J. Soil Sci. and Agric. Eng., Mansoura Univ., Vol. 4 (8): 777 - 791, 2013

IMPACT OF STEEL SLAG APPLICATION ON NUTRIENTS AVAILABILITY AND CORN YIELD GROWN ON SALINE SOIL

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ABSTRACT

A greenhouse pot experiment was conducted to evaluate the effectiveness of arc furnace steel slag as a silicon source on the nutrients availability and corn yield in alluvial soil. The experimental treatments were 0, 500 and 1000 kg steel slag/fed, and 1.68, 3.0 and 6.0 dSm^{-1} soil salinity treatments. Response variables measured included yield of grains and stover, content of nutrients and metals in leaves and grains, and the available nutrients and metals remained in the soil after corn harvest. Grains and stover yields decreased progressively with increasing salinity levels in the absence of steel slag. Application of steel slag mitigated the deterioration effect of salinity stress. Grain yield markedly increased with slag applications and optimized (16.7%) with 500 kg slag rate at 3.0 dSm^{-1} salinity level. At 6.0 dSm^{-1} salinity, the increase in grains yield was mild (10.6%) at both rates of slag (500 and 1000 kg fed^{-1}). Stover yield, though increased with slag application under salinity stress, but the increase was inconsistent. Steel slag applications significantly reduced Na and increased Ca, Mg, K and P contents in leaves and grain under saline conditions, with a greater response for P. Zinc content increased, and Fe decreased in leaves and grain with salinity in absence of steel slag, while applications of steel slag did not affect Zn content in grain and straw at any level of salinity but promoted Fe content. The changes in Cu content were very limited. The contents of Cd, Ni, Pb and Cr were slightly changed with slag application and lie within the ranges being sufficient for corn.

The available K increased with salinity in absence of slag. When slag added, available K content was rather increased with no consistent trend. Available P tended to decrease with salinity increasing, but markedly increased in the presence of slag at the same level of salinity. At 1000 kg slag rate, the available P was nearly twice than that of control either at 3.0 or 6.0 dS m^{-1} salinity level. Available Na and Si were higher in saline soils-untreated with slag. When slag applied, available Na decreased at any level of salinity, while available Si was slightly affected. This pattern was abundant with 500 kg slag rather than 1000 kg slag rate, suggesting that most of available Si combined with Na which inhibited Na translocation to plant tissues and hence its phytotoxicity. Available Fe increased with salinity, but rather increased with steel slag application. Copper, Zn and Ni availability were not affected with either salinity or slag application. In all cases the availability of the tested metals was not higher than the guide values assessing soil contamination by heavy metals. The application of the steel slag at 500 kg fd^{-1} was found to be more safety from the environmental point of view and agronomic benefits. However, field trails are still needed to confirm the greenhouse results.

Keywords: Salinity, steel slag, corn, available nutrients and heavy metals.

INTRODUCTION

Plants assimilate silicon in monomeric form ($Si(OH)_4$) in quantities ranging from 70 to 700kg Si ha^{-1} (Bazilevich, 1993). This leads to the lack of active Si compounds in the soil, decrease in crop production and reduction in soil fertility. The comprehensive review of Epstein (1994) figure out the role of Si on mitigates biotic and abiotic stress to plants, including salinity. The studies of interaction between Si and salinity suggest that Si deposition in leaf limits plant transpiration and hence salt accumulation (Matoh *et al.*, 1986). The reduction of Na uptake via the act of silicate was illustrated by Yeq *et al.* (1999) as a matter of partial blocking of the transpirational bypass flow rather than a reduction in the plant transpiration rate. Accumulation of salts associated with organic granular structure in the cytoplasm of some halophytes is considered as one of the adaptive mechanisms of salt tolerance (Ahmad, 1968). The analysis of these salt- impregnated organic structures shows the presence of 3% SiO_2 in addition to other salts which may indicate the role of Si in ameliorating salt tolerance. Silicon accumulation in some halophytic species grown in Qattara Depression of Egypt as reported by El-Ghonemy, at al. (1982) was 2.1 to 5.4% range, which further stressed the role of Si in salt tolerance of plants. In a greenhouse study, Daoud (2005) demonstrated that application of Si as sodium silicate at 1.76 mM SiO_2 increased the resistance of wheat (Triticum aestivum L.) to salinity stress and improved the grain yield by about 40% as compared to Si-free salinity treatments. Previous finding of Helal (2006) showed that added silicon to soil cultivated by corn significantly enhanced superoxide dismutase (SOD) and catalyze (CAT) enzymes, besides improvement in phytosynthetic and chlorophyll content which generally mitigate the dexterous effect of salinity. The perspectives of Si fertilization in the world (FAO data base, www.fao.org) indicated minimum guaranteed crop increase as follow: 10% (orange), 20% (maize), 25% (potato), 25% (rice, paddy), 15% (sugar beet), 25% (sugar-cane) and 20% (wheat). Additionally, silicon was reported to enhance pollen fertility of some crops (Miyake and Takahashi, 1983 and 1986), thereby overcoming the adverse effects of salinity on grain yield. Application of Si was found to increase P availability in soils with salt accumulation (Lee *et al.*, 2004), alleviate heavy metals toxicity and nutrient imbalance (Hadson and Evans, 1995; Mali and Aery, 2008 and Cunha *et al.*, 2008). Silicon was also reported to eliminate fungal and pathogen infection (Samuels *et al.*, 1991, Wiese *et al.*, 2005 and Mary *et al.*, 2010).

As reported by Hamilton and Cabral (2005), steel metallurgy slag is a useful source of high soluble Si content available to plant and has a long residual effect (3-5 years), and of poor heavy metal contents. Amaral *et al.* (1995, after Hamilton and Cabral, 2005) found that application of steel slag up to 25 ton ha^{-1}, made during 10 years period, did not result in heavy metals contamination.

The aims of this study was to evaluate the effect of electric arc furnace (EAF) steel slag of Ezz- Dekheilah steel company at Alexandria as a silicon source to mitigate salinity stress on corn (Zea mays L.). Plant growth, yield of corn and contents of nutrients and heavy metals in leaf and grains were discussed. The residual heavy metals in the slag treated soils after corn harvest were also investigated.

MATERIALS AND METHODS

Experimental layout

This experiment was conducted at the Soil Salinity Laboratory at Sabahia in Alexandria using non –saline alluvial soil collected from Kafr El-Dawar district (see Table 1 for some soil physical and chemical properties). The soil was packed in plastic pots (50 cm diameter and 40 cm height) with an out let at the bottom for drainage. Each pot contained 35 kg soil. Seeds of corn (Zea mays L., single cross hybrid 162) were planted on May 28, 2011 and kept at uniform density of 2 plants per pot. Prior to cultivation, the steel slag was mixed with the soil pots at rates of 0, 500, and 1000 kg/fed. Three soil salinity levels were used as follow: original soil of EC 1.68 dSm^{-1} (control) and artificially saline soil of EC_s 3.0 and 6.0 dSm^{-1}. Salinization of the soil was maintained by subsequent irrigation with saline waters of EC_s 3.0 and 6.0 dSm^{-1} until the EC of the effluent solutions became equal to those of the corresponding saline applied waters. Sea water was diluted to obtain the desired levels of the irrigation water salinity. Three replicates were carried out for each treatment in a complete randomized design. Phosphorus (superphosphate, 15.5% P_2O_5) and potassium (potassium sulfate, 50% K_2O) fertilizers were added uniformly in all pots as basal dressing at rates of 30 kg P_2O_5 and 36 Kg K_2O per feddan, respectively. Nitrogen (ammonium nitrate, 34% N) fertilizer at rate of 120 Kg N/fed was splited into two equal portions added after thinning and 20 days later. Fresh water (EC 0.3 dSm^{-1}) was applied for 2 weeks to all seeded pots in amounts lower than the soil field capacity (FC) to enhance seed germination and plant establishment. Subsequent irrigation with the saline water treatments was practiced onward according to the plant needs with an extra 20% over the soil F.C. to prevent the salt accumulation in rhizosphere. The percolated solutions of the experimental pots were collected every two weeks and analyzed for EC and concentrations of Na^+ and Cl^- to ensure the salinity status in rhizosphere.

At silk stage, samples of the entire ear leaf were collected and washed with distilled water, dried at 70°c for 24 hr and ground in stainless steel blender and kept for chemical analysis. At teaseling, the plant height was measured. At maturity, the plants were cut just above the soil surface where yields of stover and grains were recorded. Samples of grain were collected, air dried, ground in stainless steel blender to pass a 20-mech screen and stored for chemical analysis. After harvest, samples were collected from each pot for chemical analysis.

Because the steel slag had high pH value (11.14), a laboratory study was made to figure out its effect on the soil reaction. The steel slag was mixed with the soil at rates of 500 and 1000kg/fed. The treated soil was suspended in distilled water (1:2.5 ratio), shaked for 3hr, and measured for pH.

Analysis

The main chemical properties of the soil (EC, pH, soluble cations and anions) were measured in saturated paste extract according to the methods outlined by Page *et al.* (1982). The soil field capacity (F.C.) and particle size distribution were measured according to Black *et al.* (1965). Organic matter content was determined according to Walkely and Black method, (Mckeague, 1979). The soil available–P was extracted with 0.5 M $NaHCO_3$, pH 8.5 and measured calorimetrically (Olsen and Sommer, 1982). Available Ca, Mg, K and Na were extracted with neutral normal NH_4OAC (Knudsen *et al.*, 1982) and measured according to Page *et al.* (1982). Available Si was extracted with 0.5 M NH_4OAC of pH 4.8 (Fox *et al.*, 1967) and measured colorimetrically (Iler, 1979). Available Fe, Mn, Zn, Cu, Cd, Pb and Ni were extracted using DTPA as recommended by Lindsay and Norvell (1978) and measured by Atomic Absorption Spectrometer (AAS, 3300 Perkin Elmer).

Duplicate samples of the steel slag were digested using acids mixture of HNO_3+ HCl+ $HClO_4$ at 3:1:1 ratio (Cottenie *et al.*, 1982) and analyzed for total P (Page *et al.*, 1982), Si, Ca, Mg, Zn, Ni, Cu, Fe, Cr and Cd using AAS. Electrical conductivity and pH were measured in 1:10 slag/water ratio (w/v). Available Si, P, Ca and Mg, and DTPA extractable metals were analyzed as previously outlined.

The samples of leaves and grains were digested with HNO_3 and $HClO_4$ at 3:1 ratio (Cottenie *et al.* 1982) and measured for Ca, Mg, Na, K, Cu, Zn, Fe, Ni, Cr and Cd using AAS. In the same digest, P was measured colorimetrically using yellow molybdo – vanado complex method (Chapman and Pratt, 1961). Nitrogen was determined according to Bremner and Mulvaney (1982). The silicon concentration was determined using colorimetric method (Iler, 1979) after digestion by mixture acids of HNO_3, HCl and HF (Novozamski *et al.*, 1984).

Statistical analysis

All the obtained data were statistically analyzed according to Snedecor and Cochran (1967).

RESULTS AND DISCUSSION

Characterization of soil and steel slag

Some physical and chemical properties of the soil are shown in Table (1). The data show that the soil is loamy texture, non-saline, slightly alkaline and non-calcareous with moderate content of available nutrients. Sodium and chloride are the dominant ions. The available heavy metals are relatively low.

Concerning the steel slag analysis, Table (2) reveals that this slag is non-saline, highly alkaline (pH 11.14) and contains considerable amounts of total silica, calcium and iron, but of low heavy metals content, meaning that it can not consider a source of pollution by heavy metals.

Table (1): Characteristics of the Initial alluvial soil

Parameter	Value
Sand %	37.30
Silt %	42.50
Clay %	20.20
Soil texture class	Loamy
F.C. %	19.2
Total $CaCO_3$ %	1.66
Organic matter %	1.65
EC , dSm^{-1}	1.68
pH	7.69
Soluble cations , $mmol_cL^{-1}$	
Na+	10.00
K+	0.40
Mg^{2+}	2.00
Ca^{2+}	5.00
Soluble anions , $mmol_cL^{-1}$	
Cl^-	14.00
CO_3 + HCO_3	5.00
Available elements , mg kg^{-1}	
Si	25.17
P	8.65
K	30.0
Ca	4.00
Mg	3.12
Na	10.12
DTPA-extractable metals , mg kg^{-1}	
Zn	2.00
Ni	0.50
Cu	4.10
Fe	15.0
Cr	0.20
Cd	0.18

Table 2: Characteristics of steel slag used

Parameter	Value
EC , dSm^{-1}	0.760
pH	11.14
Available elements , mg kg^{-1}	
Si	2835
P	47.00
Ca	14.400
Mg	18.000
DTPA-extractable metals , mg kg^{-1}	
Zn	bdl*
Ni	28.600
Cu	2.100
Fe	137
Cr	bdl*
Cd	bdl*
Total element content , %	
P_2O_5	0.510
Ca	22.100
Mg	5.190
Si	13.200
Zn	0.020
Ni	0.007
Cu	0.006
Fe	6.200
Cr	0.030
Cd	bdl*
Pb	bdl*

***bdl = below detection level of AAS.**

The data in Table (3) show that application of steel slag at rates 500 or 1000 kg/Fed did not affect the pH of the soil, though the slag is highly alkaline. This may be due to the buffering capacity of the soil, besides the low rate of slag additions.

Table (3): Effect of steel slag application on the EC and pH values of soil

Treatment	EC,dSm^{-1}	pH
Original soil	1.68	7.69
Soil + steel slag at rate 500 kg/fed	1.69	7.80
Soil + steel slag at rate 1000 kg/fed	1.71	7.85

Salinization efficiency

The percolated solution from the soil pots were analyzed for EC and concentrations of Na^+ and Cl^- ions as shown in Table (4). The data indicated that the salinization of the soil was kept at the desired salinity treatments with no considerable change in the levels of the major ions throughout the period of the experiment. Therefore, the plant growth parameter and grains yield were obtained under the desired conditions of the experiment.

Table (4): Some chemical data in the effluent solutions of the soil treated with steel slag under salinity stress

Parameter	Leachate No.	Treatments								
		G_0S_1	G_0S_2	G_0S_3	G_1S_1	G_1S_2	G_1S_3	G_2S_1	G_2S_2	G_2S_3
EC, dSm^{-1}	1	1.61	3.80	6.90	1.59	3.34	7.09	1.52	3.02	6.90
	2	1.68	4.45	7.10	1.65	3.32	7.4	1.63	4.17	6.65
	3	1.93	3.38	5.68	1.88	3.32	5.85	1.70	3.15	5.57
	4	1.65	3.60	5.74	1.60	3.32	6.65	1.68	3.32	5.89
	5	1.85	3.80	6.90	1.87	3.93	7.90	1.72	4.40	7.00
Na^+, $mmol_c\ L^{-1}$	1	9.90	26.00	50.00	10.00	21.00	50.00	10.2	21.00	53.0
	2	9.20	34.00	56.00	9.60	24.00	54.00	9.80	29.00	48.00
	3	8.80	20.00	48.00	9.40	27.00	48.00	9.40	26.00	48.00
	4	9.30	22.00	45.00	9.40	24.00	50.00	9.00	24.00	45.00
	5	8.80	25.00	47.00	8.20	18.00	58.00	9.20	29.00	40.00
Cl^-, $mmol_c\ L^{-1}$	1	15.3	28.50	56.00	14.80	28.50	65.00	13.60	30.00	62.00
	2	14.0	35.00	66.00	14.00	30.00	70.00	11.50	43.00	61.00
	3	13.5	27.00	57.00	13.00	30.00	58.00	10.10	27.00	60.00
	4	13.0	26.00	52.00	13.90	27.50	61.00	10.20	30.00	57.00
	5	12.1	26.00	56.00	12.80	30.00	57.00	10.00	27.00	55.00

S_1= Original soil with EC 1.68 dSm^{-1} — G_0= Steel slag rate of 0 kg/fed
S_2= Saline soil with EC 3.0 dSm^{-1} — G_1= Steel slag rate of 500 kg/fed
S_3= Saline soil with EC 6.0 dSm^{-1} — G_2= Steel slag rate of 1000 kg/fed

Effect of steel slag and salinity on some growth parameters

Effects on plant height

Data in Table (5) show that the plant height was decreased from 240 to 220 and 190 cm as the salinity of the soil raised from S_1(1.68 dS/m) to S_2 (3.0 dS/m) and S_3 (6.0 dS/m), respectively. This decrease was noticed in the absence of steel slag. As for the effect of application of steel slag, data indicate that no consistent trend or regular effects was observed (Table 6).

Table (5): Main effect of steel slag and salinity on grains yield (g/pot), stover yield (g/pot) and plant height (cm) of corn

treatment	grains yield	stover yield	plant height
1- Steel slag			
G_0	315	700	240
G_1	360	900	225
G_2	330	800	290
$LSD_{0.05}$	22.91	82.15	24.04
2- Salinity			
S_1	315	700	240
S_2	270	650	220
S_3	195	560	190
$LSD_{0.05}$	39.49	48.95	25.17

Table (6): Effect of steel slag and salinity treatments on grains yield (g/pot) stover yields (g/pot) and plant height (cm) of corn

Treatment	Grain yield	Stover yield	Plant height
G_0S_1	315	700	240
G_0S_2	270	650	220
G_0S_3	195	560	190
G_1S_1	360	900	225
G_1S_2	315	850	200
G_1S_3	222	800	200
G_2S_1	330	800	190
G_2S_2	318	820	230
G_2S_3	216	750	190
$LSD_{0.05}$	65.15	82.24	31.67

Effects on grains yield

Data in Table (5) show that in the absence of steel slag, the grains yield was decreased from 315 to 270 and 195 gm/pot as the salinity raised from S_1 (control) to S_2 and S_3, respectively. In contrary, with application of steel slag at 500kg Kg/fed rate, the grain yield increased markedly by 14.3, 16.7 and 10.4% with respective salinities as compared to their counterparts in the absence of steel slag. When steel slag increased to 1000 Kg/fed, the grains yield also increased by 4.8, 17.82 and 10.8% at the salinity soil levels S_1, S_2 and S_3, respectively (Table6). These results indicate that the application of steel slag caused considerable increase in the grains yield at all levels of salinity and inhibited partially the adverse effect of salinity on corn grain yield. The effect of steel slag in increasing the grains yield was also noticed in the non-saline soil, where the yield increased from 315 to 360 and 330 gm/pot under 0, 500 and 1000 kg slag/fed., respectively (Table 5). This increasing in yield could be attributed to the role of silicon. The silicon content before cultivation was 20.6, 34.6 and 48.6 mg/kg in the soil with 0, 500 and 1000 kg slag/fed., respectively. It was reported that Si inhibits the uptake of Na and increases the uptake of K and consequently mitigates Na^+ toxicity to plants (Yongchao *et al.*, 1996, and Ma and Takahashi, 1993). Therefore, the observed increase in grains yield under the studied salinity levels with slag application indicates an improvement in the translocation of mineral nutrients necessary for seed setting as discussed below.

Effects on stover yield

Data in Table (6) summarized the effect of salinity and steel slag applications on stover yield. Generally, addition of steel slag at 500 or 1000 kg fed^{-1} had promoted stover yield of corn at any given level of salinity compared to non-slag treatment. In absence of steel slag, the yield of stover was gradually decreased with increasing salinity i.e., 7.1% at S_2 and 20% at S_3, as compared to the non-saline soil (S_1) (Table 5). When steel slag was added at 500 Kg/fed, the stover yield increased by 28.5, 30.8 and 42.9% at the salinity levels S_1, S_2 and S_3, respectively as compared to their counterparts in the absence of steel slag (Table 6). The respective increases with 1000 kg slag rate were mild and account for 14.3, 26.2 and 33.9% suggesting that the higher rate of slag may cause nutritional imbalance. Such promotion in biomass production with slag application could be a function of increased water influx which prevents physiological drought and saline injury on plant growth as reported by Ahmad *et al*, (1992). The stimulation of growth might also due to enrichment of slag with Si which provides rigidity to plant tissues (Epstein, 1994), as well as its involvement in cell elongation and/or cell division (Elawad *et al*., 1982).

Effects on nutrients content in grain and leaves

Data in Table (7) reveal that Na, Ca and Mg content in leaves and grains were progressively increased with increasing soil salinity. An additive increase in both Ca and Mg contents in these organs were also recorded with steel slag application along the soil salinity levels (Table 8). In contrast, Na content in leaves and grains was severely depressed in the saline soils with increasing steel slag application rates (Table 8). Increasing salinity tolerance of plants with Si addition may be attributed to the binding of soluble silicon with Na^+ in root and formation of some sort of complex which retard Na^+ upward translocation (Ahmad et. al, 1992). The formation of such complexes could partially block the transpirational bypass flow and thus reduce their internal water stress, causing the plant withstand salt stress better (Yeq *et al*., 1999).

Table (7): Main effect of steel slag and salinity on nutrients contents in grains and leaves of corn

Treat.	Na	Ca	Mg	N	P	K	Cu	Zn	Fe	Ni
	mgkg^{-1}			%	%	%	mgkg^{-1}			
	Grains									
1- Slag										
G_0	460	61.0	90	1.26	0.25	0.37	1.06	25.30	16.30	0.17
G_1	390	91.0	99	1.29	1.27	0.43	1.18	26.50	19.05	0.18
G_2	310	130.0	129	1.43	0.33	0.32	1.25	26.00	22.10	0.18
$LSD_{0.05}$	55.05	24.6	9.42	0.09	0.04	0.05	0.09	0.60	2.90	0.01
2- Salinity										
S_1	460	61.0	90	1.26	0.250	0.367	1.06	25.30	16.30	0.170
S_2	540	76.0	94	1.24	0.240	0.530	0.99	26.71	15.83	0.176
S_3	640	83.0	97	1.20	0.231	0.281	0.92	29.00	15.10	0.180
$LSD_{0.05}$	60.182	11.241	3.51	0.029	0.012	0.124	0.071	1.865	0.606	0.003
	Leaves									
1- Slag										
G_0	970	3540	2420	2.48	0.21	1.65	8.39	45.10	122.40	0.70
G_1	760	4290	2690	2.59	0.25	1.81	9.18	43.90	140.20	0.78
G_2	620	4710	2940	2.70	0.27	1.89	9.96	44.00	160.00	0.86
$LSD_{0.05}$	116.2	452.7	153.0	0.11	0.03	0.12	0.78	0.66	9.81	0.08
2- Salinity										
S_1	970	3540	2420	2.48	0.21	1.65	8.39	45.10	122.4	0.70
S_2	1260	3590	2560	2.36	0.20	1.90	8.96	47.31	118.9	0.74
S_3	1750	4060	2610	2.30	0.19	1.70	10.12	48.90	116.5	0.80
$LSD_{0.05}$	274.3	186.9	78.5	0.094	0.012	0.129	0.882	1.906	2.965	0.053

Regarding, the effect of steel slag additions on K, N and P content in leaves and grains under salinity stressed conditions, data in Table (8) show that the content of K was irregular, while N and P contents tended to increase with increasing slag rates at any level of salinity, with a greater response for P (Table 8). Ma and Takahashi (1990) recorded higher P content in rice with increasing Si supply. Thus, the observed increase in N and P and the decrease in Na in leaves and grains might be correlated with the optimum yield recorded in the steel slag treated-saline soil (Tables 6 and 8). These results are in agreement with those reported by Daoud (2005) on wheat grown on sandy soil where sodium silicate was used as a silicon source. According to Yongchao *et al.* (1996) inhibition of Na uptake and enhancing K uptake could mitigate salt toxicity to barley and improve the vegetative growth of the salt stressed plant.

Table (8): Effect of steel slag and salinity treatments on nutrients content in grains and leaves of corn

Treat.	Na	Ca	Mg	N	P	K	Cu	Zn	Fe	Ni
	mgkg^{-1}			%	%	%	mgkg^{-1}			
	Grains									
G_0S_1	460	61.0	90.0	1.26	0.25	0.37	1.06	25.30	16.30	0.17
G_0S_2	540	76.0	94.0	1.24	0.24	0.53	0.99	26.71	15.83	0.18
G_0S_3	640	83.0	97.0	1.20	0.23	0.28	0.92	29.00	15.10	0.18
G_1S_1	390	91.0	99.0	1.29	0.27	0.43	1.18	26.50	19.05	0.18
G_1S_2	450	98.0	121.0	1.25	0.25	0.52	1.12	27.91	17.83	0.18
G_1S_3	490	100.0	126.0	1.20	0.24	0.50	0.98	30.50	17.21	0.19
G_2S_1	310	130.0	129.0	1.43	0.33	0.32	1.25	26.00	22.10	0.18
G_2S_2	390	139.0	133.0	1.40	0.30	0.45	1.18	27.10	21.64	0.19
G_2S_3	410	143.0	138.0	1.36	0.28	0.28	1.00	29.90	20.93	0.20
$LSD_{0.05}$	96.31	28.92	18.86	0.09	0.03	0.10	0.11	0.797	2.61	0.01
	Leaves									
G_0S_1	970	3540	2420	2.48	0.21	1.65	8.39	45.10	122.4	0.70
G_0S_2	1260	3590	2560	2.36	0.20	1.90	8.96	47.31	118.9	0.74
G_0S_3	1750	4060	2610	2.30	0.19	1.70	10.12	48.90	116.5	0.80
G_1S_1	760	4290	2690	2.59	0.25	1.81	9.18	43.90	140.2	0.78
G_1S_2	1000	4690	2730	2.56	0.24	1.90	11.00	45.06	137.0	0.83
G_1S_3	1500	4900	2860	2.50	0.23	1.86	11.75	47.12	135.1	0.89
G_2S_1	620	4710	2940	2.70	0.27	1.89	9.96	44.00	160.0	0.86
G_2S_2	830	5310	3010	2.62	0.26	1.99	11.12	45.92	156.1	0.86
G_2S_3	1200	5940	3600	2.58	0.25	1.89	11.95	47.01	153.0	0.89
$LSD_{0.05}$	264.6	584.7	245.8	0.13	0.029	0.11	1.27	1.677	12.68	0.11

Table (8) shows that the content of Zn in plant leaves and grains increased with increasing salinity levels. This increase reached maximum in both grain and leaves at the highest salinity (6.0 dSm^{-1}) with slag application at 500 and 1000 kg rates, respectively. On the other hand, the content of Fe in grain and leaves was decreased with increasing salinity, but increased with the steel slag applications. The same trend was found in the content of Cu in grain. However, Cu in leaves was increased with increasing salinity and promoted with increasing slag rates. Even though, the increase in Cu under steel slag treatments was very limited comparing with Fe or Zn (Table 7). This is probably due to the low Cu content in steel slag and to its strong chelation in root cell sap which restrict its mobility (Chaney, 1984). As seen in Table (8) the concentrations of Cu, Zn and Fe in leaves and grains under the studied salinity and slag treatments were respectively within the ranges 6-20, 20-70 and 21-250 mg/Kg being considered sufficient for corn (Jacobs, 2008). Nickel content in grains and leaves was slightly increased with increasing slag application rate maximum of 0.2 and 0.89 mg/Kg, respectively, with the highest slag and salinity rates (Table 8). These levels of Ni content were also within the range sufficient for corn (Jacobs, 2008). Its worth mentioning that Pb, Cr and Cd contents in leaves and grains were blew the detection limits. The toxicities of heavy metals in plant tissues were found to be alleviated by silicon application to soil (Verma and Minhas, 1989 and Epstein, 1994). According to Cunha *et al* (2008) application of Si in form $CaSiO_3$ to Cd and Zn contaminated soil effectively diminished the metal stress and resulted in increasing biomass of corn, compared to metal-contaminated soil untreated with Si.

Effect on residual available elements in the soil

Concentrations of the amounts of available elements in soils treated with slag, after corn harvest, are shown in Table (9). The data revealed that the available Ca and Mg in soils had increased with increasing steel slag application rates and salinity levels, and were optimum with 1000 Kg slag fed^{-1} at all levels of salinity. This may be attributed to the high content of Ca and Mg in the steel slag (Table 2). Available K also increased with high levels of salinity, but showed non consistent trend with slag application under saline conditions. In contrary, available P declined with increasing salinity, but markedly increased with slag application in saline environments. The availability of P with 1000 kg//fed slag at 3 or 6 dSm^{-1} salinity was nearly twice that of the control (Table 9). This increase in P might due to replacement of silicate for P on soil matrix, which is reported to take place within 3h in pH range from 7 to 9 (Yong *et al.* 2004).

Data also show that available Na and Si had shown a particular interest. The highest concentration of available Na and Si were found in the absence of slag. When steel slag applied, available Na decreased at both salinity treatments while available Si was slightly affected. Available Na in the soils treated with 1000 kg slag fed^{-1} was lower than those of 500 kg slag fed^{-1} at all salinity levels. This may suggest that most of the available Si combined with Na forming Na–Si complex which hinder upward translocation of Na to the aerial parts of the plant causing therefore reduction in Na toxicity (Bradbury and Ahmad, 1990). Ahmad *et al* (1992) reported that Na and Si bound in hydrophilic–siliceous gel unable to release in xylem, which could reduce Na toxicity and protects plants from physiological drought.

Table (9): Effect of steel slag and salinity on the amount of available nutrients in the soil after corn harvest

Treatment	Na	Ca	Mg	K	Si	P	Cu	Zn	Fe	Ni
	mgkg^{-1}									
G_0S_1	920	700	491	198	25.0	6.12	3.43	1.63	9.23	0.36
G_0S_2	1576	1186	775	286	25.8	5.68	3.45	1.66	8.82	0.36
G_0S_3	3100	2370	1500	484	26.2	5.33	3.48	1.69	8.49	0.36
G_1S_1	900	787	510	225	30.2	11.19	3.49	1.68	11.68	0.36
G_1S_2	1548	1269	798	359	24.0	10.79	3.52	1.74	11.00	0.36
G_1S_3	2990	2381	1590	387	22.5	10.05	3.54	1.77	10.40	0.36
G_2S_1	890	900	540	237	31.1	13.02	3.55	1.75	13.76	0.35
G_2S_2	1529	1380	846	355	25.0	12.24	3.58	1.80	13.10	0.36
G_2S_3	2915	2510	1628	364	24.3	11.58	3.64	1.84	12.00	0.35

Data in Table (9) show that application of steel slag at 500 or 1000 kg/fed has no considerable effect on the concentrations of residual available Cu, Zn and Ni in soils after corn harvest. However, available Fe decreased with increasing salinity levels, but increased with increasing rate of steel slag application at the same levels of salinity. The increases in available Fe were from 9.23 to 11.68 and 13.76, and from 8.82 to 11.00 and 13.10, and from 8.49 to 10.40 and 12.00 mg/kg at slag rates of 0, 500 and 1000 Kg/fed under salinity levels of S1, S2 and S3, respectively (Table 9). These levels of available Fe along with the other elements (Cu, Zn and Ni) were not higher than the guide values and quality standards for assessing soil contamination by heavy metals reported elsewhere (Moen *et al*, 1986). Also, it is worth noting that the available Cd and Cr in the slag treated soils after corn harvest were below the detection limits of AA spectrometry.

From the above discussion it concluded that the steel slag with a rate of 500 kg/fed could be used safely from the environmental point of view to ameliorate the salinity hazard on corn and optimize grain yield production. However, field experiments should be carried out to confirm the obtained results.

Acknowledgment

This work was financially sponsored by the Agricultural Research for Development Fund (ARDF), Grant No 283 to Dr. A.M. Daoud

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تاثير اضافة خبث الصلب على اتاحة العناصر الغذائية وانتاجية الذره تحت ظروف الأراضى الملحية

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تم اجراء هذا البحث فى صوبة بمعمل بحوث الأراضي الملحية والقلوية بالصالحية ـ الإسكندرية وذلك بهدف تقييم تأثير اضافة خبث الصلب كمصدر للسيليكون على اتاحة العناصر الغذائية وانتاجية الذره النامى تحت ظروف الأراضى الملحية. وكانت معدلات اضافة الخبث صفر، ٥٠٠ و١٠٠٠كج/فدان أما مستويات الملوحة فكانت ١.٦٨، ٣.٠٠، ٦.٠٠ ديسيسيمز/متر. وبناء على ذلك قيست استجابة المتغيرات المختلفة مثل انتاجية الحبوب والحطب وكذلك محتوى الأوراق والحبوب من العناصر الغذائية والثقيلة وأيضا المتبقى فى الأرض بعد الحصاد. والنتائج المتحصل عليها أوضحت الأتى:-

انخفاض ملحوظ فى كلا من محصول الحبوب والحطب مع زيادة مستويات الملوحةوذلك فى غياب خبث الصلب. بينما ادت اضافة الخبث الى تقليل التاثير الضار للاجهاد الملحى وانعكس ذلك على محصول الحبوب حيث زاد بمعدل ١٦.٧% مع اضافة ٥٠٠ كجم/فدان عند مستوى ملوحة ٣ ديسيسيمنز/متر أما عند مستوى ٦ ديسيسيمنز/متر فان الزيادة فى محصول الحبوب كانت ١٠.٦% عند مستوى اضافة ٥٠٠ و ١٠٠٠ كجم/ فدان وكذلك زيادة طفيفة فى محصول الحطب. كما أدت اضافة خبث الصلب الى تقليل محتوى الاوراق والحبوب من الصوديوم مع زيادة كلا من الكالسيوم والماغنسيوم والبوتاسيوم والفوسفور وتحفيز امتصاص الحديد بينما لم يتأثر محتوى الاوراق والحبوب من الزنك والنحاس حيث كان المحتوى ضئيل. بالنسبة لتركيزات الكادميوم والنيكل والرصاص والكروم كانت تقع فى الحدود الآمنة مع معدلات الخبث المضافة.

أما بالنسبة لتركيز العناصر المتاحة المتبقية فى الأرض بعد الحصاد فقد لوحظ زيادة فى تركيز البوتاسيوم مع زيادة مستويات الملوحة فى غياب الخبث بينما كانت الزيادة كبيرة وغير ثابتة مع اضافة الخبث. وعلى العكس من ذلك وجد ان الفوسفور المتاح انخفض مع زيادة مستويات الملوحة، ومع ذلك توجد زيادة واضحة فى تركيز الفوسفور المتاح مع اضافة خبث الصلب عند نفس مستوى الملوحة حيث وجد ان معدل ١٠٠٠ كجم/فدان ادت الى تضاعف الفوسفور المتاح مقارنة بعدم الاضافة فى كلا من مستويات ملوحة ٣و٦ ديسيسيمنز/متر. توجد زيادة فى تركيز الصوديوم والسيليكون المتبقى بعد الحصاد فى الارض الملحية الغير معاملة بخبث الصلب وقد لوحظ انخفاض الصوديوم مع اضافة الخبث عند المستويات المختلفة للملوحة بينما تأثر السيليكون كان طفيفا. هذا الاتجاه كان واضح عند معدل اضافة ٥٠٠ كجم/فدان وهذا راجع الى ارتباط الصوديوم مع السيليكون الذى ادى الى تثبيط انتقال الصوديوم الى أنسجة النبات وبالتالى تقليل سميته. الحديد المتاح زاد مع زيادة مستويات الملوحة ولكن الزيادة كانت ملحوظة مع اضافة خبث الصلب اما تركيزات النحاس والزنك والنيكل لم تتاثر بمستويات الملوحة او اضافة خبث الصلب. وعموما فان تركيز العناصر المتاحة فى الأرض لم تكن زائدة عن المستوى المسموح به لتلوث الارض بالمعادن الثقيلة. عموما كانت اضافة خبث الصلب بمعدل ٥٠٠ كجم/ فدان اكثر امانا من المنظور البيئى والزراعى وهناك حاجة الى تجارب حقلية لتاكيد النتائج المتحصل عليها من تجارب الصوب.

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