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Converter Slag as a Liming Agent in the Amelioration of Acidic Soils

MOHAMMADI TORKASHVAND ALI[1] AND SEDAGHAT HOOR SHAHRAM
College of Agriculture, Islamic Azad University, Rasht Branch, Rasht, Iran
[1]Corresponding author's e-mail: mohammadit_a@yahoo.com

ABSTRACT

Amelioration of acid soils with liming materials is a common practice. Some industrial byproducts are also being used as liming agent. The most important byproduct in amending acid soils is steelmaking basic slag. In this research, the possibility of using converter slag, as a soil amendment was investigated in three acid soils. Slag compound contains 52.8% CaO and 2.2% MgO plus large amounts of other elements such as Fe, P, Si, and Mn. First stage was incubation phase and treatments were 0, 0.5, 1, 2, 4, 8 and 16% (w/w) of converter slag kg^{-1} soil and soil moisture content was adjusted closer to field capacity. The changes in pH, EC and AB-DTPA-extractable Fe, Mn, Zn, P and K were determined after 1, 10, 30 and 60 days. Second phase was a greenhouse study that treatments with due attention to incubation results were determined on maize. Treatments were 0, 0.5, 1 and 2% w/w and 0, 1, 2 and 4% w/w of slag in rice field and tea orchard soils, respectively. Slag increased soil pH and the rate of increase was proportional to the amount of slag used. The slag decreased Fe availability at pH range of 7.4 - 8.5 but increased at higher pH, while use of slag proportionately increased the P and Mn availability. In greenhouse studies the application of 1 and 2% (w/w) of slag in tea garden soil and 0.5, 1 and 2% slag in rice field soil increased plant shoot dry yield and P and Mn uptake. Fe and K uptake increased in rice field, K uptake decreased in tea garden soil and Fe uptake was not changed. In conclusion, the converter slag was a suitable amendment for acid soils.

Key Words: Slag; Converter; Amendment; Acid soil

INTRODUCTION

Amelioration of acid soils with liming materials is a common practice (Ponnette *et al*., 1991; Souza & Nemptune, 1991; Conradie, 1995; Haby *et al*., 1995; Quoggio *et al*., 1995), but other materials are also used as acid soil amendment, such as gypsum, phosphate rocks (Alva *et al*., 1990; McLay & Ritchi, 1995; He *et al*., 1996) and some industrial byproducts (Edward *et al*., 1985; Vityakon *et al*., 1995; Oguntoinbo, 1996; Stuczynski *et al*., 1998; Abbaspour *et al*., 2004; Dong Xiang *et al*., 2005; Curnoe *et al*., 2006; Alves *et al*., 2006; Franco-Hernandes & Dendooven, 2006). The most important byproduct in amending acid soils is steelmaking basic slag (Subramanian & Copalswamy, 1990; Surendra, 1993; Rodriguez *et al*., 1994; Basak & Saha, 1995; Pinto *et al*., 1995; Khan, 1996; Kristen & Erstad, 1996; Besga *et al*., 1997; Prado & Fernandes, 2001; Abou Seeda *et al*., 2002; Prado *et al*., 2003; Barbosa Filho, 2004).

In steel industries the iron ore is mixed with calcitic lime in order to remove silica, phosphate and other elements from the melted iron. The lime reacts with the un-desired components in the raw material and forms a slag, which comes up to the surface of the converter. For production of every tone of steel, near 150 kg of slag is generated. Approximately 250 million kg of slag is produced annually in Isfahan, Iran (Aflaki, 1995). In Germany, 20% of slags are used as fertilizer or soil amendment (Economic Commission For Europe, Geneva, 1990). Slag increases soil pH and mobile fractions of P, K, Ca and Mg during the incubation period (Abou Seeda *et al.,* 2002). Prado *et al.* (2003) used basic slag and limestone in Brazil sugarcane fields and concluded that these materials in pre-planting caused a beneficial residual effect on the yield of ratoon sugarcane. After 48 months, both calcitic limestone and basic slag generated a beneficial residual effect in correction of soil acidity and increase of base saturation.

In Sweden, application of slag increased the crop yield as compare with limestone (Kristen & Erstad, 1996). Slag has been reported to increase pH, available P and decrease Al in south Nigeria acidic soils. Also, slag increased Ca, K uptake, promoted micronutrients uptake and increased dry matter by plant (Oguntoinbo *et al*., 1996). Moreover, LD steel slag controlled the clubroot disease on sugukina and maintained the acid level in the soil effectively (Murakami & Goto, 2004). Application of calcium silicate slag in Goias, Brazil resulted in significant grain yield increase, tissue silicon content and silicon accumulation in straw and the filled percentage in the first and in the second year of rice cultivation. Slag can also reduce soil acidity and increase available P, Si, exchangeable Ca and base saturation (Barbosa Filho *et al*., 2004). Carvalho-Pupatto *et al.* (2004) reported that blast furnace slag produced maximum root growth in depth and better distribution in the profile, which resulted to higher shoot dry matter and grain yield. Murakami *et al.* (2005) reported that the application of fungicide (flusulfamide) at 300 kg ha^{-1} although restricted the outbreak of club-root disease, the density of dormant spores in the soil did not decrease. Therefore, Using both converter slag and fungicide to suppress the disease was totally essential.

The present study was planned to investigate the possibility of using LD converter slag as an amendment in three acid soils of Guilan, Iran and to evaluate the value of the waste as an agriculture liming material and effects of slag on maize (*Zea mays* L.) growth.

MATERIALS AND METHODS

The converter slag was obtained from Isfahan steel factory, Isfahan, Iran. Total elemental analysis was carried out using HF-$HClO_4$ digestion (Hossner, 1996). The slag pH and EC were determined in 1:2.5 slag: water suspension (Rhoads, 1996) using Metrohm 320 pH-meter and Metrohm 644 conductometer, respectively.

Incubation study. The incubation study was conducted with three soils that have been collected from the tea garden (soil no. 1); tobacco and rice fields (soils no. 2 & no. 3, respectively) in Guilan, Iran. Some physical and chemical properties of soils have been shown in Table I (soils 1 - 3). Soils were air-dried and crushed to pass a 2 mm sieve. Then, treatments were applied to 500 g of soils and treated samples were moistened to field capacity (FC) with deionized water and incubated in 1 L plastic container for up to 60 days. Sub-samples were taken after 1, 10, 30 and 60 days of incubation, air-dried and crushed to pass a 2 mm sieve and stored for chemical analysis.

Treatments were control (S_0) and 0.5, 1, 2, 4, 8 and 16% (w/w) converter slag ($S_{0.5}$, S_1, S_2, S_4, S_8 and S_{16}). Data were analyzed in a factorial completely randomized design with two factors and three replications. Moisture of containers was kept near FC soil moisture content throughout the experiment by periodically weighing and replenishing evaporated water. At each sampling period (1, 10, 30 & 60 days), 50 g of soil was taken from each container to determine pH, EC and Fe, Mn, Zn, Cu, K and P extractable with AB-DTPA (Soltanpour & Schwab, 1977). Micronutrients concentrations were measured by atomic absorption spectrophotometer (Perkin Elmer 3030) and flame photometer, respectively.

Greenhouse study. A pot experiment was conducted in a greenhouse with two soils (soils no. 1 and no. 3 in Table I) and three replicates. Treatments consisted of 0, 1, 2 and 4% (w/w); 0, 0.5, 1 and 2% (w/w) of converter slag in soils no. 1 and no. 3, respectively. Maize (Zea mays L. single cross) was used as the test plant and four seeds were sown in each pot. Seedlings were thinned to 2 when they were about 10 cm high. During the growth period, pots were irrigated with distilled water as needed. All pots received 50 mg N kg^{-1} as ammonium nitrate one week after thinning. The shoots were harvested eight weeks after germination and determined for dry matter yield after drying them at 70°C for 48 h. Sub-samples of dry shoots were ground, dry-ashed in a furnace at 550°C and then extracted with 2 N HCl. Concentrations of Fe, Mn, Zn and Cu were measured on an atomic absorption spectrophotometry. Soil samples from each pot were analyzed for AB-DTPA extractable Fe and Mn as well as EC and pH. Soil EC and pH were determined in 1:2.5 soil water suspensions as described above. Data were analyzed by standard ANOVA procedures using MSTATC and SAS software's and significance were based on Duncan's Multiple Range Test ($P < 0.05$).

Table I. Physical and chemical properties of soils used

Soil no.	1	2	3
Soil series	Lahijan	Rasht	Rasht
Classification	Hapludalf	Hapludalf	Epiaqualf
Texture	Loam	Sandy Loam	Clay Loam
pH[a]	4.1	5.5	6.7
ECe (dS m^{-1})	0.7	1.3	1.1
O.M (%)	2.75	1.24	0.79
N (%)	0.27	0.07	0.03
P (mg kg^{-1})	10.2	12.6	2.1
K (mg kg^{-1})	195	115	127
Fe (mg kg^{-1})	307	101	461
Mn (mg kg^{-1})	27.8	14.4	14.4
Zn (mg kg^{-1})	1.45	1.45	1.95
Cu (mg kg^{-1})	2.45	2.25	2.60

[a]pH in saturated paste, electrical conductivity in saturated paste extract, organic matter by the walkly and Black method, total N by the Kjeldahl method, calcium carbonate by titration with NaOH, P using ascorbic acid method, K extracted with ammonium acetate 1 N, Fe, Mn and Zn extracted with AB-DTPA

Table II. Chemical analysis of converter slag

Compound	%	Compound	%
TFe	16.83	P_2O_5	4.76
FeO	7.87	Al_2O_3	0.78
MnO	4.46	S	0.18
SiO_2	8.92	ZnO	0.057
CaO	52.85	Na_2O	0.075
MgO	2.22	K_2O	0.032
V_2O_5	2.31		

RESULTS AND DISCUSSION

The chemical composition of the converter slag is presented in Table II. The compound contained about 52.8% CaO; 2.2% MgO and considerable amounts of Mn, P and Si, which may be useful to plant.

Soil pH. Slag increased soil pH, which was proportional to the added amount of converter slag (Table III). This is the most important characteristic of slag as a liming agent for amelioration of acid soils. In soil No.1, time of incubation effect on soil pH was considerable. pH of soils No. 1 - 2, initially increased and then decreased slowly under most of treatments, but this increase of pH in $S_{0.5}$ and S_1 treatments was higher than control. This can be due to the high amounts of clay resulted buffering power. Rodriguez *et al.* (1994) utilized LD slag and found that soil pH decreased

Table III. Effects of the treatments on soil pH during incubation period

Soil No.	Incubation Time (days)	Treatments						
		S_0	$S_{0.5}$	S_1	S_2	S_4	S_8	S_{16}
1	1	4.43 l	5.06 k	5.76 hi	6.20 j	7.30 f	7.73 e	10.50 a
	10	4.48 l	5.03 k	5.76 hi	6.18 g	7.20 f	8.23 d	10.00 b
	30	4.28 l	5.16 jk	5.43 ij	6.28 g	7.06 f	8.13 d	9.08 c
	60	4.20 l	5.06 jk	5.26 jk	6.20 g	7.20 f	8.08 d	9.36 c
	Means	4.35 g	5.11 f	5.55 e	6.17 d	7.19 c	8.04 b	9.37 a
2	1	6.03 i	6.30 hi	7.70 g	7.63 g	8.36 de	10.53 bc	10.70 b
	10	5.86 ij	6.30 hi	7.16 h	7.83 fg	7.30 d	10.40 bc	11.55 a
	30	5.93 ij	6.90 h	7.13 h	7.76 g	8.50 d	10.33 bc	11.50 a
	60	5.91 ij	6.10 h	7.03 h	7.93 efg	8.26 def	10.16 def	11.33 a
	Means	5.93 g	6.65 f	7.25 e	7.79 d	8.40 c	10.35 b	11.52 a
3	1	7.28 hi	7.50 h	7.63 gh	8.53 cd	9.03 c	9.03 c	11.13 a
	10	7.36 hi	7.58 gh	7.80 efgh	8.30 de	7.81 efgh	9.03 c	10.40 b
	30	7.48 h	7.34 hi	7.70 fgh	8.25 def	8.13 defg	8.90 c	10.90 ab
	60	7.48 h	7.43 h	6.80 i	7.86 efgh	8.66 cd	8.53 cd	10.88 ab
	Means	7.40 d	7.46 d	7.48 d	8.23 c	8.41 c	8.87 b	10.82 a

Values followed by the same letters in each row are not significantly different at the 0.05 level (Duncan,s Multiple Range Test)

Table IV. Effects of the treatments on AB-DTPA extractable P during incubation period

Soil No.	Incubation Time (days)	Treatments						
		S_0	$S_{0.5}$	S_1	S_2	S_4	S_8	S_{16}
1	1	9.07 ijkl	9.05 ijkl	9.38 ijkl	11.43 hijk	10.89 hijk	20.04 def	27.90 b
	10	10.54 hijk	9.43 ijkl	9.71 ijkl	11.38 hijk	13.28 ghij	22.12 ed	28.52 b
	30	12.83 hijk	6.99 kl	8.64 ijkl	15.81 efgh	21.18 cde	25.79 bc	16.21 efgh
	60	8.13 jkl	4.65 l	8.84 ijkl	14.52 fghi	18.76 defg	36.21 a	15.80 efgh
	Means	10.14 e	7.53 e	9.14 e	13.28 d	16.03 c	26.04 a	22.10 b
2	1	11.37 k	11.37 k	15.10 jk	25.84 hi	27.22 ghi	39.46 abcde	40.81 abc
	10	11.37 k	13.55 k	14.76 k	33.90 cdefg	41.51 ab	40.22 abcd	39.70 abcde
	30	11.37 k	13.99 k	23.84 i	38.31 abcdef	34.97bcdefg	32.97 defgh	31.47 fgh
	60	11.37 k	12.61 k	22.02 ij	34.55abcdefg	41.99 a	32.47 efgh	22.29 aij
	Means	11.37 c	2.03 c	19.03 b	33.15 a	36.24 a	36.28 a	33.57 a
3	1	1.17 j	2.17 hij	3.16 hij	3.40 ghij	8.71 g	13.94 f	35.04 b
	10	1.31 j	3.21 hij	4.04 ghij	6.33 ghij	14.21 f	23.73 de	32.75 bc
	30	1.51 ij	7.34 hij	7.39 gh	7.07 ghi	27.90 cd	24.10 de	28.59 cd
	60	1.37 j	2.34 hij	4.48 ghij	4.29 ghij	20.85 e	40.38 a	27.99 cd
	Means	1.35 f	2.44 ef	4.77 de	5.27 d	17.92 c	25.54 b	31.09 a

Values followed by the same letters in each row are not significantly different at the 0.05 level (Duncan,s Multiple Range Test)

along incubation time. It is concluded that clays Fe^{3+} might have hydrolyzed leading to time dependent decreased in pH.

Phosphorus. Increase in P was proportional to the amount of slag added (Table IV). Kristen and Erstad (1996) found that the effect of slag on soil P was also because of Si in slag. Si replaces P in exchange sites and release P to solution phase (Subramanian & Copalswamy, 1990). The P increased with time in S_4, S_8 treatments in soil no. 1, in S_1, S_2, S_4 treatments in soil no.2 and S_4, S_8 treatments in soil no. 3. It seemed that P increased due to the increase in pH. This culminated in increased microbial activity and mineralization of organic P (Aliasgharzadeh, 1997). The P decreased in S_{16} treatment with time in all soils. It seems that P has re-precipitated as calcium-three phosphate compounds in higher pH.

Iron. Slag affected Fe depending on initial pH (Table V). In the beginning of incubation experiment, increase in pH in the range of 7.4-8.5 increased Fe level. It was found that Fe was precipitated as $Fe(OH)_3$ due to the increased pH when it existed as Fe^{3+}, while increase in Fe was found as another anion species $Fe(OH)^{-4}$ (Norvell & Lindsay, 1982). In most treatments, Fe decreased with time, resulting re-precipitation of iron as insoluble compounds.

Manganese. Slag proportional to the applications, significantly increased Mn (Table VI). The increase of Mn might be due to the high amounts of Mn in slag compound. It has been considered that AB-DTPA extractable Mn was precipitated as compounds with less dissolution.

Potassium. Slag treatments reduced K content in soil No. 1, which might be due to the potassium fixation (Table VII), due to increase in pH. Al and Fe hydroxides polymers decline in clays interlayer or insoluble compounds, as K alominosilicates are formed consequently increasing K fixation (Malakouti & Afkhami, 1999). In soil No. 2, trend of treatments was almost similar to soil No. 1 and 3, but treatments effects were not great. In soil No.2 and 3, interactions of treatments and time were not significant ($p > 0.05$). Overall, mean K reduced 58.5 and 25.5% with the application of 16% slag in soils No. 1 and 2, respectively.

Greenhouse experiment. Maize dry matter increased significantly in 1 and 2% converter slag treatments (S_1 & S_2) as compared to the control in soil no. 1 (Table VIII). In S_1

Table V. Effects of the treatments on AB-DTPA extractable Fe during incubation period

Soil No.	Incubation Time (days)	Treatments						
		S_0	$S_{0.5}$	S_1	S_2	S_4	S_8	S_{16}
1	1	308.8 bcd	285.3 def	272.6 defg	251.2 efgh	205.7hijk	283.7def	226.4 ghijk
	10	338.5 bc	287.0 cdef	246.2 efgh	241.8 fghi	239.1fghi	189.4 ijkl	216.5hijk
	30	307.1 bcd	298.4bcde	235.8 fghi	220.4 ghijk	149.4 lm	184.2 jklm	215.7 hijk
	60	432.5 a	344.8 b	224.3ghijk	205.7 hijk	135.8 m	182.3 klm	282.9 def
	Means	346.7 a	303.8 b	244.7 hijk	229.2 cd	191.0 e	209.9 de	235.3 c
2	1	101.9 jkl	71.8 mn	85.8 klm	125.7 gh	105.3 ijk	262.1 a	222.3 bc
	10	90.2 jklm	67.3 nop	76.1 mn	107.5 hij	174.1 f	241.1 b	233.8 b
	30	76.8 mn	62.8 no	103.3 jk	96.1 jkl	81.8 lm	185.0 ef	135.8 g
	60	62.8 no	48.6 o	61.1 no	98.2 jkl	124.1 ghi	206.9 cd	193.5 de
	Means	82.9 e	62.6 f	61.6 e	33.8 d	121.3 c	223.7 a	196.3 b
3	1	61.8 hi	62.2 hi	94.4 g	124.7f	153.8 e	171.3 de	175.7 de
	10	53.2 hij	52.1 hij	64.3 h	64.5 hi	102.0 fg	202.6 c	187.5 cd
	30	32.6 j	51.8 hij	61.7 hi	69.2 h	99.7 g	187.3 cd	246.3 ab
	60	54.6 hij	42.9 hij	35.4 ij	57.2 hij	109.2 fg	233.8 b	260.3 a
	Means	50.6 f	52.3 f	63.9 e	78.1 d	116.2 c	198.7 b	217.4 a

Values followed by the same letters in each row are not significantly different at the 0.05 level (Duncan,s Multiple Range Test)

Table VI. Effect of the treatments on AB-DTPA extractable Mn during incubation period

Soil No.	Incubation Time (days)	Treatments						
		S_0	$S_{0.5}$	S_1	S_2	S_4	S_8	S_{16}
1	1	23.0 lmno	28.4ijklmn	34.5ghijkl	39.5 fghi	205.0 f	106.2 d	221.4 a
	10	24.3 lmno	31.9hijklm	32.4hijkl	32.4 hijkl	239.2 fg	68.1 e	157.6 b
	30	24.8klmno	38.4fghij	22.6lmno	20.1 mno	149.6fghijk	105.8 d	154.7 b
	60	27.5jklmn	42.5fgh	17.5 no	15.4 o	135.6ijklm	127.6 d	115.5 d
	Means	24.9 d	35.3 c	26.7 d	26.8 d	191.8 c	101.9 b	163.3 b
2	1	20.7 jkl	20.7 jkl	20.0 jkl	22.6 jkl	29.2 ijk	91.8 d	153.4 a
	10	8.6 m	9.3 m	15.2 l	34.6 hi	53.0 f	82.4 e	116.0 c
	30	13.0 klm	3.3 m	17.5 kl	25.4 jk	40.4 gh	93.4 d	91.8 d
	60	3.0 m	3.6 m	6.8 m	35.5 hi	44.2 g	76.0 e	136.8 b
	Means	11.4 de	9.3 f	14.9 e	29.5 d	41.7 c	85.9 b	124.5 a
3	1	20.0 jk	16.9jklm	30.2 i	39.5 h	64.6 g	83.0 f	190.9 a
	10	13.4 klm	9.3 m	16.6 jklm	24.2 ij	44.8 h	91.3 e	138.2 bc
	30	12.2 klm	19.0 jkl	12.4 klm	40.8 h	46.8 h	133.0 c	107.4 d
	60	10.2 lm	10.3 lm	8.1 m	17.6 jklm	58.1 g	135.7 c	145.1 b
	Means	13.9 e	13.9 e	16.8 e	30.5 d	53.7 c	110.7 b	145.4 a

Values followed by the same letters in each row are not significantly different at the 0.05 level (Duncan,s Multiple Range Test)

Table VII. Effect of the treatments on AB-DTPA extractable K during incubation period

Soil No.	Incubation Time (days)	Treatments						
		S_0	$S_{0.1}$	S_1	S_2	S_4	S_8	S_{16}
1	1	153.2 a	145.5 a	149.4 a	105.0 de	122.1 bcd	80.8 f	70.9 fg
	10	145.5 a	153.3 a	134.1 abc	1471.7 ab	112.1 d	84.2 f	67.6 fg
	30	145.6 a	145.6 a	115.8 cd	105.1 de	115.7 cd	87.6 ef	58.0 g
	60	153.4 a	149.4 a	123.0 bcd	123.0 bcd	112.1 d	67.6 fg	51.7 g
	Means	149.4 d	148.4 a	130.6 b	118.6 c	115.7 c	80.0 d	62.0 e
2	1	105.1 a	105.1 a	91.0 jkl	94.5 abc	77.5 cd	84.2 abcd	80.8 bcd
	10	105.1 a	105.1 a	101.4 ab	87.7abcd	87.6abcd	87.6 abcd	70.9 d
	30	105.1 a	80.8 bcd	91.0 abcd	80.9 bcd	81.0 bcd	77.5 cd	80.9 bcd
	60	105.1 a	101.4 ab	91.0 ab	84.3abcd	77.5 cd	77.5 cd	80.8 bcd
	Means	105.1 a	96.2 ab	93.6 ab	86.5 bc	80.9 c	81.7 c	78.3 c
3	1	94.4abcd	112.0 a	91.2abcd	98.0 abcd	105.0 ab	91.3 abcd	80.8 cd
	10	94.4abcd	97.9abcd	91.2abcd	91.0abcd	87.6 bcd	94.5 abcd	84.2 bcd
	30	91.0abcd	94.4abcd	91.0abcd	101.4 abc	87.6 bcd	80.8 cd	80.8 cd
	60	84.2 bcd	91.0abcd	84.2 bcd	87.6 bcd	77.5 d	77.5 d	84.2 bcd
	Means	91.0 abc	98.8 a	89.4 abc	94.5 ab	89.4 abc	86.0 bc	84.2 c

Values followed by the same letters in each row are not significantly different at the 0.05 level (Duncan,s Multiple Range Test).

and S_2, increase in dry matter was 1.42 and 1.47 times more than control treatment, respectively. Oya *et al.* (1990) used slag in an acid soil (pH 4.7) and observed that Rhodes grass yield significantly increased. Dry matter yield in S_4 treatment nominally decreased, which could be due to higher soil pH. Oguntoinbo *et al.* (1996) used basic slag at the rates 250 and 500 mg Ca kg^{-1} soil and found 1.5 times greater plant dry matter, but it reduced at 1000 mg Ca kg^{-1}

Table VIII. Effect of treatments on dry matter yield and uptake of maize in pot experiment

Soil Series	Treatments	Dry weight ($g\ pot^{-1}$)	P	K	Fe	Mn	Zn
			($mg\ pot^{-1}$)				
Lahijan tea garden (soil no.1)	S_0	6.20 b	9.50 b	189.7 a	1.01 ab	2.35 b	0.54 a
	S_1	8.56 a	16.95 a	86.6 b	1.40 a	3.75 a	0.48 a
	S_2	9.12 a	15.05 a	86.1 b	1.35 ab	3.72 a	0.31 b
	S_4	5.10 b	8.78 b	63.1 b	0.97 b	1.53 b	0.15 c
Rasht rice field (soil no.3)	S_0	1.66 c	0.99 d	40.9 c	0.15 c	0.17 b	0.085 c
	$S_{0.5}$	4.05 a	10.2 a	74.3 ab	0.49 b	0.59 a	0.21 b
	S_1	4.15 a	5.87 b	79.1 a	0.70 a	0.73 a	0.38 a
	S_2	3.16 b	3.44 c	65.3 b	0.46 b	0.57 a	0.24 b

soil. Similar results have reported in other studies (Pinto *et al.*, 1995; Abou Seeda *et al.*, 2002; Prado *et al.*, 2003; Barbosa Filho *et al.*, 2004). In soil No.3, dry matter highly increased in $S_{0.5}$ and S_1 treatments. In S_1 and S_2 treatments, dry matter 2.44 and 2.5 times was more than control treatment. Kristen and Erstad (1996) concluded that slag increased dry matter of forage species, and increase in yield was due to the increase of P, Fe, Mn, Si and other nutrients. It appeared that dry matter yield increased in soils due to the increase of Ca, Mg, P, Si, Mn and reclamation of soil pH.

The effect of treatments on nutrients uptake is indicated in Table VIII. Phosphorus uptake distinctly increased in S_1 and S_2 treatments as compared with control in soil no. 1. S_4 treatment was not much different from control. In soil no. 3, P uptake highly greatly in all treatments so that 10.3, 5.9 and 3.4 times increased in $S_{0.5}$, S_1 and S_2 was obtained as compared to control, respectively. Slag adds the great amounts of phosphorus to soil.

Potassium uptake decreased significantly in soil No. 1. Previously it was seen that slag decreased K in soil. K uptake increased in soil No. 3 that could be due to the higher yield (Dawwey, 1993; Basak & Saha, 1995; Abou Seeda *et al.*, 2002; Barbosa Filho *et al.*, 2004). Fe uptake was not significant in soil No. 1. Slag decreased Fe at incubation stage in this soil, which increased significantly in soil No. 3. Mn uptake increased in S_1, S_2 and other treatments in soils No. 1 and 3, respectively.

CONCLUSIONS

Results indicated a promising potential for converter slag to be used as an inexpensive source of available liming material for correcting pH in acid soils. This, however, needs further studies in the field and with various crops to determine the correct rates and to study the residual and environmental impact of application of this material especially vanadium to the soil.

REFERENCES

Abbaspour, A., M. Kalbasi and H. Shariatmadari, 2004. Effect of steel converter sludge as iron fertilizer and amendment in some calcareous soils. *J. Pl. Nutr*, 27: 377–94

Abou Seeda, M., H.I. EI-Aila and S. EI-Ashry, 2002. Assessment of basic slag as soil amelioration and their effects on the uptake of some nutrient elements by radish plants. *Bulletin National Res. Centre (Cairo),* 27: 491–506

Aflaki, A., 1995. Evaluation of effective parameters in recovery of Vanadium compounds from slag. *M. Sc. Thesis.* Materials college, Isfahan Technology University, Isfahan, Iran

Aliasgharzadeh, N., 1997. *Soil Biochemistry and Microbiology*. Tabriz University, Tabriz, Iran

Alva, A.K., M.E. Sumner and W.P Miller, 1990. Reactions of gypsum or phosphogypsum in highly weathered acid sub-soil. *Soil Sci. Soc. American J.* 54: 993–8

Alves, M.C., A. Paz Gonzalez, G. Colorado, H. Perecin Junior and V. Vidal, 2006. Influence of biosolids rate on chemical properties of an Oxisol in Sao Paulo, Brazil. *Commun. Soil Sci. Pl. Anal.,* 37: 2481–93

Barbosa Filho, M.P., F.J.P. Zimmwrmann and O.F. Da Silva, 2004. Influence of calcium silicate slag on soil acidity and upland rice grain yield. *Ciencia e Agrotecnologia,* 28: 323–31

Basak, R.K. and S.N. Saha, 1995. Solubilization of rock phosphates and basic slag in tarai acid soils of west Bengal. *Environ. Ecol.,* 13: 173–5

Besga, G., M. Pinto, M. Rodriguez, F.A. Lopez and N. Balcazar, 1997. Agronomic and nutritional effects of Linz-Donawitz slag application to two pasture in northern Spain. *Nutr. Cycling Agroecosys,* 46: 157–67

Carvalho-Pupatto, J.G., L.T. Bull and C.A.C. Crusciol, 2004. Soil chemical attributes, root growth and rice yield according to slag application. *Pesq. Agropec. Brasileria,* 39: 1213–8

Conradie, W.J., 1995. Efficiency of surface-applied ameliorants for alleviating acidity in two vineyard soil types. *Plant-Soil Interactions at Low pH: Principle and Management,* pp: 531–6

Curnoe, W.E., D.C. Irving, C.B. Dow, G. Velema and A. Unc, 2006. Effect of spring application of a paper mill soil conditioner on corn yield. *Agron. J.,* 98: 423–9

Dawwey, E.L., 1993. Effectiveness of sewage sludges basic slag on wheat plants grown in sandy calcareous and loamy soils. *Assiut J. Agric. Sci.,* 24: 171–84

Dong Xiang, W., K.S. Katsumata and G. Meshitsuka, 2005. Characterization of lignin fragments in alkaline oxygen-stage waste liquor as soil-conditioning agent. *J. Wood Sci.,* 51: 357–62

Edward, J.H., B.D. Horton, A.W. White and O.L. Bennet, 1985. Fluidized bed combustion residue as an alternative liming material and Ca source. *Commun. Soil Sci. Pl. Anal,.* 16: 621–37

Franco-Hernandez, O. and L. Dendooven, 2006. Dynamics of C, N and P in soil amended with biosolids from a pharmaceutical industry producing cephalosporines or third generation antibiotics: a laboratory study. *Bio-resource Technol.,* 97: 1563–71

Haby, V.A., R.H. Loeppert, R. Villavicecio, A.T. Leonard and J.V. Davic, 1995. Limestone efficiency and boron effects on forage yield and soil properties. *Plant-Soil Interactions at Low pH: Principle and Management*, pp: 505–10

He, Z.L., V.C. Baligar, D.C. Martens, K.D. Ritchey and W.D. Kemper, 1996. Kinetics of phosphate rock dissolution in acidic soil amended with liming materials and cellulose. *Soil Sci. Soc. American J.,* 60: 1589–95

Hossner, L.R., 1996. Dissolution for total elemental analysis. *In*: Sparks, D.L. (ed.), *Methods of Soils Analysis, Part 3,* pp: 49–64. Chemical Method Soil Science society of America: Madison, WI

Khan, H.R., 1996. Dynamic in composition of percolating solutions from acid sulfate soil under rice and selected amendments. *Curr. Agric.* 20: 51–60

Kristen, M. and K.J. Erstad, 1996. Converter slag as a liming material on organic soils. *Norwegian J. Agric. Sci,.* 10: 83–93

Malakouti, M.J. and M. Afkhami, 1999. *The Necessity to Prevent Potassium Depletion in Rice Fields of Northern Regions*. Soil and Water research institution. Technical publication, No 62, Tehran, Iran

McLay, C.D. and G.S.P. Ritchi, 1995. Effect of gypsum application rate and leaching regime on wheat growth in a highly acidic subsoil. *Plant-Soil Interactions at Low pH: Principle and Management,* pp: 527–30

Murakami, K. and I. Goto, 2004. Effect of controlling the clubroot disease of sugukina by the application of converter slag for soil amendments. *Japanese J. Soil Sci. Pl. Nut.,* 75: 233–5

Murakami, K., H. Shinoda, F. Nakamura and I. Goto, 2005. The effect of fungicide on the inhibition of clubroot disease by the application of converter slag for soil amendment. *Japanese J. Soil Sci. Pl. Nut.,* 76: 59–61

Norvell, W.A. and W.L. Lindsay, 1982. Effect of ferric chloride additions on the solubility of ferric iron a near-neutral soil. *J. Pl. Nutr.,* 5: 1285–95

Oguntoinbo, F.I., E.A. Aduay and R.A. Sobulo, 1996. Effectiveness of some local liming materials in Nigeria as ameliorants of soil acidity. *J. Pl. Nutr.,* 19: 999–1016

Oya, K., N. Kinjo and M. Shimo, 1990. The improving effect of several liming materials on the growth and nutrient uptake of Rhodes grass. *Sci. Bull. College Agric. University Ryukyus Okinawa,* 37: 7–17

Pinto, M.M. Rodriguez, B.N. Besga and F.A. Lopez, 1995. Effects of Linz-Donawitz (LD) slag on soil properties and pasture production in the Basque County (northern Spain). *New Zealand J. Agric. Res.,* 38: 143–55

Ponnette, Q., R. Frankart, W. Poma Rojas and C. Petit, 1991. Effects of mineral amendments on the physico-chemical properties of a brown acid soil in a beech stand in the Belgian Ardennes. *Pedologie,* 41: 89–100

Prado, R.M. and F.M. Fernandes, 2001. Response of sugarcane to application of iron and steel slag as a corrective for acidity in soil. *Revista Brasileria De Ciencia Do Solo,* 25: 199–207

Prado, R.M., F.M. Fernandes and W. Natale, 2003. Residual effect on calcium silicate slag as soil acidity corrective in sugar cane rattoon. *Revista Brasileria De Ciencia Do Solo,* 27: 287–96

Quoggio, J.A., P.B. Gallo and H.A. Mascarenhas, 1995. Agronomic efficiency of limestone with different acid-neutralizing capacity, under field condition. *Plant-Soil Interactions at Low pH: Principle and Management,* pp: 491–6

Rhoads, J.D., 1996. Salinity: electrical conductivity and total dissolved solids. *In*: Sparks, D.L. (ed.), *Methodes of Soils Analysis Part 3*, pp: 417–35. Chemical Methods Soil Science Society of America: Madison, WI

Rodriguez, M., F.A. Lopez, M. Pinto, N. Balcazar and G. Besga, 1994. Basic Linz-Donawits slag as a liming agent for pastureland. *Agron. J.,* 86: 904–9

Soltanpour, P.N. and A.P. Schwab, 1977. A new soil test for simultaneous extraction of macro- and icroutrients in alkaline soils. *Communication in Soil Sci. Pl. Analysis,* 8: 195–207

Souza, E.C.A. and A.M.L. Nemptune, 1979. Effects of dolomitic limestone fineness on chemical properties of a latosol. *Brazil J. Soil Sci.,* 3: 120–5

Stuczynski, T.I., G.W. McCarty and R.J. Wright, 1998. Impact of coal combustion product amendments on soil quality: 1. Mobilization of soil organic nitrogen. *Soil Sci. Soc. American J.,* 163: 952–9

Subramanian, S. and A. Copalswamy, 1990. Influence of silicate and phosphate materials on availability and uptake of silicon and phosphorus in acid soil. *Oryza,* 27: 267–73

Surendra, S., K.P. Singh, B.P. Sarkar and B.P. Gupta, 1993. Release pattern of phosphorus from indigenous phosphatic sources in acid soil. *J. Indian Society of Soil Sci.,* 41: 774–5

Vityakon, P., S. Seripong, R.A. Date, N.J. Grundon, G.E. Rayment and M.E. Probert, 1995. Evaluation of paper mill lime sludge as an acid soil amendment in northeast Thailand. *Plant-Soil Interactions at Low pH: Principle and Management,* pp: 595–9

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