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Assessing the Effectiveness of Zn Acetate and Oxide as Alternatives for Corn and Soybean Seed Treatment in Sandy and Clay Soil

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Abstract

Zinc (Zn) is the micronutrient with the lowest availability in agricultural soils, and consequently 50 % of the world's soils present Zn deficient. To test the viability of alternative Zn sources (Zn acetate and Zn oxide) to corn and soybean seed treatments, we ran an experiment using these two alternatives at contrasting application rates (0; 0.25; 0.50; 0.76 and 1.01 g kg^{-1}) applied to soybean and corn seeds that were subsequently sowed in sandy and clay soils. We measured: Zn accumulation, dry matter and germination, and analyzed this data using uni (LSD-test) and multivariate analysis (Principal Component Analysis, PCA). Results of the PCA showed that the sandy soil yielded higher dry matter and Zn accumulation than the clay soil. The corn provided higher dry matter while the soybean showed enhanced Zn accumulation and germination. The LSD test showed that corn presented positive Zn accumulation in response to Zn rates in both sandy and clay soil. For soybeans, this effect was only observed in sandy soil, while the clay soil presented decreases in dry matter and germination due to Zn rates. Overall, our findings reveal that both Zn acetate and Zn oxide are viable alternatives for supplying Zn to corn seed treatment in sandy and clay soil, and to soybean seed treatment in sandy soil. We suggest that more research should be undertaken to understand the response of soybean seed treatments to Zn supply, especially in clay soil.

Keywords: plant Zn accumulation, plant emergence, soil textures, zinc sources, zinc rates

1. Introduction

Zinc (Zn) is widely considered to be the micronutrient with the lowest availability in agricultural soils (Alloway, 2011), and consequently, 50 % of the world's agricultural soils have been classified as Zn low level (Fageria et al., 2002). Under normal conditions, Zn is found within the soil superficies due to its low mobility and strong relationship with organic matter (Dechen & Nachtigall, 2006) and clay present in the soil (Alloway, 2011).

With respect to plant metabolism, Zn plays an essential role in nitrogen metabolism (Faquin, 2005), and enzymatic activation (Dechen & Nachtigall, 2006; Nonogaki et al., 2010), which are in turn strongly related to crop development and the resulting productivity of grain and cereal crops (Fageria et al., 2002), and the Zn causes decrease in radicular development.

Zn fertilization of plants can be performed through direct addition to soils, or application to seeds and leaves. Soil Zn fertilization has been shown to enhance corn, *Zea mays* L. (Pereira et al., 1973; Galrão, 1996) and soybean (*Glycine max* L. Merril) productivity (Sousa et al., 1993). On the other hand, Zn fertilization of seeds has been shown to improve crop productivity, seed germination and plant growth (Nonogaki et al., 2010), which presents advantages in terms of application uniformity and small rates with precision (Lopes & Souza, 2001), and can be considered the best alternative to Zn fertilization (Boneccarrére et al., 2004; Ribeiro et al., 1994). However, the seed treatment efficiency should be tested according to the seed characteristics, Zn application rates and sources.

The main Zn sources used to seed treatments are Zn oxide and Zn sulfate (Galrão, 1996). According to Prado et al. (2007), Zn oxide is a more efficient means of increasing early corn growth compared to Zn sulfate. To date however, there have been no studies testing the potential for Zn acetate to be used as an alternative to seed treatments. Therefore, the aim of this study was to test the hypotheses that there would be no significant difference in the potential for Zn acetate and oxide to be viable alternatives for Zn supply to corn and soybean seed treatment. We ran an experiment using these two contrasting Zn sources at different application rates on soybean and corn seeds planted in sandy and clay soil.

2. Method

2.1 Study Site & Growing Conditions

Greenhouse experiments were conducted at the Soil Science Department, University of São Paulo/USP, Piracicaba, Brazil. The studies were conducted from, during May to June in 2016 (Figure 1). The experimental design involved a completely randomized block in four replications. Two Zn sources (Zinc acetate and zinc oxide) were tested and five Zn rates (0; 0.25; 0.51; 0.76; and 1.01 g kg^{-1}), were applied to corn and soybean seeds in clay and sandy soil, making a total of 40 treatments for corn as well as soybean.

Figure 1. Set of both soybean and corn using clay and sandy soils in the greenhouse

The clay and sandy soils were collected from a sugarcane area located in São Paulo state, with material taken from the top 0.2 m of the soil surface, at four different positions within an area of 1 hectare. Prior to installation of experiment, the soil samples were analyzed in the laboratory for soil chemical properties (Organic matter-OM; Phosphorus-P; Sulfur-S; Calcium-Ca; Magnesium-Mg; Potassium-K; Aluminum-Al; Hydrogen+Aluminum-H+Al; Sum of bases-SB; Cation exchange capacity-CEC; Boron: B; Copper: Cu; Iron: Fe; Manganese: Mn; Zinc: Zn) following Raij et al. (2001), and for physical analysis following Camargo et al. (1986), as shown in Table 1.

The initial chemical characterization of Zn oxide and Zn acetate was done according to the methods of MAPA (2004), following contents, respectively: Zn: 40.0 and 8.5%; N: 1.0 and 5.0%; and density 1.7 and 1.2 g mL^{-1}. Moreover, Zn acetate was also characterized using measures of electrical conductivity (2.2 mS cm^{-1}); saline index (23.4 mS cm^{-1}); arsenic-As (0.4 mg L^{-1}); cadmium-Cd (0.1 mg L^{-1}); chrome-Cr (< 0.1 mg L^{-1}); and mercury-Hg concentration (< 0.1 mg L^{-1}). The electrical conductivity values and Saline index were considered appropriate according to the MAPA normative instructions (No. 05 of 23/02/2007), and heavy metal concentrations were low when compared to the maximum permitted values (As: 10.0; Cd: 20.0; Cr: 200.0; Hg: 0.2 mg kg^{-1}) described by the MAPA normative instructions (No. 53 of 10/24/2013).

Table 1. Soil chemical and physical characterization and seed characterization

Soil chemical and physical characterization[1]

Soils	pH	OM	P	S	Ca	Mg	K	Al	H+Al
		g dm^{-3}	mg dm^{-3}	mmol$_c$ dm^{-3}					
Sandy	4.9	5.0	4.3	6.1	4.1	2.1	1.1	1.0	22.0
Clay	4.5	16.9	6.1	63.1	8.0	2.0	0.5	3.0	64.0

	SB	CEC	V	B	Cu	Fe	Mn	Zn	Sand	Silt	Clay
	mmol$_c$ dm^{-3}		%	mg dm^{-3}					g kg^{-1}		
Sandy	7.3	29	24	0.26	< 0.4	7.0	< 0.5	0.1	872	29	99
Clay	10.5	75	14	0.35	0.6	5.0	0.8	0.2	220	181	599

Seed characterization

Seeds	Protein[2]	Lipid[2]	Carbohydrates[2]	Storage structure[2]	Phytic acid[3]
	%				g 100g^{-1}
Soybean	37	17	26	Endosperm	1.2-1.7
Corn	10	05	80	Embryo	0.8-1.1

Note. [1] Organic matter-OM; Phosphorus-P; Sulfur-S; Calcium-Ca; Magnesium-Mg; Potassium-K; Aluminum-Al; Hydrogen+Aluminum-H+Al; Sum of bases-SB; Cation exchange capacity-CEC; Boron: B; Copper: Cu; Iron: Fe; Manganese: Mn; Zinc: Zn. [2] Marcos Filho (2005); [3] Hídvégi and Lásztity (2002).

2.2 Experiment Installation

In the greenhouse facility, the sandy and clay soils were prepared using the rate of 1.99 and 6.26 g pot^{-1} calcium carbonate, and 0.85 and 2.68 g pot^{-1} magnesium carbonate, respectively, of according of soil tests to achieve 60% of base saturation. Prior to being incubated, samples were maintained at 70% of the field capacity for two weeks, aiming the time reaction. After this period, fertilizers (5.1 mg kg^{-1} of urea, 100 mg kg^{-1} of Mono-Ammonium-Phosphate and 50 mg kg^{-1} of Potassium sulfate) were broadcast evenly across the soils and mixed thoroughly. Micronutrients were also provided during planting in the form of 0.2; 5.0; 3.0; 0.1; and 1.5 mg kg^{-1} of Boric acid, EDTA Iron, Manganese oxide, Ammonium molybdate and Copper sulfate, respectively, according to plant needs and soil test (Table 1).

Posteriorly, pots were filled with soil (4.5 kg soil pot^{-1}, total volume of 4.3 L). Zn acetate and oxide application rates were prepared by dissolving the appropriate volumes of material in deionized water and applied at soybean (Cultivar TMG 1168 RR) and corn seeds (Hybrid 2B810PW). Six seeds were planted in every pot at a depth of 3 centimeters.

Fifteen days after sowing, seedlings were thinned two plants per pot and another application of fertilizer was performed via nutrient solution containing 12.5; 12.5; 18.7 and 0.1 mg kg^{-1} of Urea, MAP, Potassium chlorate and boric acid, respectively. Throughout the experiment, plants were irrigated every day with deionized water and humidity was maintained at about 60 % of the soil field capacity.

2.3 Parameters Measured and Data Analysis

On the 8th and 13th day after sowing, the number of emerging plants were counted to check the seed germination (GD) per pot, using the physiological criterion of protrusion ($\geq$ 5 mm), of the first visible structure. The dry biomass production of the aerial part was collected on the 30th day after sowing (V6-V8 corn stage and R6 soybean stage), dried to a constant weight at 75±2 °C and weighed. Dry biomass samples were used to determine the plant zinc accumulation as described in Malavolta et al. (1997), with the value (Zn concentration) multiplied by the aerial dry biomass to obtain the total zinc accumulated.

The descriptive statistics assessed included: the mean, standard deviation, minimum and maximum values. The assumptions of normality were evaluated using the Shapiro-Wilk test and outliers were identified by the Grubbs' test (Grubbs, 1969) and homogeneity of variance was assessed using the Bartlett test.

We used Principal Component Analysis (PCA) to identify variation between soil textures and plant species using the variables: dry matter, zinc accumulation, 8th and the 13th germination day after sowing. Therefore, initially, the date group was standardized to obtain a zero mean and constant variance (Sneath & Sokal, 1973), and a Euclidean matrix was calculated (Manly, 2008) using the Ward algorithm to group similar data points (Hair et al., 2010). The Principal Component (CP) with eigenvalues greater than 1, was used because it provides relevant information about the original variables (Kaiser, 2002). The results of the PCA were presented separately as Bi-plots for each soil texture and plant species to identify the groupings of information.

The results were assessed using analysis of variance (ANOVA) based on the F-test statistic. Where the F-test was significant at the level of $p \leq 0.1$, the qualitative parameters (Zn Sources, Soil textures and plant species) were compared using LSD-test, while the quantitative parameter (Zn rates) was analyzed through regression analysis ($p \leq 0.1$).

3. Results

3.1 Soil Texture and Plant Species

PCA was able to identify differences between the soils through the formation of two distinct groups (Figure 2), with the main difference observed for dry matter and Zn accumulation in sandy soil, which provided a significant increase of 50 % and 70 % compared to clay soil (Table 2). On the other hand, soil texture did not influence seed germination counts on the 8th and 13th day, as evidenced in the biplots by the overlapping vectors for the 8th and 13th GD (Table 2).

Corn and soybean also formed two distinct groups (Figure 2). The dry matter vector was closer and higher to corn with a mean of 1.4 g pot^{-1}, and an increment of 35 % compared to soybean. On the other hand, soybean presented higher germination counts on both the 8th and 13th day, with vectors closer in the bi-plot (Figure 2) and a significant difference, representing an increase of 47 % compared to corn (Table 2).

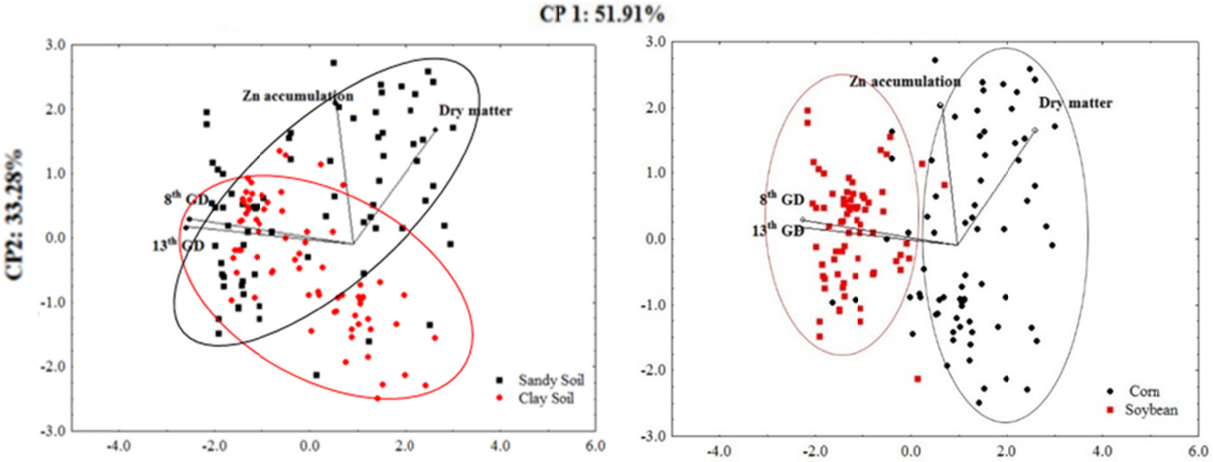

Figure 2. Principal Component Analysis (PCA) for the soil textures (Clay and Sandy soil) and plant species (Corn and Soybean) using the variables: Dry matter, Zn accumulation, 8th and 13th germination day

As expected, the correlation between dry matter and Zn accumulation was high ($r = 0.35$; $p < 0.0.5$), also represented on bi-plot with the same direction of the vectors and being clearly evident the positive effect of Zn accumulation on plant development. The variance concentration was fixed along the axis CP1, which explained 51.9 % of the variance, followed by CP2 with 33.2 %, and these components together accounted for 74.2 % of the total variance.

Table 2. Correlation coefficients of the principal components (CP1 and CP2), dry matter, Zn accumulation (Zn Acc.), 8th and 13th germination day - GD (%)

Variables	Factor[1]		Soils[2]			Species[2]		
	CP1	CP2	Sandy	Clay	p Value	Corn	Soybean	p Value
Dry Matter g pot^{-1}	0.4	0.7	1.9A	0.9B	p <0.01	1.4A	0.9B	p<0.01
Zn Acc. ($\mu\text{g pot}^{-1}$)	-0.1	0.8	38.2A	11.5B	p<0.01	24.4B	30.5A	p: 0.01
8th GD (%)	-0.9	0.1	0.4A	0.4A	p: 0.82	0.4B	0.9A	p<0.01
13th GD (%)	-0.9	0.1	0.4A	0.5A	p: 0.70	0.5B	0.9A	p<0.01

Note. [1]: Factor coordinates, of the variables, based on correlations obtained by CP. [2]: Means followed by a distinct letter differ between soil textures and plant species by the LSD's test ($p \leq 0.1$).

3.2 Zinc Rates

For sandy soil, the effect of Zn application rates on Zn accumulation by soybean plants fitted a linear response curve ($R^2 = 88.5$ %; $P < 0.01$), as did corn plants (R2 = 81.7 %; $P < 0.01$), Table 3 and Figure 3.

Table 3. Mean estimates of dry matter (DM), Zn accumulation (Zn Accu.), 8th and 13th germination day (GD) for corn and soybean seeds in sandy soil

Rates	Soybean				Corn			
	Zn Accu.	DM	8th GD	13th GD	Zn Accu.	DM	8th GD	13th GD
g kg^{-1}	µg pot^{-1}	g pot^{-1}	----------- % -----------		µg pot^{-1}	g pot^{-1}	----------- % -----------	
0	16.7	0.4	83.2	91.7	27.0	1.6	50.0	50.0
0.25	29.4	0.5	89.3	100.0	29.6	1.8	43.8	43.7
0.51	42.2	0.4	93.6	93.6	47.6	1.8	52.0	52.0
0.76	49.0	0.5	87.3	93.6	53.1	2.1	43.0	49.8
1.01	48.1	0.4	81.3	93.6	50.1	2.0	35.3	41.7
p_{rate}	<0.01[1]	0.65	0.59	0.55	0.01[1]	0.28	0.38	0.76
p_{source}	0.17	0.50	0.87	0.43	0.20	0.78	0.78	0.86
$p_{inter.}$	0.70	0.43	0.71	0.92	0.49	0.45	0.92	0.98

Note. [1]: p values < 0.1, means significant regression using the liner model adjust.

Furthermore, in sandy soil the control treatments provided the lowest Zn accumulation by plants with the decrease of 43 % and 9 % compared to the smallest Zn rate tested, respectively for soybean and corn plants. The effect of Zn application rate was not significant for estimates of dry matter weight or germination counts. For all tested variables, there was no significant interaction between Zn rates and sources (Table 3).

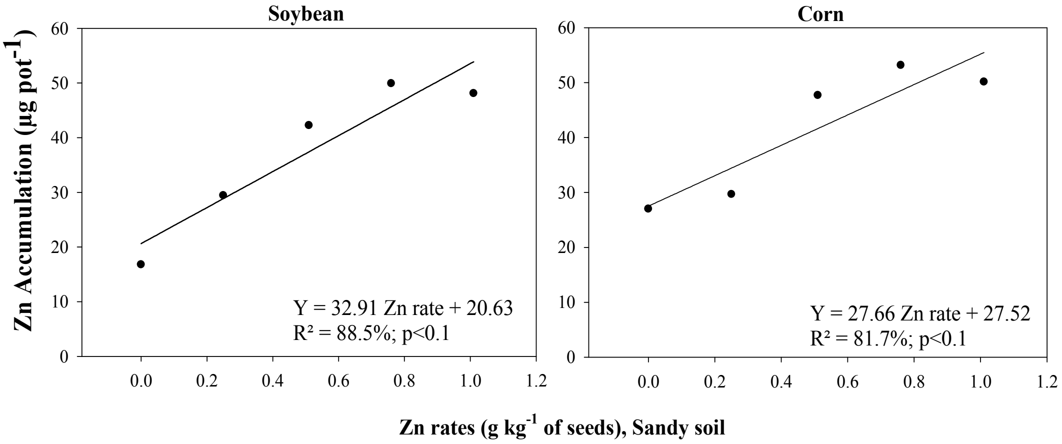

Figure 3. The effect of Zn rate on Zn accumulation (µg pot^{-1}) for corn and soybean seeds in sandy soil

In clay soil, the effect of varying Zn application rate on soybean seeds fitted a negative quadratic response curve for dry matter ($R^2 = 95.1$ %; $P < 0.01$), and for the 8th ($R^2 = 95.7$ %; $P < 0.01$) and 13th ($R^2 = 40.3$ %; $P < 0.01$) germination day (Table 4 and Figure 4).

In other words, the control treatment yielded 100 % germination and dry matter estimates that were 23 % higher, while there was no significant effect observed for corn seeds. Both types of seed, presented distinct characteristics, with corn having a high amount of carbohydrates, while soybean comprised of high protein, lipid and phytic acid concentrations (Table 1).

Table 4. Summary of dry matter (DM), Zn accumulation (Zn Acc.), 8th and 13th GD for corn and soybean seeds treated with Zn Acetate (Zn Ac) and Zn oxide (Zn Ox.) in Clay soil

Rates	Soybean				Corn					
	Zn Acc.	DM	8 th	13th	Zn Acc.		DM		8th	13th
					Zn Ac	Zn Ox	Zn Ac	Zn Ox		
g kg^{-1}	µg pot^{-1}	g pot^{-1}	------- % -------		----- µg pot^{-1} -----		------ g pot^{-1} ------		------- % -------	
0	24.4	1.6	100.0	100.0	6.2	6.2	0.6	0.6	41.7	50.2
0.25	23.5	1.4	89.5	97.8	11.8	9.5	1.1	0.9	52.0	56.2
0.51	25.7	1.1	79.2	89.3	12.1	6.6	1.1	0.6	54.1	60.5
0.76	32.8	1.1	83.2	97.8	12.5	13.2	0.9	0.9	39.5	48.0
1.01	33.4	1.3	87.5	91.6	10.7	18.9	0.8	1.1	52.8	63.2
p_{rate}	0.29	0.08^2	0.05^2	0.05^2	<0.01^{1,2}		0.10^2		0.40	0.49
p_{source}	0.36	0.48	0.33	0.32	0.84		0.51		0.36	0.54
$p_{inter.}$	0.29	0.95	0.52	0.58	<0.01		0.08		0.29	0.42

Note. ^{1}: p values < 0.1, indicates a significant regression using the liner model; ^{2}: quadratic model.

Additionally, in clay soil corn seeds presented a positive interaction between Zn sources and application rates with respect to Zn accumulation and dry matter content (Table 4 and Figure 4). Zn acetate provided an average increase of 7.6 % and 8.9 % in Zn accumulation and Dry matter when compared to Zn oxide.

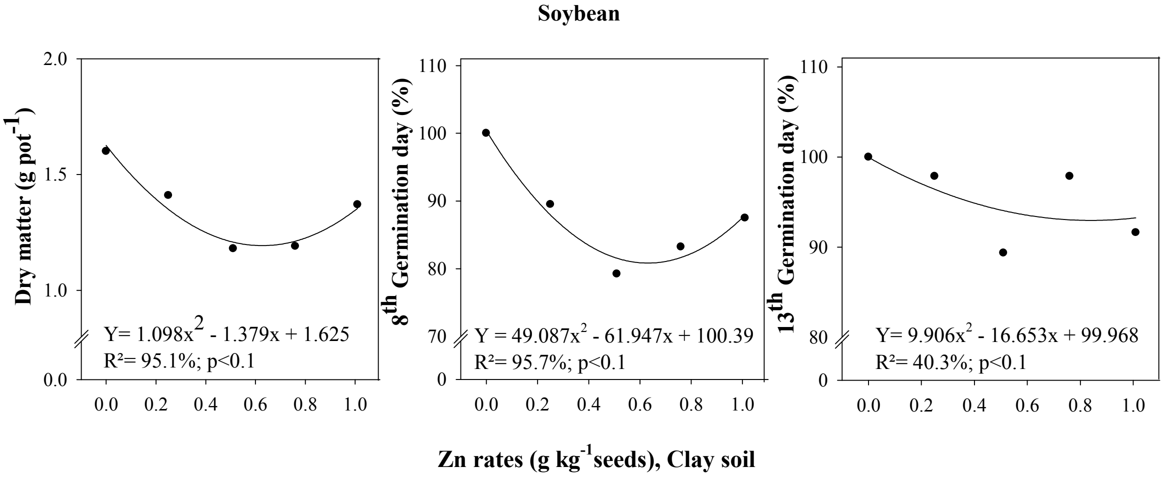

Figure 4. The effect of Zn application rates on dry matter content (g pot^{-1}), 8th and 13th germination day for soybean seeds in Clay soil

For Zn oxide, a positive curve described the relationship between application rate and both Zn accumulation (Linear, R^2 = 76.3 %; $P < 0.01$) and dry matter (Quadratic, R^2 = 66.3 %; $P < 0.01$). While, for Zn acetate it was possible to fit a quadratic response curve to describe Zn accumulation (R^2 = 92.7 %; $P < 0.01$), and dry matter (R^2 = 83.9 %; $P < 0.01$), with increment by the rate of 0.6 and 0.5 g kg^{-1} seeds (Table 4 and Figure 5). According to these trends, it was possible to recommend a Zn oxide application rate of 1.0 g kg^{-1}, and a Zn acetate application rate of 0.5-0.6 g kg^{-1} to obtain the highest Zn accumulation and dry matter for corn seed treatments.

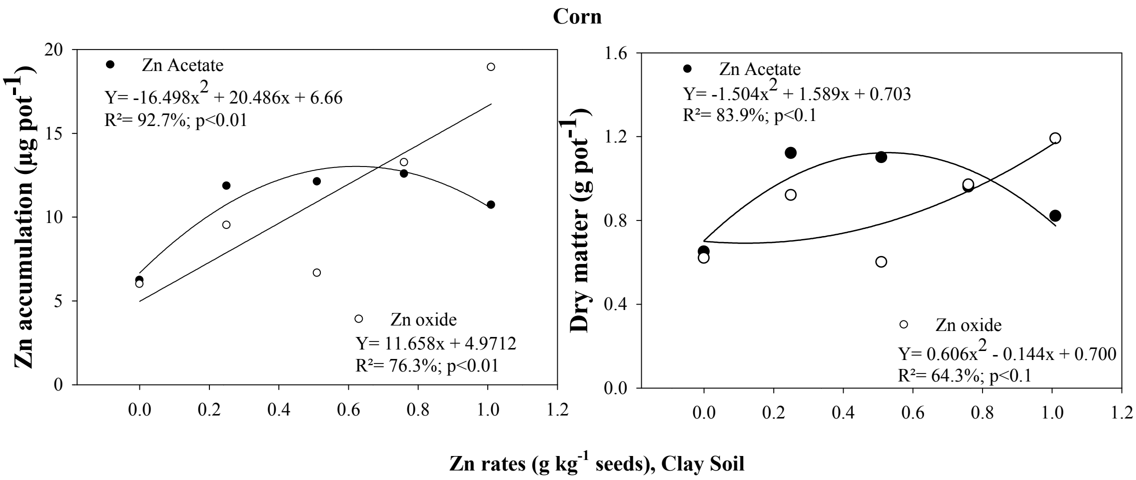

Figure 5. The effect of Zn application rate on Zn accumulation (µg pot^{-1}) and dry matter (g pot^{-1}) of corn seeds treated with Zn acetate and oxide at clay soil

3.3 Zinc Sources

When applied as alternative sources of fertilizer for corn and soybean seed treatments, Zn acetate and Zn oxide showed no significant differences in dry matter yield or Zn accumulation (Figure 6). The overall lack of difference between these different sources can be observed for both crop, with the exception of the Zn accumulation difference of 0.4 and 0.1 µg pot^{-1} between Zinc acetate and oxide for corn plants, respectively cultivated in clay and sandy soil, as well as the small difference of 3.5 and 8.5 µg pot^{-1} for soybean plants. It is worth pointing out that dry matter estimates showed a small, practically insignificant difference of 0.1 g pot^{-1} among all treatments in clay and sandy soil.

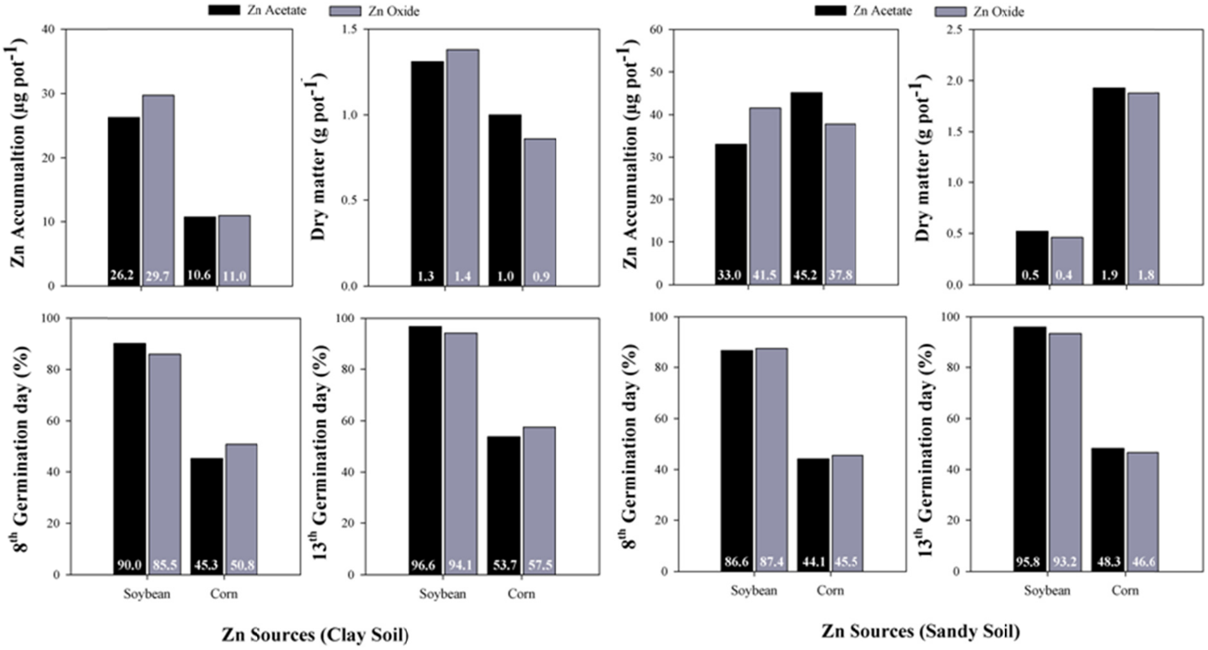

Figure 6. Plots summarizing Zn accumulation (µg pot^{-1}), dry matter content (g pot^{-1}), 8th and 13th germination day (%) for corn and soybean seeds in sandy and clay soil

4. Discussion

4.1 Soil Texture and Plant

PCA results showed that the variance concentration along the axis CP1 and CP2, accounted for 74.2 % of the total variance, and attending the criteria of at least 70 %, described by Senath and Sokal (1973). Therefore, PCA appears to be an appropriate statistical approach to examine the relationship between soils and plant.

The differentiation of soil type into two distinct groups (sand *vs.* clay) can be attributed to the increases of 50 % and 70 % dry matter and Zn accumulation in clay soils, which may be governed by the soil Zn dynamics, and the fact that this element is intrinsically associated with soil minerals, mainly clay (Malavolta, 2006; Inocêncio et al., 2012) and organic matter (Malavolta, 2006). Both, were higher in clay soil, and are able to adsorb Zn from the soil over relatively short periods to trigger Zn decrement for plants and seeds. This is backed up by the observation that prior to experiments, the clay soil presented higher concentrations of Ca^{2+}, Cu^{2+} and P, which are known to inhibit Zn absorption. Interestingly, there was no effect on germination, probably because of adequate water availability during the experiment for both soils.

PCA also highlighted the clear disparity between corn and soybean, through the observation that the dry matter vector was closer and higher with respect corn, representing an increase of 35 % when compared to soybean. This may be partially explained by plant physiology, as corn plants given adequate temperature and soil moisture achieve the V3-V4 stage at 30 days and present greater development, three developed leaves (Magalhães & Durães, 2002). Over a similar period of time, the soybean plants also presented the V3-V4 stage, but showed a dramatic increase in visible root nodules (Fehr & Caviness, 1977) and greater root development. In this way, our results reflect the differential development of plant crops, with soybean showing rapid initial developed of roots while corn showed greater increases in above ground part.

Interestingly, we observed that soybean presented higher germination on the 8th and 13 th day in sandy and clay soil, which represented an increase of almost 47 % compared to corn. While the positive effect of Zn application have been shown for both soybean germination (Santos et al., 1986), and corn seeds (Ribeiro, 1993), these benefits are probably more pronounced for corn seeds than soybean. The Zn applied to seeds triggers the translocation of Zn from the seed to the plant during and after germination (Muraoka, 1981).

4.2 Zinc Rates

Corn and soybean usually present high responsiveness to Zn addition in soils that have pronounced Zn deficiency. Our results concur with this observation, showing that in sandy soil, corn and soybean fitted a linear response curve for the relationship between Zn accumulation and Zn application rates, as has been affirmed by Prado et al. (2007) testing Zn rates using corn seed treatments. The addition of 1 g kg^{-1} of Zn, regardless of source, appears to have a positive effect on Zn accumulation and it is associated lower Zn level and clay concentration, before the experiment. This is apparent when we compare the control treatments, which yielded the lowest Zn accumulation by plants with the lowest Zn application rate (*i.e.*, decreases of 43 % and 9 %, respectively for soybean and corn plants). It is also likely that plants found adequate soil chemical conditions which facilitated root growth that allowed development through the soil and absorb the Zn due to the essentiality and the Zn absorb by seeds (Malavolta et al., 1987), which was manifest by higher Zn accumulation in plants (Prado et al., 2007).

Interestingly for clay soil, Zn rates presented a negative effect on soybean seed germination following a decrease and a small increase. Yagi et al. (2006) have previously shown a negative effect of Zn on the germination of *Sorghum bicolor* sp. that was related to the amount of Zn applied to the seeds. It should be kept in mind that any negative responses may be because soybean seeds have a higher phytic concentration, as well as high protein and lipid concentration and low carbohydrates in the endosperm when compared to corn. The high level of phytate, protein bodies, in soybean seed has be described by Gupta et al. (2015), located in endosperm and representing 10.7% of phytic acid on soy seeds (Lehrfeld, 1994). Therefore, we hypothesized that phytate may have blocked zinc absorption during the germination process, in a way similar to that described by Couzy et al. (1998) who showed phytate to be a potent inhibitor of Zn absorption in humans.

On the other hand, corn seeds responded positively to Zn oxide in terms of Zn accumulation and dry matter, leading us to recommend an application rate of 1.0 g kg^{-1} for corn seed. With respect Zn acetate, we recommend a lower rate between 0.5 and 0.6 g kg^{-1} seeds. The positive outcomes of using Zn acetate on soybean seed treatment have been observed by Milléo and Cristófoli (2015) and Gomes et al. (2016), who reported increases in soybean plant height, plant number and root dry mass (Milléo & Cristófoli, 2015), while for corn seed there have been reports of reduction in the time of emergency (Gomes et al., 2016).

4.3 Zinc Sources

The absence of major differences in the effect of Zn acetate and Zn oxide as a fertilizer for corn and soybean seed treatment is a promising result. Although there was a small disparity of 0.1 g pot^{-1} for dry matter among treatments in clay and sandy soil, for practical purposes this can be considered insignificant. Even though Zn acetate presented low Zn (78 % lower) and N content (4 % higher) it appeared sufficient to supply additional Zn to plants. Our results contrast those done on other Zn sources such as Zn sulfate described by Malavolta et al. (1987), and Prado et al. (2007) which have been reported as less viable when compared to Zn oxide. One explanation for our findings is that both fertilizers tested here are soluble and the amount of Zn necessary to elicit a response may be lower in seed treatments.

Our findings are important because they show that Zn supply can be effective at the seed treatment stage, which has the advantages of permitting uniform application and the need for comparatively lower application rates because of the homogeneous distribution. Soil having Zn deficiency may be more responsive to corn and soybean seed treatment, which can be supplied as either Zn acetate or Zn oxide because both seem to be viable alternative sources with little difference between them. We do not recommend using the soybean seed treatment in clay soil because of the germination decrease, but we do draw attention to the need for further research aimed at understanding the relationship between soybean treatments and Zn supply.

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