	3850	481.12	

The largest effect was due to soil moisture, which was the main source of variation, the difference between the leaf area registered under optimum soil moisture conditions, averaged across treatments, being of 1200 mm² in case of water use and between 948-1125 mm² for treatments with iron oxide solution. Under hydric stress conditions it was not significantly differences concerning the leaf area of maize plants, average across treatments, being of 637 mm² in case of treatment with water and between 618-630 mm² for treatments with iron oxide solution (Figure 2).

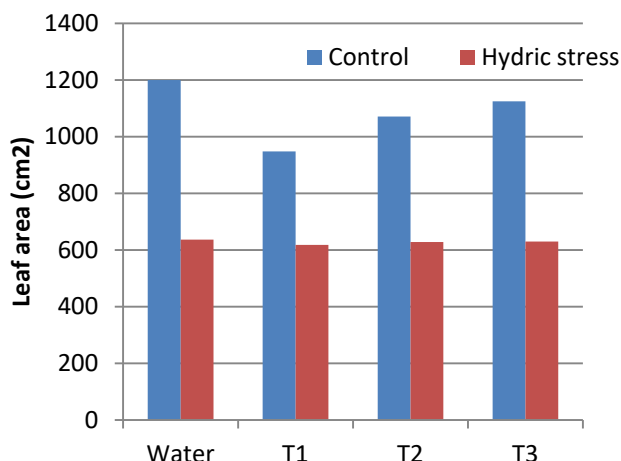


Fig. 2. The effect of iron oxide solutions and soil moisture on leaf area. Ground treatments (T1 = concentrated iron oxide solution, T2 = dilution 1% and T3 = dilution 1 ‰)

The results obtained for maize plants grown in optimal and hydric stress and treated with different iron oxide solutions (concentrated and diluted) showed that main root length of the plants was less influenced by the concentration of iron used in the fertilizing solutions than the height of plants (Table 3). Even following the fertilization at maximum iron concentration, growth process differences between root length of fertilized plants and control plants were insignificant. In the case of control plants, the main root length was 362 mm, while for the fertilized plants with iron oxide concentrated solutions was 348 mm. On the other hand, a positive effect on the plant dry matter content was observed for both plants fertilized with iron oxide concentrated solution and the ones fertilized with iron oxide diluted solution (Table 3). The highest content of dry matter per plant was obtained in the case of plants fertilized with concentrated iron oxide solution (0.51 g/plant). Plants fertilized with diluted iron oxide solution had a dry matter content per plant of 0.5 g/plant in no stressed conditions and 0.39 g/plant under hydric stress conditions. Control plants had a dry matter content of 0.43 g/plant in no stressed conditions and 0.32 g/plant under hydric stress conditions.

Table 3. The effect of treatments with iron oxide solutions and hydric stress on root (length and dry matter)

Treatments	Soil moisture	Length of root (mm)	% from control	Dry matter (g/plant)	% from control
Water	Control	362	100	0.43	100
	Hydric stress	325	89.8	0.32	74.4
T1	Control	348	100	0.51	100
	Hydric stress	320	91.9	0.39	76.4
T2	Control	359	100	0.5	100
	Hydric stress	320	89.2	0.38	76.1
T3	Control	362	100	0.51	100
	Hydric stress	325	89.7	0.39	76.4

The negative effect of water stress on main root length and accumulation of dry matter was more evident when using water than iron oxide solutions. Following these observations, we can say that fertilization with iron oxide solutions (concentrated and diluted) led to the development of new adventitious roots, which helped the new plants have a better absorption of water and nutrients.

3.2. Treatments with iron oxide solution applied to the plants (foliar applications)

The results of the analysis of variance showed that the height of plants was affected by the iron oxide solutions, soil moisture, as well as by interactions between these factors and these influences were statistically very significant (Table 4).

Table 4. Analyses of variance for height of plants

Source of variance	DF	Sum of squares	Mean square	<i>F value and significance</i>
Factor A (treatments)	3	1048.12	349.3	16.93***
Error A	6	123.75	20.6	
Factor B (soil moisture)	1	234.37	234.37	19.32***
Interaction AxB	3	1960.12	653.37	53.88***
Error B	8	97	12.12	

It is noted that in the case of foliar treatments, we have a relatively small positive effect in case of fertilization with diluted iron oxide solution (1 % dilution) (figure 3).

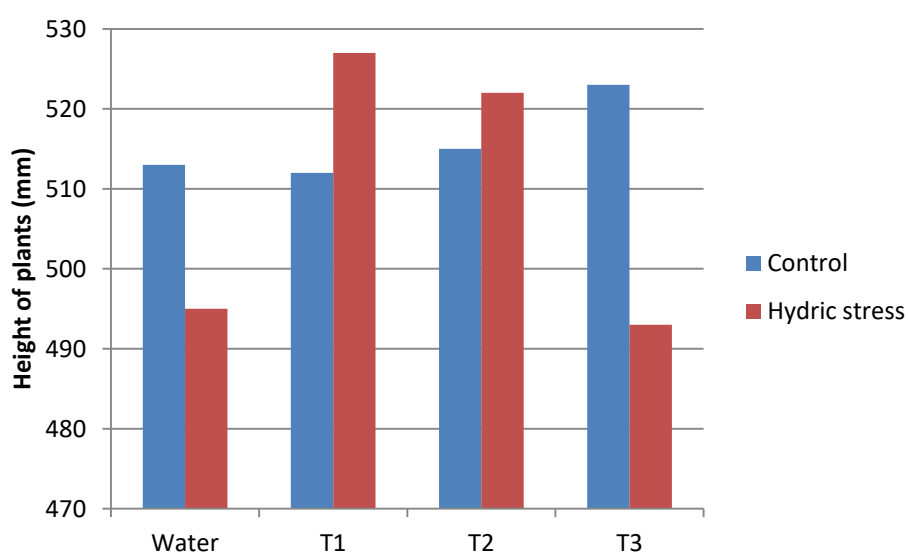


Fig. 3. The effect of iron oxide solutions and soil moisture on height of maize plants. Plant treatments - spraying (T1 = concentrated iron oxide solution, T2 = dilution 1% and T3 = dilution 1 %)

In case of hydric stress (soil moisture was maintained at 40% from the soil water capacity, which means severe water stress), treatment with iron oxides had a beneficial effect on height of plants, the recorded values being superior to the control. This is all the more evident as with the very low concentration of oxides of iron (dilution 1 %), the values were comparable to the control (493 and 495 mm respectively) (Figure 3).

The leaf area was also positively influenced by iron oxide treatments (Table 4). It was observed that for optimal conditions, the largest effect on the foliar surface was registered for diluted 1‰ solution (T3), followed by T1 and then by T2. Under water stress conditions, the concentrated iron oxide solution had a negative effect on the leaf area, but iron oxide dilute solutions had a positive effect on this trait (Table 5).

Table 5. Effect of water stress and iron oxide treatment on leaf area

Variants	Optimum soil moisture	% from control	Hydric stress	% from control
Water	977	100	816	100
T1 - concentrated iron oxide solution	1223	125	658	81
T2 - diluted iron oxide solution, 1‰	1053	108	1123	138
T3 - diluted iron oxide solution, 1‰	1517	155	875	107

Table 6. Analyses of variance for main root length and dry matter

Source of variance	DF	<i>F value and significance for main root length</i>	<i>F value and significance for dry matter</i>
Factor A (treatments)	3	0.55	0.89
Error A	6		
Factor B (soil moisture)	1	41.77***	1.08
Interaction AxB	3	0.05	1.00
Error B	8		

The results of the analysis of variance for main root length showed that the source of variability for this is only soil moisture, treatments with iron oxide as well as the interactions between these factors have not a significant influence while for dry matter all analyzed factors had an insignificant influence (Table 6).

4. DISCUSSION

In this study we have shown that if the iron oxide treatments were applied to the soil, there was a reduction in the height of the maize plants and leaf area, too. This reduction was generally proportional to the concentration of the iron solution. Similar study was performed by Arruda et al., (2015) and evidentiates that iron nanoparticles reduced the length of *Arabidopsis thaliana* seedlings by about 20% on average. The reduction in root hydraulic conductivity of *Helianthus annuus* treated with Fe₂O₃ nanoparticles was observed by Martínez-Fernández et al., (2015). An assessment showed that low concentrations of aqueous ferrofluid stimulated maize (*Zea mays*) plant growth whilst high concentrations induced inhibitory or toxic effects (Racuciua and Creanga, 2007). Lee et al., (2012) reported that the seedling growth of *Phaseolus radiatus* and *Sorghum bicolor* was adversely affected by exposure to silver nanoparticles.

On contrary if the application is made foliar the effects are generally positive. In this sense are many arguments, starting with the fact that iron is one of the essential nutrients for plant growth and is the cofactor of various enzymes that speed up plant growth and development processes (Feizi et al., 2012). Therefore augmented seedling, root, and shoot growth was obtained by the use of iron oxide nanoparticles in appropriate concentrations (10–40 mg/L) for mungbean, rice, cucumber, and wheat (Sarvendra-Kumar et al., 2015). Similar results showing increased growth and development of seedlings, root, and shoot of *Arabidopsis thaliana* because of the stimulation of cell wall loosening were also reported by Kim et al. (2014). Studies revealed that the effect of iron oxide nanoparticles is

more obvious for seedlings, shoots, and growth because of the easy uptake and transfer mechanism of these particles via root cells. Thus researchers found a supportive role of iron oxide nanoparticles for the improvement of growth pattern because of the growth-stimulating effect of iron when applied within a specific range of concentrations (Bombin et al., 2015).

5. CONCLUSIONS

The laboratory study was conducted to determine the phytotoxicity and or stimulatory effect of iron oxide nanoparticles on maize under optimum soil moisture and hydric stress conditions. Another goal was to compare and determine the suitable concentrations of these treatments. These treatments enhanced vegetative growth if they were applied foliar. Application of iron oxide nanoparticle to soil reduced height of plant, leaf area in comparison to the untreated control but nanoparticles in low concentrations significantly improved root length and weight. Nevertheless, on the basis of these results it is highly recommended that the influence of low dose nanomaterial be used in order to encourage seedling growth and increasing the water stress tolerance.

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