Journal of Agricultural Science; Vol. 7, No. 5; 2015
ISSN 1916-9752 E-ISSN 1916-9760
Published by Canadian Center of Science and Education

Efficacy of Dairy Cattle Slurry in Preventing Zinc Deficiency of a Silage Corn (*Zea mays* L.) Grown on a Sandy Soil

Saad Drissi[1], Abdelhadi Aït Houssa[2], Ahmed Bamouh[1], El Madani Daoudi[3] & Mohamed Benbella[2]

[1] Plant Production, Protection and Biotechnology Department, Hassan II Agronomy and Veterinary Institute, Rabat, Morocco

[2] Department of Agronomy and Plant Breeding, National Agricultural School of Meknes, Meknes, Morocco

[3] Moroccan Laboratory of Agriculture (LABOMAG), Casablanca, Morocco

Correspondence: Saad Drissi, Plant Production, Protection and Biotechnology Department, Hassan II Agronomy and Veterinary Institute, Rabat, Morocco. E-mail: drissi_agro@yahoo.com

Received: January 26, 2015 Accepted: February 25, 2015 Online Published: April 15, 2015

doi:10.5539/jas.v7n5p56 URL: http://dx.doi.org/10.5539/jas.v7n5p56

Abstract

Corn silage (*Zea mays* L.), grown on sandy soil, was severely affected by Zinc (Zn) deficiency stress. Mineral and organic Zn sources were required to prevent this deficiency. The objective of this study is to evaluate the effectiveness of dairy cattle (*Bos taurus*) slurry as an organic source of Zn in preventing Zn deficiency in corn silage grown on sandy soil. A field experiment was conducted and six rates of dairy cattle slurry were spread just before sowing: 0 or no slurry spread; 50; 100; 150; 200 and 300 t ha^{-1}. These slurry rates were compared to an adequate mineral Zn supply of 5 mg kg^{-1} applied to soil as ($ZnSO_4 \cdot 7H_2O$). Regression analysis has shown that slurry rates ranging between 50 and 60 t ha^{-1} had almost similar efficacy to the adequate Zn mineral supply. Both of them corrected Zn deficiency symptoms, enhanced plant growth and increased silage yield by 37.5%, compared to no Zn or slurry applications. A high slurry rate of 280 t ha^{-1} maximized silage yield but may pose a threat to the environment due to its high content of nitrogen (N). At the next cropping season, a sufficient DTPA residual Zn soil content of 0.9 mg kg^{-1} was recorded only with a high slurry rate (300 t ha^{-1}).

Keywords: corn silage, zinc deficiency, dairy cattle slurry, Zn mineral, mineral content, growth, yield

1. Introduction

Zn deficiency is a worldwide nutritional constraint that reduces the yield of many crops, especially cereals (Cakmak, 2008). Maize (*Zea mays* L.) is known to be very sensitive to Zn deficiency (Lindsay & Norvel, 1977). Under Zn deficiency stress, maize has shown white bands between the midrib and the margin of leaves (Singh, Natesan, Singh, & Usha, 2005), accompanied by an obvious decline in plant height (De Vasconcelos, Clístenes, & Fernando, 2011) and in dry matter production (Van Biljon, Wright, Fouche, & Botha, 2010). These symptoms are explained by the important physiological functions performed by Zn, which include protein synthesis and energy production (Hansch & Mendel, 2009). Sandy soils are generally deficient in Zn (Bhupinder, Senthil, Singh, & Usha, 2005). In this case, an adequate soil Zn supply as mineral or organic forms can prevent this deficiency (Murphy & Walsh, 1972). In the context of many dairy farmlands from Loukkos perimeter (North-West of Morocco), corn silage grown on sandy soil has shown clear Zn deficiency symptoms. Consequently, an important silage yield decline was recorded compared to adequate fertilized plots receiving either Zn mineral supply or farmyard manures. In this regard, Wallingford, Murphy, Powers and Manges (1975) reported that farmyard manures can enhance soil Zn availability. Among farmyard manures applied, dairy cattle slurry is an important effluent of dairy farms. Many studies reported its advantageous effects in improving soil content in macronutrients, micronutrients, organic matter (Nikoli & Matsi, 2011; Matsi, Lithourgidis, & Gagianas, 2003), and thereby corn silage yield (Schröder, Ten Holte, & Brourwer, 1997). In a recent study, Nikoli and Matsi (2011) reported that liquid cattle manure as a source of micronutrients could also indirectly improve the availability of soil native micronutrients through the action of its organic matter. Also, Sinclair and Edwards (2008) reported that cattle slurry contains an amount of Zn ranging between 11 and 18 g t^{-1} (wet weight). On the other hand, Nikoli and Matsi (2011) stated that farmyard manures increased soil content in micronutrients chelated forms, and many authors like Ortega-Blu and Molina-Roco (2007), Chatterjee and Mandal (1985) and Chand, Randhawa, and Bhumbla (1981) reported that Zn chelated forms were more efficient than inorganic ones. Still, an over application of farm manures may threaten the environment because of nitrate leaching (Beckwith, Cooper, Smit, & Shepherd, 1998) and heavy metals accumulation (Berenguer, Cela, Santiveri, Boixadera, & Lloveras, 2008).

Despite the numerous researches discussing the advantages and disadvantages of farm manures application on soil nutrients enrichment, we find little information about the possibility of substituting Zn mineral supply either by dairy cattle slurry or by other animal manures. For this reason, the following work aims to compare the effectiveness of dairy cattle slurry rates to an adequate mineral Zn supply, in terms of preventing Zn deficiency in corn silage grown on sandy soil.

2. Method

2.1 Site Description

A field experiment was carried out on an agricultural farm (Bassita II) located in Loukkos perimeter (34°96′N lat., 6°21′W long., 60 m above the sea level, North West of Morocco). The climate is maritime. During the growing season (May to August), the average maximum and minimum temperatures were 18.5 °C and 27.3 °C, respectively. Also, a low precipitation rate (11 mm) was recorded during this period. A climatic comparison between the studied growing season and the long term climatic data of the last 40 years is provided in Table1.

Table 1. Climatological data of the experimental site during the growing season (May to August) of 2012 and the last 40 years average (1971-2010) *

	Min temperature (°C)		Max temperature (°C)		Evapotranspiration (mm day^{-1})		Rainfall (mm)	
	2012	Long term	2012	Long term	2012	Long term	2012	Long term
May	15.54	13.76	26.32	22.24	3.64	2.75	7	34.71
June	18.23	16.67	27.66	25.04	4.07	3.56	0	9.17
July	20.58	18.69	29.58	27.57	4.56	4.06	0	0.93
August	19.93	18.94	25.70	27.57	4.02	4.09	4	1.82

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

2.2 Soil and Dairy Cattle Slurry Characteristics

The soil is sandy (88.8% of sand, 7.5% of clay and 5.3% of silt), deficient in DTPA extractable Zn with an amount of 0.13 mg kg^{-1}, which was below the critical level of 0.8 mg kg^{-1} required for corn production (Lindsay & Norvell, 1977). It's not calcareous (0.1% of total $CaCO_3$), with a pH of 6.1 (soil/H_2O as 1/5) and a low amount of organic matter (0.4%) (Walkley & Black, 1934). The other chemical properties of soil are presented in Table 2.

Table 2. Soil characteristics

Soil property	
pH H_2O (1/5)	6.10
Cation exchange capacity (meq 100 g^{-1}) (Cobaltihexamine Chloride method)	4.40
Organic matter (%) (Walkley & Black method)	0.40
Extractable P_2O_5 (mg kg^{-1}) (Olsen method)	49
Extractable K_2O (mg kg^{-1})(Ammonium Acetate method)	81
Extractable MgO (mg kg^{-1}) (Ammonium Acetate method)	101
Extractable CaO (mg Kg^{-1}) (Sodium Acetate method)	868
DTPA extractable Zn (mg kg^{-1})	0.13
DTPA extractable Fe (mg kg^{-1})	17.45
DTPA extractable Mn (mg kg^{-1})	17.40
DTPA extractable Cu (mg kg^{-1})	0.06

The dairy cattle (*Bos taurus*) slurry used in this experiment was a mixture of feces, urine, feed residue and washing water. It had 79% of moisture. Its dry matter contained 106.79 mg kg^{-1} of total Zn and 1.91% of total N. The other chemical properties are listed in Table 3.

Table 3. Dairy cattle slurry characteristics

Total mineral content on slurry dry matter			
(%)		(mg kg^{-1})	
N	1.91	Zn	106.79
P	0.52	Cu	19.75
K	1.80	B	26.49
Mg	0.58	Mn	179.95
Ca	3.19	Fe	5534.28
Cl	0.81	Na	8466.76
Organic matter (%)		65.60	
C/N		19.84	
Moisture content (%)		79	

2.3 Crop Management and Experimental Design

Corn silage cv. Panama was seeded on May 13, 2012 in 45 cm double rows spacing, 90 cm between double rows spacing and 12 cm seed distance to approximate 120,000 plants ha^{-1}. The experimental design was a randomized complete block with five replications. The plot size was 4 by 8 m and contained three double rows. There were 4 m between adjacent plots in the same block and 1.4 m between adjacent blocks. Six rates of dairy cattle slurry were tested: 0; 50; 100; 150; 200 and 300 t ha^{-1}. The slurry rate of 50 t ha^{-1} produces a Zn amount of 1.1 kg ha^{-1} and N amount of 201 kg ha^{-1}. These slurry treatments were compared to an adequate mineral Zn supply of 5 mg kg^{-1} applied as ($ZnSO_4 \cdot 7H_2O$; 22.5% of Zn). The mineral Zn treatment was recognized in a previous study as the optimal supply for corn silage grown on a sandy soil (Drissi, unpublished MA thesis). One day before sowing, the total rates of slurry were spread using a spreading machine. Few hours after, the slurry was incorporated into the soil using a rotavator. Mineral Zn treatment was applied as a solution of Zn sulfate in the middle of each double cropping row. It was split at three different times during the growing season: i) 50% just after sowing, ii) 25% at 4-5 leaf stage, and iii) 25% at 8-9 leaf stage.

In order to make sure that Zn was the only nutrient limiting corn silage growth and yield, all treatments were adequately fertilized with 395 Kg ha^{-1} of N as ammonium nitrate and diammonium phosphate (DAP), 334 Kg ha^{-1} of P_2O_5 as DAP, 33 Kg ha^{-1} of K_2O as potassium sulfate, 3.3 Kg ha^{-1} of Mn as manganese sulfate, 6.2 Kg ha^{-1} of Cu as copper sulfate and 4.6 Kg ha^{-1} of B as boron sulfate, these amounts were split adequately during the growing season.

Each line of plants was equipped with a drip line irrigation system with 1.2 L h^{-1} emitters and 0.4 m as emitters spacing. Watering was done whenever required throughout the experiment. In order to control weeds, pre-emergence herbicides (Pendimethaline, Mesotrione, Terbuthylazine and S-metolachlor) were sprayed. Insects (Heliothis, spodoptera and sesamia) were controlled with Indoxocarb and fungal disease (Helmintosporium) was controlled with Epoxiconazole.

2.4 Measurements

According to the description of Zn deficiency symptoms in corn reported by many authors (Alloway, 2008; Singh et al., 2005), the evolution of these symptoms was described during the growing season on ten randomly chosen plants for each treatment's replication. Stem height and stem diameter were measured at harvest on ten randomly chosen plants for each treatment's replication. Also, the total leaf area was measured on three randomly chosen plants per each treatment's replication using Formula (1) (Dwyer & stewart, 1986 in Mokhtarpour et al., 2010):

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

Where,

L, W, and j are leaf length, leaf maximum width, and last leaf of a plant, respectively.

The harvest was done on August 25, 2012, approximately at a shoot moisture content of 54%. Ten randomly chosen plants per each treatment's replication were cut close to the soil surface, and the fresh weights of the harvest were measured.

For shoot dry matter partitioning, a subsample of three plants per each replication's treatment was taken and partitioned into leaves, stem, kernels, cob and husks. Then, the plants parts were dried to constant weight. Three randomly chosen ears per each replication's treatment were taken to determine kernels yield components: total number of ovules per ear using Formula (2), pollination rate using Formula (3) and thousand kernels dry weight.

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

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

In order to determine corn mineral concentration at harvest, three whole aerial tissues from 0, 100, 200 and 300 t ha^{-1} of slurry treatments and Zn mineral supply were dried in an oven at 70 °C and ground to powder. Thereafter, three subsamples of 2 g from the three chopped plants, cited above, were digested with a mixture of nitric, perchloric and sulfuric acids to analyze Zn concentration (Chintala et al., 2012a; Chintala et al., 2012b). Three other subsamples of 0.6 g were digested with a mixture of salicylic and sulfuric acids to analyze N, P, K, Ca and Mg. K, Ca, Mg and Zn were determined using an atomic absorption spectrophotometer (Varian AA 240 FS; air acetylene flame). While a continuous flow analyzer (Skalar San++) was used to determine N and P (Chintala et al., 2013; Chintala et al., 2014). Furthermore, three soil samples (0-20 cm depth) from each treatment, except 50 and 150 t ha^{-1} slurry rates, were sampled at the next growing season. Thereafter, they were ground to pass a 2 mm sieve then analyzed for available Zn by DTPA extractant method using the same atomic absorption spectrophotometer.

2.5 Statistical Analysis

All data were subjected to the analysis of variance (ANOVA) at $P \leq 0.05$ level. Regression analysis was applied to evaluate slurry rates, and the best regression lines were fitted using the highest r^2. The difference between Zn mineral supply and dairy cattle manure rates was analyzed using the Dunett test at $P \leq 0.05$ level. These statistical analyses have been done using the program SPSS (Version 17.0).

3. Results

3.1 Evolution of Visual Zn Deficiency Symptoms

Zn deficiency symptoms appeared at an earlier stage (4-5 leaf stage) for all treatments, but the severity of these symptoms was less manifested either with increasing slurry rates or with mineral Zn supply. A clear linear white area between the midrib and the margin of leaves appeared on plants grown without Zn or slurry applications while some pale green linear stripes were observed with high slurry rates (200-300 t ha^{-1}). Approximately at 8-9 leaf stage, all treatments showed a clear recovery from Zn deficiency stress. This recovery capacity manifested itself more and earlier with increasing slurry rates. From anthesis to harvest, all treatments, except for no Zn or slurry applications, didn't show any Zn deficiency symptoms.

3.2 Plant Growth

At harvest, stem height, stem diameter and leaf area showed significant quadratic responses towards slurry rates. Regression analysis showed that slurry rates around 50 t ha^{-1} induced similar growth responses to Zn fertilization. Both of them improved stem height, stem diameter and leaf area approximately by 9%, 10% and 25%, respectively, compared to no Zn or slurry applications (Figures 1A, 1B and 1C). Maximum growth was recorded with high slurry spread between 240 and 300 t ha^{-1}. It provided an increase that reaches almost 19%, 29% and 92 % on stem height, stem diameter, and leaf area, respectively.

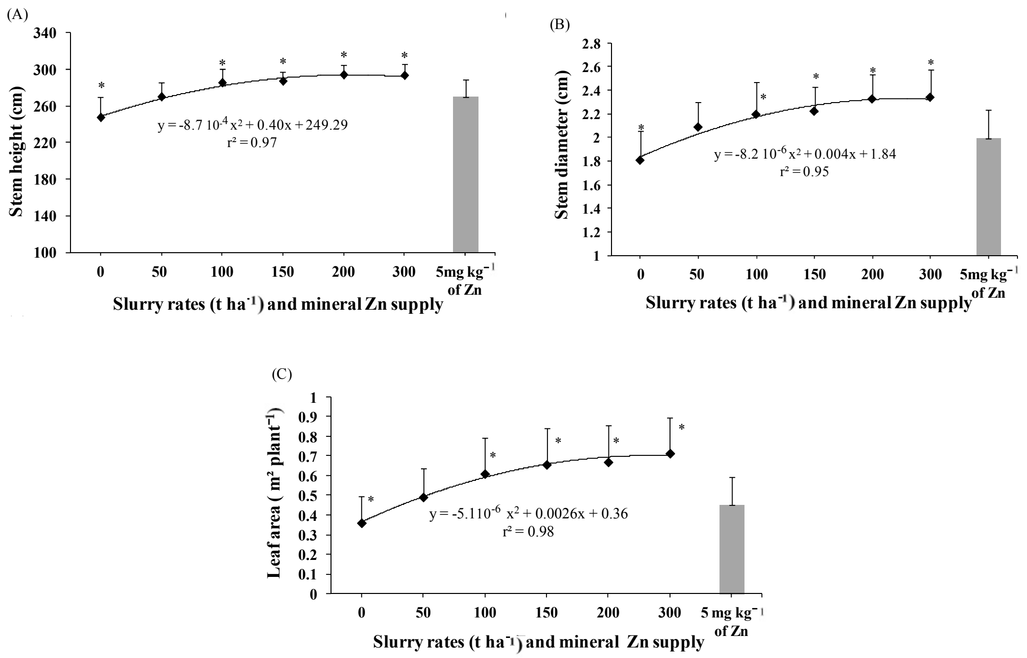

Figure 1. Stem height (A) stem diameter (B) and leaf area (C) of corn silage at harvest following application of dairy cattle slurry rates or mineral Zn. Vertical bars denote standard deviation. * The value differed from Zn treatment using Dunett test ($p \leq 0.05$)

3.3 Silage Yield and Shoot Dry Matter Partitioning

Dairy slurry or mineral Zn applications provided a significant rise in silage yield. This latter had quadratic response towards slurry spread. A rate of 63 t ha^{-1} had similar response to mineral Zn supply. Both of them induced a silage yield rise of 37.5% compared to no Zn or slurry applications (Figure 2). The maximum yield was recorded with high slurry rate of 292 t ha^{-1}, which induced an increase of 94.78% compared to no Zn or slurry applications.

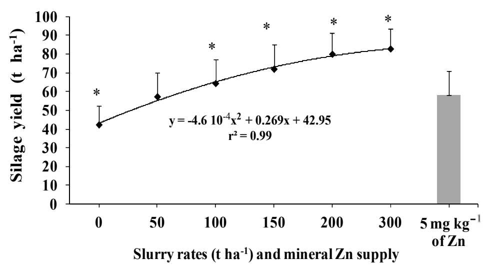

Figure 2. Corn silage yield following application of dairy cattle slurry rates or mineral Zn. Vertical bars denote standard deviation. * The value differed from Zn treatment using Dunett test ($p \leq 0.05$)

Through the analysis of shoot dry matter partitioning, we noted that leaves, stem and ears dry weights increased significantly with the addition of slurry or Zn (Figure 3A). 50 t ha^{-1} of slurry or Zn supply provided increases of approximately 28.4%, 37% and 10.5% on ear, stem and leaves dry weights, respectively, compared to no Zn or slurry applications. These increases were approximately of 43.9%; 101% and 82.5%, respectively, from slurry rate of 150 t ha^{-1}. The ear biomass partitioning analysis showed that kernels, husks and cob dry weights responded significantly to slurry and Zn treatments (Figure 3B). Compared to no Zn or slurry applications, Zn supply resulted in kernels dry weight rise of 31.2%, which was similar to the increase achieved with slurry spread of 50 t ha^{-1} while slurry application of 50 t ha^{-1} provided an increase of approximately 47.5%. Husks and cob dry weights showed significant increases of 35.1% and 36.3%, respectively, either with slurry or Zn applications.

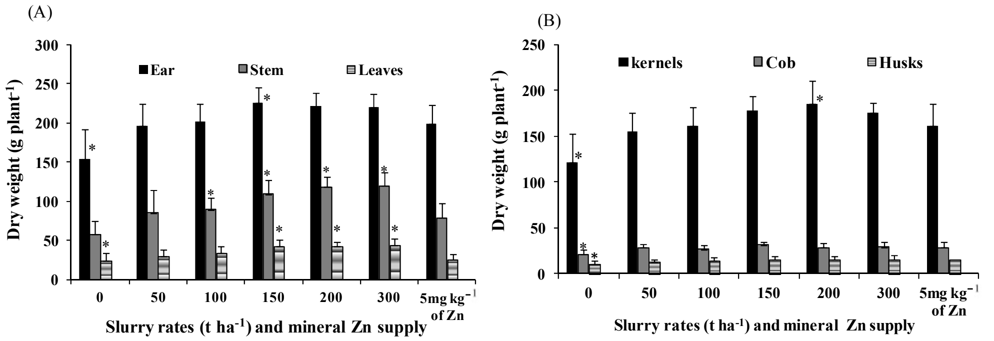

Figure 3. Shoot dry weight partitioning on different plant parts of corn silage (A and B) following application of dairy cattle slurry rates or mineral Zn. Vertical bars denote standard deviation. * The value differed from Zn treatment using Dunett test ($p \leq 0.05$)

In order to explain the kernels dry weight response, different kernels yield components were measured. No significant difference in the total number of ovules per ear was noted between different treatments (Figure 4A). However, the pollination rate was significantly enhanced by 7.2% with all slurry or mineral Zn applications (Figure 4B). The thousand kernels dry weight significantly improved; Zn or slurry rate of 68 t ha^{-1} induced an increase of 15.1% compared to no Zn or slurry applications while high slurry rate of 255 t ha^{-1} resulted in the highest rise of 25.7% (Figure 4C).

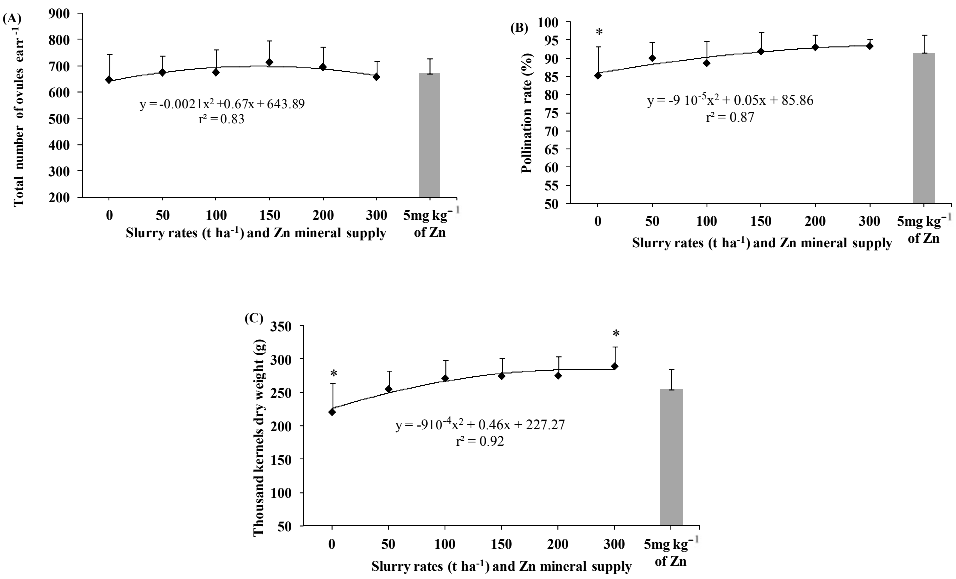

Figure 4. Number of ovules per ear (A), pollination rate (B) and thousand kernels dry weight (C) of corn silage following application of dairy cattle slurry rates or mineral Zn. Vertical bars denote standard deviation. * The value differed from Zn treatment using Dunett test ($p \leq 0.05$)

3.4 Mineral Shoot Content at Harvest

3.4.1 Shoot Zn Content

Zn deficient plants (no Zn or slurry applications) had low shoot Zn content at harvest (16 mg kg^{-1}). This content increased significantly either with slurry or Zn applications (Figure 5). We recorded the highest concentration of 31.67 mg kg^{-1} with Zn supply. Slurry rate of 63 t ha^{-1}, which induced similar yield to Zn fertilization, had a content of 18.60 mg kg^{-1} while a high amount of slurry 200-300 t ha^{-1}, which maximized yield, had a Zn content of around 22 mg kg^{-1}.

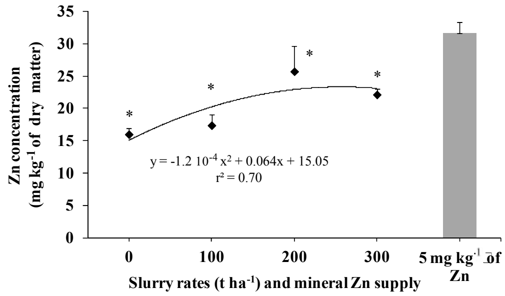

Figure 5. Shoot Zn concentration in corn silage at harvest following application of dairy cattle slurry or mineral Zn supply. Vertical bars denote standard deviation. * The value differed from Zn treatment using Dunett test ($p \leq 0.05$)

3.4.2 Shoot Content on N, P, K, Ca and Mg

High slurry rates (200-300 t ha^{-1}) resulted in a slightly significant increase in N and k shoot content compared to other treatments. They had N and K shoot contents around 1.1% and 0.92%, respectively. Under low slurry rates or Zn supply, these contents were around 0.96% and 0.70%, respectively. The P, Ca, and Mg shoot concentration, even if they were significantly enhanced with slurry rates, stay around 0.24%, 0.13% and 0.09%, respectively, for all treatments (Table 4).

Table 4. Macronutrients concentration (% of shoot dry matter) on corn silage at harvest following applications of dairy cattle slurry spread (t ha^{-1}) or mineral Zn supply

	N	P	K	Ca	Mg
0	0.96±0.05	0.25±0.01*	0.71±0.03	0.07±0.02*	0.14±0.01
100	0.99±0.01	0.24±0.00*	0.78±0.01*	0.07±0.02*	0.13±0.01*
200	1.14±0.01*	0.23±0.00*	0.91±0.01*	0.09±0.02	0.11±0.00*
300	1.13±0.11*	0.24±0.01*	0.93±0.01*	0.10±0.02	0.12±0.01*
5 mg kg^{-1} of Zn	0.95±0.00	0.27±0.00	0.66±0.03	0.13±0.01	0.16±0.01
F test	+	+	+	+	+

Note. Data are the means± standard deviation. * The value differed from Zn treatment using Dunett test ($p \leq 0.05$).

3.5 Soil Extractable Residual Zn

Soil analysis at the next cropping season showed a significant increase in residual DTPA extractable Zn either with addition of slurry or Zn (Figure 6). Slurry application of 300 t ha^{-1} induced the highest DTPA extractable Zn of 0.96 mg kg^{-1} while mineral Zn supply provided an amount of 0.26 mg kg^{-1}.

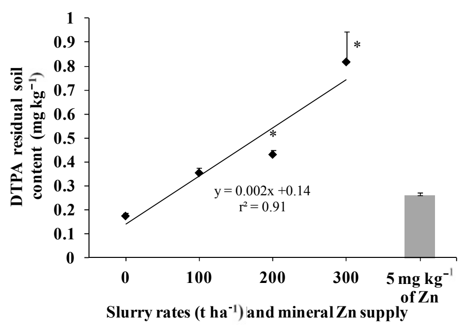

Figure 6. Residual soil DTPA extractable Zn, following application of dairy slurry or mineral Zn, in the next cropping season. Vertical bars denote standard deviation. * The value differed from Zn treatment using Dunett test ($p \leq 0.05$)

4. Discussion

Based on this investigation, slurry spread can substitute Zn mineral supply to prevent Zn deficiency on corn silage grown on sandy soil. Slurry rates between 50 and 60 t ha^{-1} showed similar growth and yield to the adequate Zn mineral supply.

4.1 Zn Deficiency Symptoms

The appearance of Zn deficiency symptoms is especially due to the low Zn content of soil 0.13 mg kg^{-1}, which was below the critical level required for corn production 0.8 mg kg^{-1} (Lindsay & Norvel, 1977). Their appearance at an earlier stage was already reported by other authors (Wang & Jin, 2007; Kuldeep & Banerjee, 1986). The obvious decline of Zn deficiency symptoms with slurry application, as well as mineral Zn supply, proved the role of dairy slurry in preventing Zn deficiency.

4.2 Plant Mineral Content and Growth

Shoot Zn content was enhanced with the addition of slurry as well as Zn supply. Sufficient Zn content, 22 mg kg^{-1} (Singh et al., 2005), was recorded either with slurry rates up or equal to 150 t ha^{-1} or with mineral Zn supply. Zn concentration didn't reach Zn phytotoxic concentration, above 95 mg kg^{-1} (Gupta, Kening, & Siyuan, 2008), despite high slurry rates. On the other hand, even if slurry rates around 50 t ha^{-1} didn't increase shoot Zn content to reach sufficient level, we observed an obvious correction of Zn deficiency symptoms. The beneficial effects of other nutrients supplied by slurry cannot be excluded even if all treatments had received adequate mineral fertilization of macro and micro nutrients. But, such effects remain weak compared to our limited and controlled nutrient factor of Zn. In fact, plants with Zn mineral supply had approximately similar shoot content of N, P, Mg, and Ca as slurry treatments. For all these treatments, we recorded that shoot N content (≈ 0.95%) was approximately equal to the required level of corn at maturity (1%) (Fageria, Baligar, & Jones, 2011). Also, shoot P content (≈ 0.24%) was around the required level ranging between 0.1% and 0.5% (Arnon, 1975), and the shoot Mg concentration (≈ 0.13%) was around the adequate concentration of 0.2% (Fox & Piekielek, 1984). Although the increase of shoot K content was recorded with high slurry rates (200-300 t ha^{-1}), all treatments had contents around the required level (between 0.7% and 0.9%) (Arnon, 1975), and no K deficiency symptoms were noticed. Plant growth was enhanced either with slurry or Zn application. The effect of Zn on stem stretching can be explained by the role of Zn in the metabolism of indole-acetic acid (IAA) as a growth regulator enzyme (Cakmak, Marshner, & Bangerth, 1988). Also, the leaf area and stem diameter were also enhanced. A significant increase of leaf area due to Zn fertilization was noted on corn by Chaab, Savaghebi, Gh, and Motesharezadeh (2011) and on wheat by Khan, Fuller, and Baloch (2008).

4.3 Silage Yield and Dry Matter Partitioning

Silage yield improved either with slurry or Zn applications. 63 t ha^{-1} of slurry resulted in similar yield to the adequate Zn mineral supply. Such slurry rate brought a Zn amount of 1.40 kg ha^{-1} which was lower than the adequate Zn mineral supply (20.25 kg ha^{-1}). This result proved that the effectiveness of Zn contained in slurry is higher than the mineral one. We may explain that by the fact that Zn organic forms, contained in slurry, are more efficient than Zn mineral compounds (Ortega-Blu & Molina-Roco, 2007; Chatterjee & Mandal, 1985; Chand et al., 1981). This also can be explained by the enhancement of soil born Zn availability through the action of organic matter (Nikoli & Matsi, 2011). On the other hand, maximum silage yield was recorded with high slurry rate of 292 t ha^{-1}. This result is consistent with earlier studies of Sutton, Nelson, Kelly and Hill (1986), who reported that liquid dairy manure rate of 224 t ha^{-1} maximized corn yields. Also, Schröder and Dilz (1987) showed that maize forage yield was promoted with cattle slurry application up to 200-300 t ha^{-1}. However, such rate brought an over amount of N (1171 kg ha^{-1}) which may threaten the environment through nitrate leaching. In this context, the nitrate directive of the European Union stated that animal manure application, for a given year, must be around an equivalent amount of 170 -210 kg on N ha^{-1} (European Union, 1991). The biomass weight decline under Zn deficiency (no slurry or Zn applications) can partially be attributed to limited photosynthesis rate (Hansch & Mendel, 2009) due to both disruption in carbonic anhydrase enzyme activity (Sasaki, Hirose, Watanabe, & Ohsugi, 1998) and chlorophyll synthesis (Cakmak & Marshner, 1993).

The dry matter partitioning analysis showed that enhancement of silage yield due to addition of slurry or Zn was mainly attributed to the increase of stem and kernels dry weights. Lithourgidis, Matsi, Barbayiannis and Doras (2007) reported that liquid cattle manure enhanced silage and kernels maize yields. The kernels dry matter, which represented about 50% of shoot dry weight (Figure 2), was mainly enhanced by two components: pollination rate and thousand kernels dry weight. A similar result was reported under Zn foliar spray on corn silage grown on Zn deficient sandy soil (Drissi, Aït Houssa, Bamouh, & Benbella, 2015). Under Zn deficiency, the pollination rate decline can be explained by mal sterility (Sharma, Chatterjee, & Saharma, 1990) while the decrease of thousand kernels weight could be attributed to the photosynthesis decline mentioned above.

4.4 Residual Soil DTPA Extractable Zn

Soil analysis at the next cropping season showed that slurry improved residual DTPA extractable Zn, but only high rate (300 t ha^{-1}) resulted in sufficient residual amount of 0.92 mg kg^{-1}, which was above the critical level of 0.83 mg kg^{-1} required for corn (Lindsay & Norvell, 1977). The Zn soil enrichment due to slurry spread can be explained by its role as a source of Zn, and by its organic matter's role in releasing native soil Zn (Nikoli & Matsi, 2011).

5. Conclusion

A dairy cattle slurry rate ranging between 50 and 60 t ha^{-1} prevented Zn deficiency and showed similar plant growth and silage yield as the adequate mineral Zn supply (5 mg kg^{-1} of Zn as $ZnSO_4 \cdot 7H_2O$). High dairy slurry rates (200 and 300 t ha^{-1}) maximized yield but brought an over amount of N which may pose a threat to the environment.

Acknowledgements

The authors would like to think Mr. Loultiti M. M. and Mr. Coquant J. M. for their financial support. We are grateful to Pr. Maataoui A. and Pr. El Midaoui M. for their valuable help during manuscript preparation. We acknowledge the contribution of Mrs. Mouhtadi R., Mrs. Zehri B., Mr. Ziti S., Mr. Soulaimani A., and Mr. Touhami D. during laboratory analysis. Special appreciation is expressed to Mr. Belbassri M. for his cooperation in conducting the experiment. Also, we address our acknowledgements to Dr. Yachoulti M. and Mr. El Gharradi Y. for language correction.

References

Alloway, J. B. (2008). *Zinc in soils and crop nutrition* (2nd ed.). International Zinc Association Communications. IZA Publications, Brussel. Retrieved from http://www.zinc.org/general/Zinc_in_Soils_and_Crop_Nutrition_ALLOWAY.pdf

Arnon, I. (1975). *Mineral nutrition of maize*. International Potash Institute, Bern. Retrieved from http://www.ipipotash.org/udocs/mineral_ nutrition_ of_ maize.pdf

Beckwith, C. P., Cooper, J., Smith, K. A., Shepherd, M. A. (1998). Nitrate leaching loss following application of organic manures to sandy soils in arable cropping. I. Effects of application time, manure type, overwinter crop cover and nitrification inhibition. *Soil Use and Management, 14*, 123-130. http://dx.doi.org10.1111/j.1475-2743.1998.tb00135.x

Berenguer, P., Cela, S., Santiveri, F., Boixadera, J., & Lloveras, J. (2008). Copper and Zinc Soil Accumulation and Plant Concentration in Irrigated Maize Fertilized with Liquid Swine Manure. *Agronomy Journal, 100*, 1056-1061. http://dx.doi.org/10.2134/agronj2007.0321

Bhupinder, S., Senthil, K. A. N., Singh, B. K., & Usha, K. (2005). Improving zinc efficiency of cereals under zinc deficiency. *Current Science, 88*, 36-44. Retrieved from http://eprints.icrisat.ac.in/46/

Cakmak, I. (2008). Enrichment of cereal grains with zinc: Agronomic or genetic biofortification? *Plant and Soil, 302*, 1-17. http://dx.doi.org/10.1007/s11104-007-9466-3

Cakmak, I., & Marshner, H. (1993). Effect of zinc nutritional status on activities of superoxide radical and hydrogen peroxide scavenging enzymes in bean leaves. *Plant and Soil, 155-156*, 1127-1130. http://dx.doi.org/10.1007/BF00025000

Cakmak, I., Marshner, H., & Bangerth, F. (1988). Effect of zinc nutritional status on growth, protein metabolism and levels of indole 3 acetique acid and other phytohormones in bean (*Phaseolus vulgaris*). *Journal of Experimental Botany, 40*, 405-412. http://dx.doi.org/10.1093/jxb/40.3.405

Chaab, A., Savaghebi, Gh. R., & Motesharezadeh, B. (2011). Differences in the zinc efficiency among and within maize cultivars in a calcareous soil. *Asian Journal of Agricultural Sciences, 3*, 26-31. Retrieved from http://www.maxwellsci.com/print/ajas/v3-26-31.pdf

Chand, M., Randhawa, N. S., & Bhumbla, D. R. (1981). Effectiveness of zinc chelates in zinc nutrition of greenhouse rice crop in a saline–sodic soil. *Plant and Soil, 59*, 217-225. http://dx.doi.org/10.1007/BF02184195

Chatterjee, A. K., & Mandal, L. N. (1985). Zinc sources for rice in soil at different moisture regimes and organic matter levels. *Plant and Soil, 87*, 393-404. http://dx.doi.org/10.1007/BF02184195

Chintala, R., McDonald, L. M., & Bryan, W. B. (2012a). Effect of soil water and nutrients on productivity of Kentucky blue grass systems in acidic soils. *Journal of Plant Nutrition, 35*, 288-303. http://dx.doi.org/10.1080/01904167. 2012.636131

Chintala, R., McDonald, L. M., & Bryan, W. B. (2012b). Optimization of water potential and nutrient levels for Kentucky bluegrass-white clover mixture on acidic soils. *Biotechnology, Agronomy, Society and Environment, 16*, 167-177. Retrieved from http://www.popups.ulg.ac.be/1780-4507/index.php?id=8619

Chintala, R., Mollinedo, J., Schumacher, T. E., Malo, D. D., Papiernik, S., Clay, D. E., … Gulbrandson, D. W. (2013). Nitrate sorption and desorption in biochars from fast pyrolysis. *Microporous and Mesoporous Materials, 179*, 250-257. http://dx.doi.org/10.1016/j.micromeso.2013.05.023

Chintala, R., Schumacher, T. E., McDonald, L. M., Clay, D. E., Malo, D. D., Clay, S. A., ... Julson, J. L. (2014). Phosphorus sorption and availability in biochars and soil biochar mixtures. *CLEAN-Soil Air Water, 42*(5), 626-634. http://dx.doi.org/10.1002/clen.201300089

De Vasconcelos, A. C. F., Clístenes, W. A. N., & Fernando, F. C. F. (2011). Distribution of zinc in maize plants as a function of soil and foliar Zn supply. *International Research Journal of Agricultural Science, 1*, 1-5. Retrieved from http://interesjournal.org/IRJAS/Pdf/2011/March/de%20Vasconcelos%20et%20al.pdf

Drissi, S., Aït Houssa, A., Bamouh, A., & Benbella, M. (2015). Corn silage (*Zea mays* L.) response to zinc foliar spray concentration when grown on sandy soil. *Journal of Agricultural Science, 7*, 68-79 http://dx.doi.org/10.5539/jas.v7n2p68

European Union. (1991). Council directive 91/676/EEC of 12 December concerning the protection of waters against pollution caused by nitrates from agricultural sources. *Official Journal of the European Communities*, L375. Brussels, Belgium. Retrieved from http://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=OJ:L:1991:375:FULL&from=EN

Fageria, N. K., Baligar, V. C., & Jones C. A. (Eds.). (2011). *Growth and mineral nutrition of field crops* (3rd ed.). Taylor and Francis Group.

Fox, R. H., & Piekielek, W. P. (1984). Soil magnesium level, corn (*Zea mays* L.) yield, and magnesium uptake. *Communications in Soil Science and Plant Analysis, 15*, 109-123. http://dx.doi.org/10.1080/00103628409367459

Gupta, U. C., Kening, W. U., & Siyuan, L. (2008). Micronutrients in soils, crops, and livestock. *Earth Science Frontiers, 15*, 110-125. http://dx.doi.org/10.1016/S1872-5791(09)60003-8

Hansch, R., & Mendel, R. R. (2009). Physiological functions of mineral micronutrients (Cu, Zn, Mn, Fe, Ni, Mo, B, Cl). *Current Opinion in Plant Biology, 12*, 259-266. http://dx.doi.org/10.1016/j.pbi.2009.05.006

Khan, M. A., Fuller, M. P., & Baloch, F. S. (2008). Effect of soil applied zinc sulphate on wheat (*Triticum aestivum* L.) grown on a calcareous soil in Pakistan. *Cereal Research Communications, 36*, 571-582. http://dx.doi.org/10.1556/CRC.36.2008.4.6

Kuldeep, S., & Banerjee, N. K. (1986). Growth and zinc content of maize (*Zea mays* L.) as related to soil-applied zinc. *Field Crops Research, 13*, 55-61. http://dx.doi.org/10.1016/0378-4290(86)90007-9

Lindsay, W. L., & Norvell, W. A. (1977). Development of a DTPA soil test for zinc, iron, manganese, and copper. *Soil Science Society of America Journal, 42*, 421-428. http://dx.doi.org/%2010.2136/sssaj1978.03615995004200030009x

Lithourgidis, A. S., Matsi, T., Barbayiannis, N., & Doras, C. A. (2007). Effect of liquid cattle manure on corn yield, composition, and soil properties. *Agronomy Journal, 99*, 1041-1047. http://dx.doi.org/10.2134/agronj2006.0332

Matsi, T., Lithourgidis, A. S., & Gagianas, A. A. (2003). Effects of injected liquid cattle manure on growth and yield of winter wheat and soil characteristics. *Agronomy Journal, 95*, 592-596. http://dx.doi.org/10.2134/agronj2003.0592

Mokhtarpour, H., Teh, C. B. S., Saleh, G., Selamat, A. B., Asadi, M. E., & Kamkar, B. (2010). Non destructive estimation of maize leaf area, fresh weight, and dry weight using leaf length and leaf width. *Communications in Biometry and Crop Science, 5*, 19-26. Retrieved from http://agrobiol.sggw.waw.pl/~cbcs/articles/CBCS_5_1_4.pdf

Murphy, L. S., & Walsh, L. M. (1972). Correction of micronutrients deficiencies with fertilizers. In J. J. Mortvedt, P. M. Giordano & W. L. Lindsay (Eds.), *Micronutrients in Agriculture*, Soil Science Society of

America (pp. 371-381). Retrieved from https://dl.sciencesocieties.org/publications/books/pdfs/sssabookseries/micronutrientsi2/frontmatter

Nikoli, T., & Matsi, T. (2011). Influence of liquid cattle manure on micronutrients content and uptake by corn and their availability in a calcareous soil. *Agronomy Journal, 103*, 113-118. http://dx.doi.org/10.2134/agronj2010.0273

Ortega-Blu, R., & Molina-Roco, M. (2007). Comparison between sulfates and chelated compounds as sources of zinc and iron in calcareous soils. *Agrociencia, 41*, 491-502. Retrieved from http://www.colpos.mx/agrocien/Bimestral/2007/jul-ago/art-1.pdf

Sasaki, H., Hirose, T., Watanabe, Y., & Ohsugi, R. (1998). Carbonic anhydrase activity and CO_2 transfer resistance in Zn deficient rice leaves. *Plant Physiology, 118*, 929-934. http://dx.doi.org/10.1104/pp.118.3.929

Schröder, J. J., Ten Holte, L., & Brourwer, G. (1997). Response of silage maize to placement of cattle slurry. *Netherlands Journal of Agricultural Science, 45*, 249-261. Retrieved from https://library.wur.nl/ojs/index.php/njas/article/view/516/230

Schröder, J., & Dilz, K. (1987). Cattle slurry and farmyard manure as fertilizers for forage maize. In H. G.Van Der Meer, R. J. Unwin, T. A. Van Dijk & G. C. Ennik (Eds.), Animal manure on grassland and fodder crops: Fertilizer or waste? *Developments in Plant and Soil Sciences* (Vol. 30, pp. 137-156). http://dx.doi.org/10.1007/978-94-009-3659-1_9

Sharma, P. N., Chatterjee, A. S. C., & Saharma, C. P. (1990). Zinc deficiency and pollen fertility in maize (*Zea mays*). *Plant and Soil, 124*, 221-225. http://dx.doi.org/10.1007/BF00009263

Sinclair, A. H., & Edwards, A. C. (2008). Micronutrient deficiency problems in agricultural crops in Europe. In B. J. Alloway (Ed.), *Micronutrients deficiencies in global crop production* (pp. 225-244). http://dx.doi.org/10.1007/978-1-4020-6860-7_9

Singh, B., Natesan, S. K. A., Singh, B. K., & Usha, K. (2005). Improving zinc efficiency of cereals under zinc deficiency. *Current Science, 88*, 36-44. Retrieved from http://www.iisc.ernet.in/currsci/jan102005/36.pdf

Sutton, A. L., Nelson, D. W., Kelly, D. T., & Hill, D. L. (1986). Comparison of solid vs. liquid dairy manure applications on corn yield and soil composition. *Journal of Environmental Quality, 15*, 370-375. http://dx.doi.org/10.2134/jeq1986.00472425001500040010x

Van Biljon, J. J., Wright, C. A., Fouche, D. S., & Botha, A. D. P. (2010). A new optimum value for zinc in the main maize producing sandy soils of South Africa. *South African Journal of Plant and Soil, 27*, 252-255. http://dx.doi.org/10.1080/02571862.2010.10639994

Walkley, A., & Black, I. A. (1934). An examination of the Degtjareff method for determining soil organic matter, and a proposed modification of chromic acid titration method. *Soil Science, 37*, 29-38. http://dx.doi.org/10.1097/00010694-193401000-00003

Wallingford, G. W., Murphy, L. S., Powers, W. L., & Manges, H. L. (1975). Effects of beef-feedlot manure and lagoon water on iron, zinc, manganese and copper content in corn and in DTPA soil extracts. *Soil Science Society of America Journal, 39*, 482-487. http://dx.doi.org/10.2136/sssaj1975.03615995003900030031x

Wang, H., & Jin, Ji-Y. (2007). Effects of zinc deficiency and drought on plant growth and metabolism of reactive oxygen species in maize (*Zea mays* L.). *Agricultural Sciences in China, 6*, 988-995. http://dx.doi.org/10.1016/S1671-2927(07)60138-2

Copyrights

Copyright for this article is retained by the author(s), with first publication rights granted to the journal.

This is an open-access article distributed under the terms and conditions of the Creative Commons Attribution license (http://creativecommons.org/licenses/by/3.0/).