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Corn Silage (*Zea mays* L.) Response to Zinc Foliar Spray Concentration When Grown on Sandy Soil

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Abstract

The objective of this study is to identify an adequate zinc (Zn) foliar spray concentration which corrects Zn deficiency without disrupting other plant mineral contents, enhances plant growth, and thereby corn silage yield when grown on sandy soil. A field experiment was conducted using five Zn foliar spray concentrations (w/v): 0.03%, 0.07%, 0.10%, 0.14% and 0.18%. Zn sulfate ($ZnSO_4$. $7H_2O$) was used as a source of Zn. Zn foliar application was realized at two growth stages (6-7 and 9-10 leaf stages). A treatment without Zn foliar spray was maintained as control. The results showed a quadratic response of corn silage towards Zn foliar spray concentrations, in which 0.09% was the optimum value for overcoming Zn deficiency. Such level increased shoot Zn concentration at harvest from 15 mg kg^{-1} to 21.8 mg kg^{-1}, didn't decrease plant mineral content below critical levels, enhanced plant growth and raised silage yield by 49.4% compared to control. On the other hand, Zn foliar spray concentration up to 0.10% induced visible leaf damage, growth inhibition and a decrease of 26% in silage yield compared to Zn foliar applications at 0.09%.

Keywords: corn silage, Zn deficiency, Zn foliar spray, growth, mineral content, yield

1. Introduction

Most plant micro-nutrition research has reported the severe effects of Zn deficiency on crop productivity especially for cereals (Cakmak, 2008). Corn (*Zea mays* L.) is one of the very sensitive cereal species to Zn deficiency stress (Lindsay & Norvel, 1977; Gupta, Kening, & Siyuan, 2008). Many authors have reported importance of Zn in completing some vital physiological functions such as energy production and protein synthesis (Hansch & Mendel, 2009; Gupta et al., 2008; Mousavi, Galavi, & Rezaei, 2013; Qiao et al., 2014).

Under Zn deficiency, corn has low Zn concentration, usually below the critical level of 22 mg kg^{-1} (Singh, Natesan, Singh, & Usha, 2005), and shows white linear bands between the midrib and the margin of leaves (Singh et al., 2005), as well as an obvious shortening of plant height and leaf area (De Vasconcelos, Clístenes, & Fernando, 2011). All this result in significant decline in silage and grain yields (Van Biljon, Wright, Fouche, & Botha, 2010; Potarzycki & Grzebisz, 2009). In order to prevent Zn deficiency stress, both soil Zn supply and Zn foliar spray have been advisable. In the context of many dairy farmlands from Loukkos perimeter (North West of Morocco), corn silage grown on a sandy soil, naturally poor in Zn, showed Zn deficiency symptoms that resulted in a silage yield decline compared to adequate fertilized plots receiving either Zn sulfate or animal manures. Zn foliar spray is still not a common fertilization method in this region, except some commercial mixtures of macro and micronutrients that provided a partial recovery from Zn deficiency stress. Many authors have reported the importance of Zn foliar applications at adequate levels to improve yields of many grown crops such as corn (Potarzycki & Grzebisz, 2009), wheat grain (Haslett, Reid, & Rengel, 2001), tomato fruit (Kaya & Higgs, 2002) and safflower (Rajabi et al., 2013). The foliage uptake depends on many factors such as plant species, timing of application, and concentration (Wojcik, 2004). Knoche, Petracek, Bukovac, and Shafer (1994) reported linear positive relationship between nutrient foliar spray concentration and the rate of its uptake by tomato's leaves. Potarzycki and Grzebisz (2009) found positive quadratic relationship between Zn foliar spray concentration and corn grain yield. They have denoted optimal yielding at concentration ranging between 0.25% and 0.37% of Zn applied at 5 leaf stage. Also, Takkar and Wallker (1993) reported that Zn foliar spray concentration at 0.5-1% of

$ZnSO_4 \cdot 7H_2O$ resulted in optimal biomass yields for many crops.

On the other hand, Zn foliar applications at high concentration induced leaf injury (Qiao et al., 2014), inhibited plant growth and declined yield (Kaya & Higgs, 2002). Moreover, it may disrupt the uptake of other macro and micronutrients. In this respect, Kaya and Higgs (2002) found that the increase of Zn foliar spray concentration on tomato increased leaves Zn concentration, but reduced potassium (K), magnesium (Mg) and iron (Fe) contents.

Despite numerous advantages of foliar spray such as being environmentally friendly, inexpensive and fast in correcting deficiency, we found little literature about managing Zn foliar spray for adequate mineral content and corn silage growth. Therefore, the present study was undertaken with the objective of identifying an adequate concentration of Zn to spray on corn silage grown on a sandy soil in order to correct Zn deficiency without disrupting mineral composition and plant growth.

2. Method

2.1 Site Description

A field experiment was conducted on an agricultural farm (Bassita II farm) located in Loukkos perimeter (34°96′N lat., 6°21′W long., 60 m above the sea level, North West of Morocco) where the climate is maritime. We recorded, during the growing season (August 09 to November 20, 2012), 16.6 °C and 24.2 °C as average of maximum and minimum temperatures, respectively. A rainfall amount of 283 mm was recorded especially between September and November. A comparison between the studied growing season weather and the climatic data of the last 40 years (1971-2010)* of the experimental site is reported in Table1.

Table 1. Temperature, evapotranspiration and rainfall during the growing season (August to November) for 2012 and long-term means (1971- 2010) of the experimental site

	Min temperature (°C)		Max temperature (°C)		Evapotranspiration (mm day^{-1})		Rainfall (mm)	
	2012	1971- 2010	2012	1971-2010	2012	1971-2010	2012	1971-2010
August	19.3	18.9	25.7	27.5	4.0	4.0	4	1.8
September	17.5	17.6	24.8	26.4	3.6	3.8	47	17.8
October	16.3	14.9	25.6	23.7	3.5	3.2	88	67.2
November	11.4	11.3	20.4	20.1	2.5	2.5	171	114.1

*Source: Taken from National Directorate of Meteorology (DMN), Morocco.

2.2 Experimental Soil

For basic soil characteristics analysis, we collected a soil sample 0-20 cm. The soil was sandy (88.8% of sand, 7.5% of clay and 5.3% of silt), no calcareous, with a very low amount of DTPA extractable Zn (0.13 mg kg^{-1}), which was below the critical level of 0.8 mg kg^{-1} required for corn (Landsay & Norvel, 1977). The other soil chemical characteristics are listed in Table 2.

Table 2. Soil characteristics

Soil property	
pH H_2O (1/5)	6.1
Cation exchange capacity (meq $100g^{-1}$) (Cobaltihexamine Chloride method)	4.4
Organic matter (%) (Walkley & Black method)	0.4
Extractable P_2O_5 (mg kg^{-1}) (Olsen method)	49
Extractable K_2O (mg kg^{-1})a	81
Extractable MgO (mg kg^{-1})a	101
Extractable CaO (mg Kg^{-1})b	868
Extractable Zn (mg kg^{-1})c	0.13
Extractable Cu (mg kg^{-1})c	0.06
Extractable Mn (mg kg^{-1})c	17.4
Extractable Fe (mg kg^{-1})c	17.45

Extractants: a = Ammonium Acetate.; b = Sodium Acetate; c = Diethylene Triamine Penta-Acetic acid (DTPA).

2.3 Crop Management and Experimental Design

The land was prepared for planting by cultivator tillage. Corn hybrid Panama was planted on 09 August 2012. The sowing was done on twin lines with a spacing of 45 cm, 90 cm between twin lines spacing and the inter-row seeding distance was 12 cm to approximate 120,000 plants ha^{-1}.

A completely randomized block design with five replications was used. Plots included 3 twin lines of plants, 4 m width and 8 m length. There were 4 m between adjacent plots in the same block and 1.4 m between adjacent blocks.

Five Zn foliar spray concentrations (w/v) were tested: 0.03%, 0.07%, 0.10%, 0.14% and 0.18%. Zn sulfate ($ZnSO_4·7H_2O$, 22.5% of Zn) was used as source of Zn. The foliar spray, about 625 l ha^{-1}, was done using a hand-held sprayer in an early and windless morning. The spray was done twice during the growth season at: i) 5-6 leaf stage and ii) 9-10 leaf stage. A treatment without Zn foliar spray was maintained as control. In order to ensure an adequate nutrition with other nutrient elements, all treatments received adequate amounts of macro and micro elements during the growing season: 480 Kg ha^{-1} of N as ammonium nitrate and diammonium phosphate (DAP), 345 Kg ha^{-1} of P_2O_5 as DAP, 331 Kg ha^{-1} of K_2O as potassium sulfate, 6.25 Kg ha^{-1} of Cu as copper sulfate, 4.61 Kg ha^{-1} of B as boron sulfate and 3.35 Kg ha^{-1} of Mn as manganese sulfate.

Each line of plants was equipped with a drip line irrigation system using 1.2 l h^{-1} emitters and 0.4 m as emitters spacing. Watering was done whenever required during the growing season. Weeds were controlled using a mixture of pre-emergence herbicides (Pendimethaline, Mesotrione, Terbuthylazine and S-metolachlor) and fungal disease (Helmintosporium) was controlled with Epoxiconazole.

2.4 Measurements

Taking into account that Zn deficiency symptoms appeared on corn as white linear areas between the midrib and margin of leaves (Singh et al., 2005; Alloway, 2008), visual Zn deficiency symptoms evolution was determined each 10 days, on 10 randomly chosen plants for each treatment's replication. The symptoms were summarized using a descriptive scale of 1 to 5: 1 = plants had no visual Zn deficiency symptoms, 2 = pale green linear stripes began to appear between the midrib and the margin of new leaves, 3 = white linear stripes appeared between the midrib and the margin of all leaves 4 = white bands appeared between the midrib and the margin of old leaves, 5 = all leaves were small showing linear white bands between their midrib and margin.

The stem height and the stem diameter were measured, on 10 randomly chosen plants per each treatment's replication, at 3 different growing stages: 6-7 leaf stage, 9-10 leaf stage and harvest.

The total leaf area per plant at harvest was measured in 3 randomly chosen plants per each treatment's replication using the formula (1) developed by Montgomery (1911) and cited in Mokhtarpour et al. (2010) for corn:

$$Total\ leaf\ area\ per\ plant = \sum_{i=1}^{j=n}(L \times W \times 0.75) \quad (1)$$

Where L, W, and n are leaf length, leaf greatest width, and last leaf of corn, respectively.

The harvest was done manually on November 20, 2012, approximately at shoot moisture content of 67%. 10 randomly chosen plants per each treatment's replication were cut close to the soil surface, and the fresh weights of the harvest were measured. 3 randomly chosen ears per each treatment's replication were taken in order to determine different kernels yield compounds: i) total number of ovules per ear using equation (2) ii) pollination rate using equation (3), and iii) thousand-kernel dry weight.

$$Total\ number\ of\ ovules\ per\ ear = Number\ of\ kernels + Number\ of\ sterilized\ ovules \quad (2)$$

$$Pollination\ rate\ (\%) = Number\ of\ kernels\ per\ ear/Total\ number\ of\ ovules\ per\ ear \times 100 \quad (3)$$

In order to evaluate macro and micro nutrients shoot contents at harvest, 3 plants from each of the following treatments (Control, 0.03%, 0.10% and 0.18%) were dried at 70 °C in an oven until constant weight, chopped and mixed. Thereafter, 3 subsamples of 0.6 g per these treatments were digested with a mixture of salicylic and sulfuric acids in order to determine plant N, P, K, Ca and Mg contents. Besides, 3 other subsamples of 2 g were digested with a mixture of nitric, perchloric, and sulfuric acids to determine plant Zn, Mn, Fe and Cu contents.

Concerning K, Ca, Mg, Zn, Fe and Mn, they were analyzed using an atomic absorption spectrophotometer (Varian AA 240 Fast Sequential; air acetylene flame). However, N and P were auto-analyzed using a continuous flow analyzer (Skalar San^{++}).

2.5 Statistical Analysis

All data were subjected to analysis of variance at 5% significance level. Taking into account that Zn concentration treatment is a quantitative variable, an appropriate regression analysis, which was selected on the basis of higher r^2, was used to evaluate the response of each measured parameter. The optimum Zn foliar spray for each parameter was determined by equating the first derivative of the regression equation to zero. These statistical analyses were performed using the program SPSS (Version 17.0).

3. Results

3.1 Visual Zn Deficiency Symptoms

Zn deficiency symptoms appeared at an earlier stage (5 leaf stage) as white linear stripes between the midrib and the margin of leaves for all treatments (score 3). Zn foliar applications up to 0.03% induced a clear disappearance of these symptoms (score ≈ 1). But, some green pale lines persisted on plants during all growing season even with high Zn foliar spray concentration (0.14% and 0.18%). Control plants also showed a slight recovery from Zn deficiency at 8-9 leaf stage (score 2). On the other hand, due to high Zn level concentration (up to 0.10%), an obvious leaf injury with brown leaf areas was observed after one day of each application. This damage concerned only the touched leaves, thereafter, new safety leaves appeared.

3.2 Plant Growth

Just after the first Zn foliar application (6-7 leaf stage), a clear increase on stem height was marked. At 9-10 leaf stage, all Zn foliar treatments induced a significant increase of 14.6% compared to control. While at harvest, a clear positive quadratic response was recorded. Zn foliar application at 0.10% induced the most significant stem height increase of 11.8% compared to control. Moreover, the total leaf area per plant at harvest was significantly raised. Compared to control, all Zn foliar treatments induced a significant rise of 23.40%. Concerning stem diameter, it was significantly increased at 9-10 leaf stage. But at harvest, no significant difference between treatments was recorded. Nonetheless, an obvious growth inhibition was marked with high Zn foliar spray concentrations up to 0.10% (Table 3).

Table 3. Effect of Zn foliar spray concentration (%) on stem height, stem diameter and total leaf area of corn silage

Zn foliar spray concentrations	Stem height (cm)			Stem diameter (cm)			Total leaf area at harvest (dm² plant^{-1})
	6-7 leaf stage	9-10 leaf stage	Harvest	6-7 leaf stage	9-10 leaf stage	Harvest	
Control	16.2±3.0	39.8± 12.5	199.7±21.0	1.2±0.2	1.4±0.2	1.4±0.2	30.20±8.76
0.03	17.7±3.9	46.5±10.8	215.2±17.8	1.3±0.2	1.5±0.2	1.5±0.1	36.02±4.77
0.07	16.8±2.7	45.9±9.9	214.9±13.2	1.2±0.2	1.5±0.1	1.4±0.2	36.47±6.42
0.10	16.2±2.8	45.5±8.1	223.3±10.6	1.2±0.2	1.5±0.1	1.5±0.2	38.67±4.69
0.14	16.7±2.4	44.4±7.9	214.4±12.9	1.3±0.2	1.5±0.1	1.4±0.2	37.33±7.11
0.18	17.2±2.9	45.7±10.4	210.4±12.2	1.3±0.2	1.5±0.2	1.4±0.2	37.92±7.94
F test	*	*	*	n. s.	*	n. s.	*
Regression							
r^2	0.03	0.50	0.81	0.06	0.65	0.42	0.86
b_0	16.79	41.60	201.76	1.30	1.47	1.44	31.20
b_1	-2.63	82.71	362.42	-0.44	2.03	1.12	115.87
b_2	20.86	-366.00	-1787.11	2.53	-8.86	-7.33	-455.74

Data are the means ± standard deviation.

* Significant at 5% probability level; n.s.-Not significant at 5% probability level.

3.3 Silage Yield and Shoot Dry Matter Partitioning

Silage yield was significantly influenced with Zn foliar spray. It had a positive quadratic response and the highest yield was recorded with Zn spray at 0.09%. It induced an increase of 49.4% compared to control. However, a clear decline of about 26% in optimal yield was noted with Zn spray concentration up to 0.10% (Figure 1).

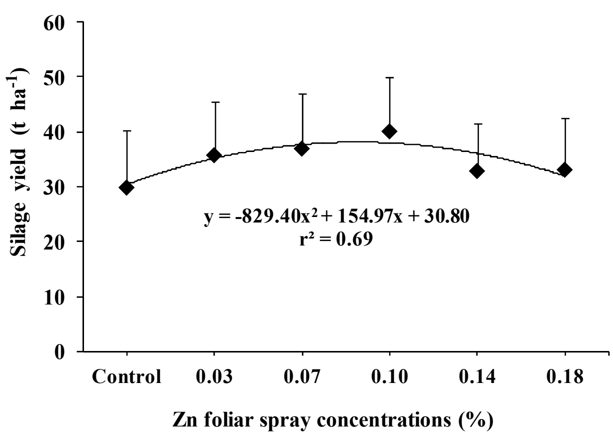
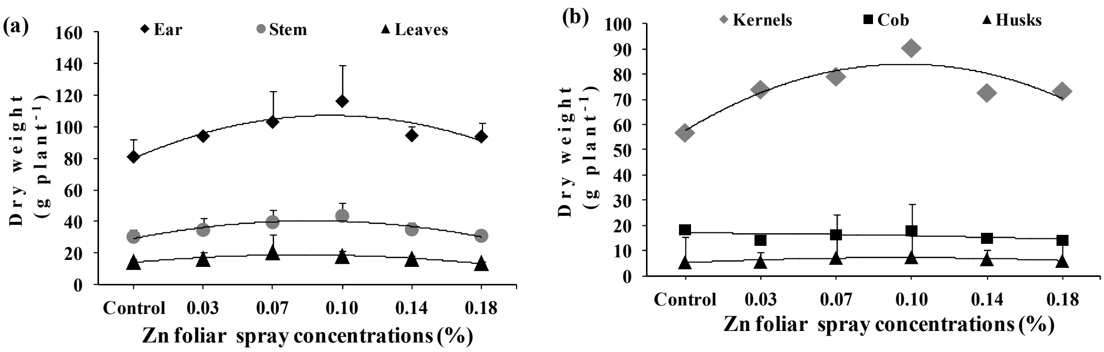


Figure 1. Effect of Zn foliar spray concentration on silage yield. Vertical bars denote standard deviation

The shoot dry matter partitioning analysis showed that stem, leaves and ear dry weights were all significantly enhanced by Zn foliar applications and had the same trend of the regression equation describing silage yield (Figure 2a). Within ear, we found that especially kernels dry weight was significantly influenced (Figure 2b).



$y=-2648.86x^2+530.36x+80.78$	$r^2=0.75$ for ear	$y=-2374.22x^2+490.52x+58.67$	$r^2=0.77$ for kernels
$y=-1321.71x^2+240.14x+29.46$	$r^2=0.86$ for stem	$y=-196.4x^2+39.69x+5.25$	$r^2=0.83$ for husks
$y=-634x^2+108.2x+14.14$	$r^2=0.85$ for leaves	$y=-78.24x^2+0.14x+16.86$	$r^2=0.26$ for cob

Figure 2. Effect of Zn foliar spray concentration on shoot dry matter partitioning into ear, stem, leaves (a), kernels, cob and husks (b) of corn silage at harvest. Vertical bars denote standard deviation

The analysis of kernels yield components showed no significant effect of Zn foliar spray on the total number of ovules per ear (Figure 3a). But, two main components were significantly influenced: the pollination rate and the thousand-kernel dry weight (Figures 3b and 3c). Both had quadratic responses and the highest response was approximately at 0.10% of Zn. Compared to control, this Zn rate induced significant increases of 15.4% and 19.1% on pollination rate and on thousand-kernel dry weight, respectively.

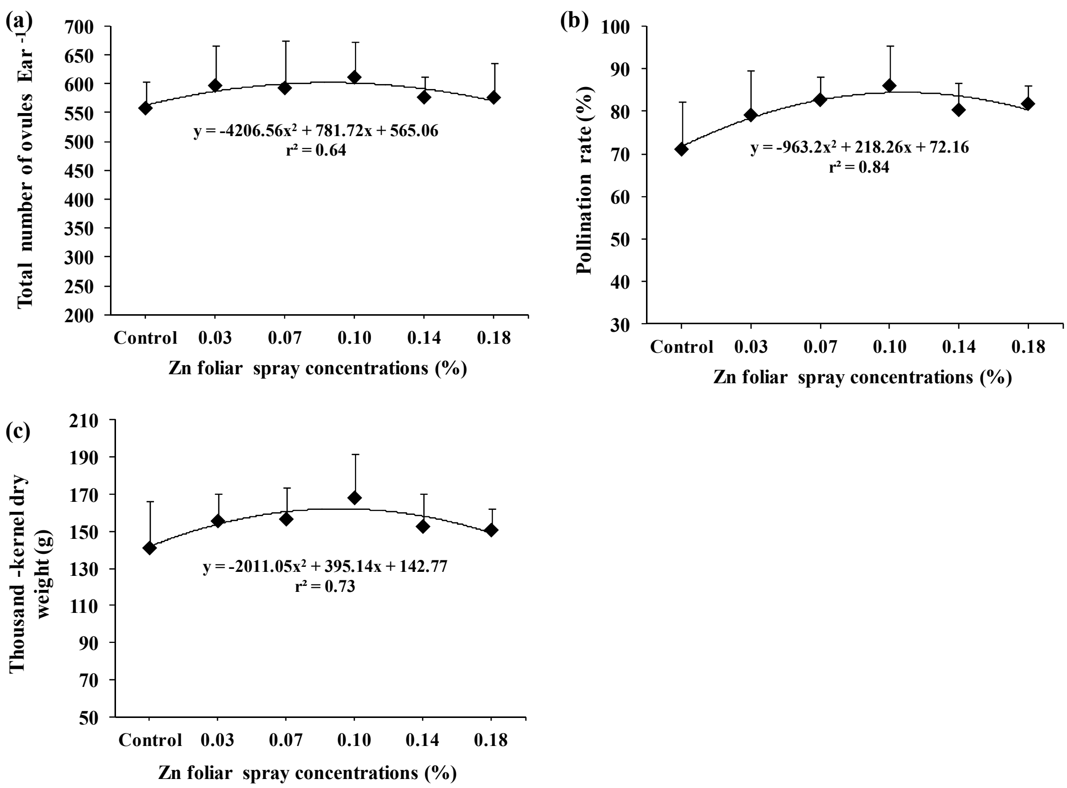


Figure 3. Effect of Zn foliar spray concentration on total number of ovules per ear (a), pollination rate (b) and thousand-kernel dry weight (c) of corn silage at harvest. Vertical bars denote standard deviation

3.4 Mineral Shoot Content

3.4.1 Micro Elements Shoot Content

The chemical analysis of shoot dry matter at harvest showed that Zn foliar spray influenced some micro nutrients plant concentrations (Figures 4a, 4b, 4c and 4d). The increase of Zn foliar spray concentration resulted in significant linear increase in shoot Zn content. Zn spray concentration at 0.09% which induced optimal yielding led to a shoot Zn content of 21.8 mg kg^{-1}. However, plant concentration in Mn, Fe and Cu showed linear significant decrease with increasing Zn foliar spray concentration. Zn foliar applications at 0.09% induced mineral contents of 93, 35.8, 6.7 mg kg^{-1} for Fe, Mn and Cu, respectively.

3.4.2 Macro Elements Shoot Content

Furthermore, shoot concentration in K and Mg had negative linear relationship with Zn concentration spray. At Zn foliar application of 0.09%, we recorded 0.8% as shoot k content and 0.12% as Mg content (Figures 5a and 5b).

In contrast, shoot P content showed a quadratic response towards Zn foliar spray concentration (Figure 5c). Zn applications at 0.09% induced shoot P content of 0.27%. Other macro elements as N and Ca didn't show any significant difference between treatments and were in adequate levels (DATA not shown here).

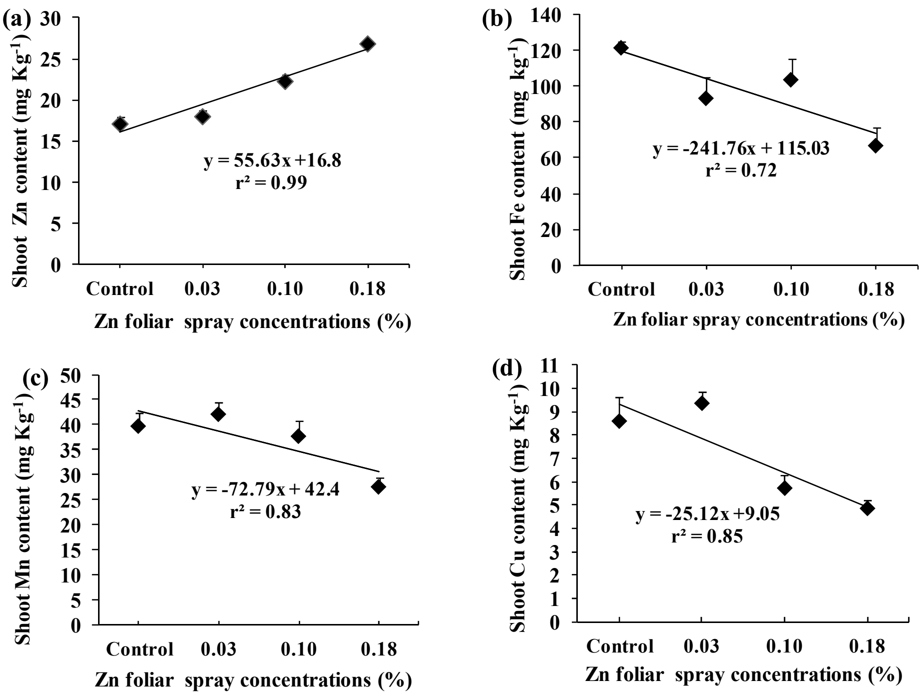


Figure 4. Effect of Zn foliar spray concentration on Zn (a), Fe (b), Mn (c) and Cu (d) contents of the shoot dry matter for corn silage at harvest. Vertical bars denote standard deviation

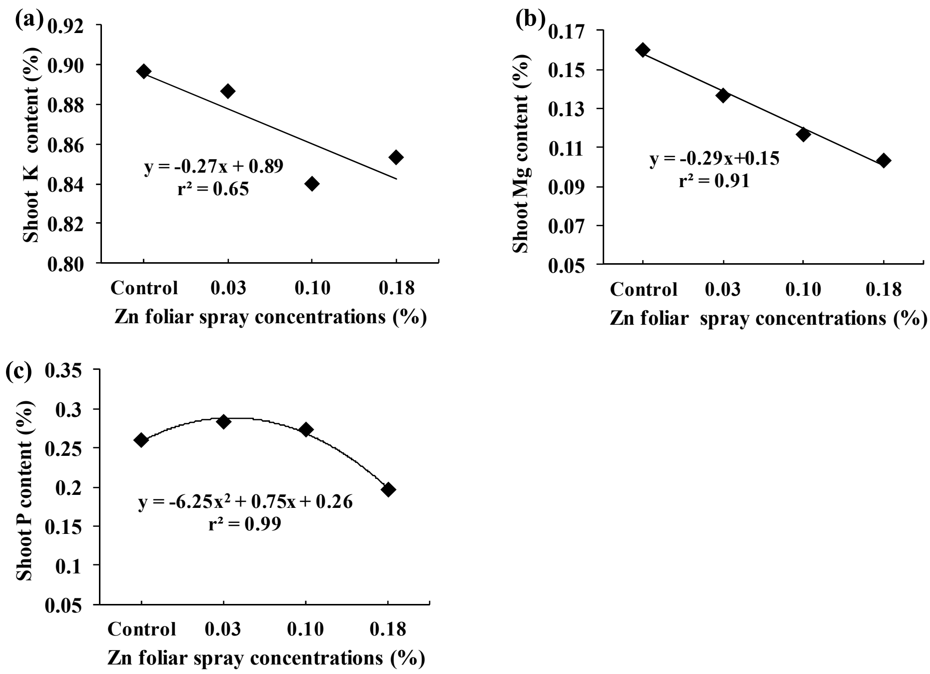


Figure 5. Effect of Zn foliar spray concentration on K (a), Mg (b), and P (c) contents of the shoot dry matter for corn silage at harvest. Vertical bars denote standard deviation

4. Discussion

Results from the present study have shown that Zn foliar spray prevented Zn deficiency stress in corn when it's applied at adequate level. Approximately 0.09% is the optimum Zn foliar spray concentration for corn silage production when grown in Zn deficient sandy soil. Furthermore, adverse effect on plant growth can happen with higher Zn foliar spray concentration.

4.1 Visual Zn Deficiency Symptoms

The appearance of Zn deficiency symptoms on corn was mainly attributable to a low soil born Zn content (0.13 mg kg^{-1}) which was below the critical level of 0.8 mg kg^{-1} required for corn production (Landsay & Norvel, 1977). Their appearance at an earlier stage (5-6 leaf stage) was reported by many authors (Kuldeep & Banerjee, 1986; Sharma, Chatterjee, & Saharma, 1990; Wang & Jin, 2007). As soon as we increased Zn foliar spray concentration, these symptoms became less severe. The same result was reported by Kaya and Higgs (2002) on tomato. Nevertheless, the slight recovery from Zn deficiency noticed in control plants at 8-9 leaf stage agreed with earlier result reported by Rungruang, Doyle, and Raymond (1978). On the other hand, the clear leaf injury noted at high Zn foliar spray concentration (up to 0.10%) was noticed in rice with Zn foliar spray concentration up to 0.03% (Qiao et al., 2014) and in tomato at 0.015% of Zn (Kaya & Higgs, 2002).

4.2 Plant Growth, Silage Yield and Shoot Dry Matter Partitioning

Synchronization of visual Zn deficiency symptoms and stem height shortening in control and low Zn foliar spray concentrations (0.03% and 0.07%) supported the physiological mediating function of Zn in the metabolism of growth regulators as indole 3 acetic acid and gibberellic acid (Cakmak, Marshner, & Bangerth, 1988; Balal et al., 1998). The leaf area was also enhanced by Zn foliar spray; a result which was reported by Chaab, Savaghebi, and Motesharezadeh (2011) on maize due to Zn soil supply. While no increase in stem diameter at harvest was noted, this result agreed with the finding of Rajabi et al. (2013) on safflower. In contrast, high Zn foliar spray concentration (up to 0.09%) induced a clear inhibition of plant growth and yield decline, which agreed with the result of Kaya and Higgs (2002) on tomato. In this regard, a recent study by Qiao et al. (2014) explained that Zn foliar application at high concentration on rice, exceeding 0.03%, induced a significant decrease in phosynthesis rate. They explained this decrease by the inhibition of chlorophyll synthesis and by inactivation of β-carbonic anhydrase enzyme which contains Zn and plays crucial role in photosynthesis.

Many authors reported the importance of Zn foliar applications at adequate levels to enhance yields of many crops such as corn (Potarzycki & Grzebisz, 2009), wheat grain (Haslett, Reid, & Rengel, 2001), tomato fruit (Kaya & Higgs, 2002) and safflower (Rajabi et al., 2013). From this study, the highest silage yield was recorded with Zn foliar applications at 0.09% of Zn, equivalent to 0.40% of $ZnSO_4.7H_2O$, applied at 5-6 and 9-10 leaf stages. Similarly, Lindsay (1972) reported in his review that Zn foliar applications at 0.5% of $ZnSO_4 \cdot 7H_2O$, applied at 3 and at 5 leaf stages corrected Zn deficiency on corn. In contrast, Potarzycki and Grzebisz (2009) reported that optimal maize grain yield was recorded with high Zn foliar spray concentration ranging between 0.25% and 0.37% of Zn. This latter was applied as oxysulfate at 5 leaf stage and was equivalent to 1.11-1.64% of $ZnSO_4.7H_2O$. Dry matter partitioning analysis showed that stem, leaves and ear biomass were all influenced by Zn foliar applications. The marked positive effect of Zn foliar spray on biomass can be explained through the role of Zn in increasing both the carbonic anhydrase enzyme activity (Qiao et al., 2014; Sasaki, Hirose, Watanabe, & Ohsugi, 1998) and chlorophyll synthesis (Qiao et al., 2014; Cakmak & Marshner, 1993), which improved photosynthesis rate (Qiao et al., 2014). As kernels presented about 50% of the total aerial dry matter (Figure 6), the silage yield response was especially linked to kernels weight. This latter was enhanced mainly through two components: thousand-kernel dry weight and pollination rate. The increase of thousand-kernel dry weight was reported by Potarzycki and Grzebisz (2009) on corn, and by Rajabi et al. (2013) on safflowers. It could be attributed mainly to photosynthesis activation mentioned above. Regarding pollination rate, its increase with adequate Zn foliar application can be related to male fertility enhancement found by Sharma et al. (1990).

4.3 Mineral Shoot Content

Control plants showed insufficient shoot Zn content at harvest (15.8 mg Kg^{-1}) which was below the critical level required in corn 22 mg kg^{-1} (Singh et al., 2005). This content was linearly increased with raising Zn foliar spray concentration, the same result was reported by Cakmak et al. (2010) on wheat and by Kaya and Higgs (2002) on tomato. This linear positive relationship illustrates the luxurious consumption character of corn silage towards Zn.

Zn foliar supplementations at 0.09%, which induced the highest silage yield, provided an adequate shoot Zn content (21.8 mg kg^{-1}). This was approximately equal to the critical level cited above (22 mg kg^{-1}). Adequate Zn level in corn can both enhance silage nutritional quality and suppress or minimize Zn feed additives supply used in dairy cattle feeding. Even if we remarked negative relationships between shoot Zn content and Mg ($r^2 = 0.73$), K ($r^2 = 0.59$), Mn ($r^2 = 0.63$), Cu ($r^2 = 0.68$) and Fe ($r^2 = 0.59$) at harvest, Zn foliar spray at 0.09% resulted in adequate plant content of k (0.8%) which was approximately equal to the critical level ranging between 0.7% and 0.9% (Arnon, 1975). Also, it induced adequate levels of Mn, Cu and Fe (Rashid & Ryan, 2008). The plant Mg content (0.12%) was lower than the adequate concentration of 0.20% requested for corn silage by Fox and Piekielek (1984). In the case of this study, no Mg deficiency symptoms were noticed. In this context, Arnon (1975) reported that Mg deficiency symptoms in corn appeared at Mg concentration below 0.06%, and content around 0.12% and 0.24% induced optimal yields.

The negative interactions between Zn and other nutrients were in line with the finding of Kaya and Higgs (2002) who reported that Zn foliar applications on tomato induced antagonism between Zn and K, Mg and Fe. The same relationship was found between Zn and Cu (Kumar et al., 2009) and between Zn and Fe (Ai-Qing et al., 2011) on wheat. This kind of interaction, which is presumably related to an inhibition of elements uptake due to Zn foliar applications, hasn't been well explained in the literature yet, and gives a reason for further investigation.

The shoot P content behaved differently from the other elements; it was enhanced with slight Zn concentration applications (below or equal to 0.06%) and decreased with higher ones (up to 0.06%). At an earlier study, Orabi, Mashadi, Abdllah, and Morsy (1981) found a positive relationship between P and Zn on corn. However, Zhu, Smith, and Smith (2001) reported that high soil P supply induced a low Zn content on wheat. Interaction between P and Zn is widely reported in the literature for different crops, but little is known about the specific mechanism involved either under Zn foliar spray or soil Zn supply. On the other hand, the optimal silage yield recorded at 0.09% had an adequate P content (0.27%) which was around the required level (0.1-0.5%) (Arnon, 1975).

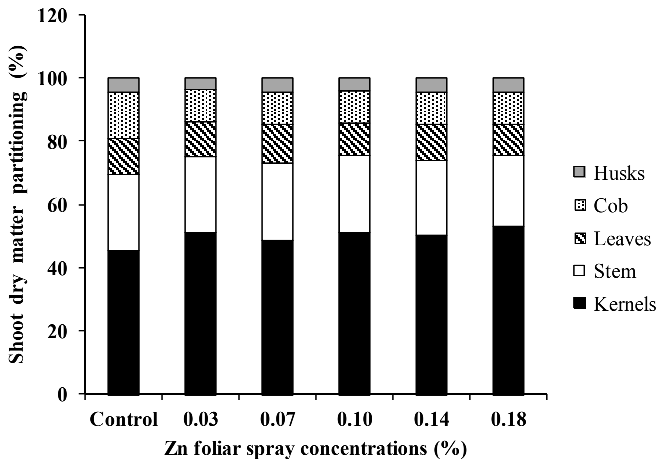


Figure 6. Effect of Zn foliar spray concentration on ratio of kernels, stem, leaves, cob and husks dry weights to total shoot dry weight

5. Conclusion

Results have indicated that 0.09% of Zn, using as source Zn sulfate ($ZnSO_4 \cdot 7H_2O$), is the adequate concentration to spray at 5-6 and 8-9 leaf stages of corn silage in order to cure Zn deficiency. Such level of concentration proved to increase plant Zn content without any disruption in plant mineral composition, and to enhance plant growth, thereby increasing silage yield. However, caution must be taken with Zn foliar spray at concentration up to 0.10% which induced leaf injury, disrupted mineral plant composition and inhibited plant growth.

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