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LABORATORY EXPERIMENT CONCERNING THE USE OF FLY ASH AS A RECLAMATION MATERIAL IN SALINE-SODIC SOILS

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Abstract: Soil degradation caused by salinization and sodification is a worldwide phenomenon. Therefore, amelioration of these problematic soils is of great importance for sustainable agriculture. The effect of fly ash in reclamation of saline-sodic soils was studied under laboratory conditions using 3 fly ash application rates (2, 4, and 8 t da^{-1}) and 3 soil materials from A horizon with different salinity and sodicity levels. Results obtained from this study have shown that for heavy textured soil 2 and 4 t da^{-1} application rate is much more effective in reducing ESP and EC value, with regard to soil infiltration rate. However, application of fly ash in the rate of 8 t da^{-1} decreases infiltration rate, thus does not make any sense on soil ESP value. Results presented in this study showed that fly ash can be used for reclamation of saline-sodic soils. However, its effectiveness in enhancing reclamation depends on some factors such as initial organic matter and lime content, EC and ESP value of the soil and the amount of fly ash applied and the acidity of the leaching water. It can be concluded that, use of fly ash as a reclamation material for saline-sodic soils will not only help to reclaim these soils but also help prevention of environmental pollution.

Key Words: Saline-sodic soil, fly ash, electrical conductivity, exchangeable sodium percentage, infiltration rate

1. INTRODUCTION

Soil degradation caused by salinization and sodification is a serious problem worldwide. Food and Agriculture Organization (FAO) of the United Nations reported that 831 million hectares of soils (6.5%) around the world are suffering from some degree of salinization and sodification problem (FAO, 2000). Magnitude of the problem can be clearly realized with asking the questions of “how will be the world fed in future?” and “can we find new arable lands?”. Nowadays, there are a lot of nations which are facing with food scarcity and hunger and in the last 25 years; arable land around the world has increased by less than 6 percent. Salinization and sodification is becoming an increasing serious threat to welfare of human being. Consequently, reclamation of soils suffering from saliniziation and sodification is of great importance for sustainable agriculture.

Accumulation of excess sodium (Na^+) in soil causes numerous adverse effects, such as elevation of the osmotic pressure, soil dispersion, reduced hydraulic conductivity and permeability, and specific ion toxicity (Akhter et al., 2004; Hanay et al., 2004). These soils can be reclaimed by a source of calcium (Ca^{2+}), such as gypsum, which then replace excess Na^+ found on cation exchange sites. However, increased costs and low-quality (impurity) of chemical amendments lead scientists to search alternatives (Qadir et al., 2006). For this aim various organic amendments have been investigated (Diez & Krauss, 1997; Wahid et al., 1998; Hanay et al., 2004; Angin & Yaganoglu, 2009). Although improvements in soil properties are seen when they are applied alone, their effect did not reach desired levels. Therefore, alternatives should be searched.

Fly ash, a by-product of combustion of coal at high temperature, can be an alternative to chemical and organic amendments. Many studies have shown that fly ash can be used as a sodic soil amendment (Brown et al., 1997; Kumar & Singh, 2003; Sahin et al., 2008).

Application of lime can prompt a number of chemical and biological changes to the soil. While the main benefit is to decrease the tendency of ‘cap’ formation in light-textured soils, for heavy-textured soils these include increases in friability of the soil and reduction in draft forces (Chan & Heenan, 1998). However, lime is added to provide soluble calcium to replace exchangeable sodium adsorbed on clay surfaces in sodic soils. Due to its high lime content, fly ash can be used as a calcium source in the reclamation of sodic soils. High solubility of calcium can provide sufficient Ca^{2+} to affect amelioration of saline-sodic soils. Thus, its reclamation potential should be taken into account. Use of fly ash as a reclamation material for saline-sodic soils will not only help to reclaim these soils but also help prevention of environmental pollution.

Therefore, this study was carried out to determine the effectiveness of fly ash addition rates (2, 4, and 8 t da^{-1}) on reclamation of saline-sodic soils.

2. MATERIALS AND METHODS

This study was conducted using disturbed soil samples under laboratory conditions with a relative humidity and average temperature of 50 ± 5% and 18 ± 2ºC, respectively. Three soils samples (Typic Natrargid) with different salinity and sodicity levels were sampled to a depth of 0-30 cm from Igdir plain, Turkey. Igdir plain is located in the northeast part of Turkey. It covers about 68,000 ha of irrigated land at a mean slope of 0.1%. About 36% of the Igdir plain soils suffer from some degree of salinity and/or alkalinity (Ardahanlioglu et al., 2003). Mean annual precipitation, temperature, and relative humidity of the area are 253 mm, 11.7 °C, and 71%, respectively (Smith, 1993). Soil humidity and temperature regimes are defined as Aridic and Thermic (Soil Survey Staff, 1999).

Soil samples collected from the plain were air-dried, well-mixed and crumbled to pass 8 mm. Soils were then filled into twenty seven drainage type columns (50 cm x 10 cm, length x diameter) to a depth of 30 cm. The bottom of each column was padded a 5 cm layer of gravel and sand to facilitate leaching. The soil columns were tapped 25 times after each 10 cm soil was added. The bulk density of columns was approximately 1.38, 1.24 and, 1.36g.cm^{-3} in soil materials from A horizon I, II and III, respectively.

Fly ash, obtained from Afsin-Elbistan Thermal Power Plant, was used in this study. Almost >50% of this material passes through 0.075 mm sieve opening, so no additional sieving was made. Characteristics of fly ash and soils prior to the experiment were given in table 1.

To determine the effect of fly ash addition on reclamation, fly ash was added to the surface layer (2-3 cm) of each column in the rates of 2, 4, and 8 t da^{-1} (15.7, 31.4, and 62.8g fly ash per column). Leaching was achieved with the application of 45 cm good quality water (pH = 7.90, electrical conductivity (EC) = 0.31 dS m^{-1}, and sodium adsorption ration (SAR) = 0.26) in three portions (3 x 15 cm) with 24 h intervals when the previous application had fully infiltrated (Sahin & Anapali, 2005). To facilitate reclamation and decrease the pH of soil, H_2SO_4 was added to the last portion of leaching water (0.92 N H_2SO_4).

Table 1. Major physical and chemical properties of the soil materials from A horizon and fly ash

Properties	Materials			
	Soil I	Soil II	Soil III	Fly ash
Clay (%)	16.82	35.71	14.94	-
Silt (%)	39.02	45.78	43.90	-
Sand (%)	44.16	18.51	41.16	-
Texture	Loam	Silty Clay Loam	Loam	-
pH$^{\$}$	10.06	8.98	8.01	12.30
EC$^{\$}$ (dS m^{-1})	81.40	90.60	21.40	6.62
CEC ($cmol_{(+)}$ kg^{-1})	34.55	43.70	31.50	15.24
ESP (%)	47.70	56.58	42.44	2.83
$CaCO_3$ (%)	11.14	16.28	11.78	16.60
Organic matter (%)	0.43	2.66	0.87	1.22

$^{\$}$In saturation extract for soils and in 1:2.5 (solid:water) extract for fly ash.

After leaching pH and electrical conductivity (EC) of soils were measured in saturation extracts according to Demiralay (1993) and Rhoades (1996). Lime content of the soils was determined with "Scheibler Calcimeter" as described by Nelson (1982). Ammonium acetate buffered at pH 7 (Rhoades, 1982) was used to determine Na^+. Cation exchange capacity (CEC) was determined with flame photometer (Jenway PFP-7, England) using sodium acetate – ammonium acetate buffered at pH 7 according to Sumner & Miller (1996). Exchangeable sodium percentage (ESP) was calculated as {Exc. Na^+/CEC} x 100. Infiltration rate measurement was done under 10 cm hydraulic load, with collection of leachate after 24 hour.

Analysis of variance (ANOVA) was performed by SPSS Statistical Package (SPSS 13.0, SPSS Science, Chicago, IL) using GLM. Mean differences were considered significant if $P \leq 0.05$ (Duncan's Multiple Range Test).

3. RESULTS AND DISCUSSION

Effects of fly ash addition on soil pH, EC, ESP and $CaCO_3$ were given in table 2. Jala & Goyal (2006) have stated that fly ash can be used to buffer the soil pH depending on the source from which it is produced. It is expected that fly ash used in this study may offset decreases in soil pH due to its high alkaline (12.30) character (Zhang et al., 2007). However, fly ash addition has decreased pH values in all of the soil types, but it is only found significant in soil II. pH values of the soils have almost reached neutral values after fly ash addition. Decrease in soil pH can be due to H_2SO_4 addition to the last portion of leaching water. This situation shows that alkaline fly ash can be used in sodic soils with proper acid treatment to the last portion of leaching water.

Application of fly ash to saline-sodic soil materials from A horizon has decreased soil EC significantly in all of the application rates (Table 2). Among the rates tested 2 and 4 t da^{-1} applications have same effect in soil II and III. Application of fly ash in the rate of 2 t da^{-1} has decreased soil EC in the percent of 88.39, 95.10 and 75.61 in soil I, II and III, respectively, while these percentages were as 85.09, 95.85 and 75.09 in 4 t da^{-1} application rate. However, except soil I, 8 t da^{-1} had no significant effect as 2 and 4 t da^{-1} application rates in soil II and III, due to clogging of soil pores, almost >50% of fly ash passes through 0.075 mm sieve opening, which caused decrease in infiltration rate thus, reduced leaching (Figure 1) (Sahin et al., 2003). As seen from Table 2, EC value of soil II has reached almost to 4 dS m^{-1} in 2 t da^{-1} and below 4 dS m^{-1} in 4 t da^{-1} application rates. This can be due to initial EC value and organic matter content of soil II, which helped aggregation, hence increased infiltration rate (Fig. 1). Infiltration rate of soil II was much higher than soil I and III. In contrast to soil II and III, decrease of EC in soil I with the application rate of 8 t da^{-1} can be due to higher infiltration rate (Fig. 1).

Lime content of soils was about same as in the initial level (Table 1, 2). Application of fly ash in the rate of 2 t da^{-1} has decreased soil $CaCO_3$ content slightly in all of the soil types, but it was not found statistically significant (Table 2). Slight decrease in soil $CaCO_3$ can be due to not only replacement of excess Na^+ found on cation exchange sites and H_2SO_4 addition to the last portion of leaching water but also high leach-ability of fly ash. Various researchers have stated that Ca^{+2} in fly ash is water soluble and its leach-ability is high (Kim et al., 2003; Ugurlu, 2004). However, except soil I, application of fly ash in the rates of 4 and 8t da^{-1} has increased soil $CaCO_3$ content in soil II and III, due to decreased infiltration rate (Figure 1).

Application of fly ash to saline-sodic soils has decreased ESP significantly in all of the application rates (Table 2). Application of fly ash in the rate of 2 t da^{-1} has decreased ESP in the percent of 40.21, 80.79 and 58.15 in soil I, II and III, respectively, while these percentages were as 30.86, 83.56 and 56.48 in 4 t da^{-1} and 29.77, 20.02 and 33.20 in 8 t da^{-1} application rates. Decrease in ESP can be due to increased solubility of soil and fly ash $CaCO_3$ with H_2SO_4 application to the last portion of leaching water. Abrol et al. (1988) has stated that solubility of $CaCO_3$ increases with pH decrease. Among the rates tested 2 and 4 t da^{-1} applications have same effect in soil II and III. However, ESP was above 15 in all of the treatments, except 2 and 4 t da^{-1} application rates in soil II. Decrease of ESP<15 in soil II, 2 and 4 t da^{-1} application rates can be due to high infiltration rate and initial organic matter content (Table1, Fig. 1), which caused leaching. As seen from table 2, in contrast to its infiltration rate (Fig. 1), ESP values of soil I were higher than that of soil II and III.

Table 2. Effects of fly ash addition on pH, EC, ESP and $CaCO_3$ of soil materials from A horizon: (Mean±SD)

Soil	Application rate (t da^{-1})	pH	EC (dS m^{-1})	ESP (%)	$CaCO_3$ (%)
Soil I	2	7.61±0.04	9.45±1.29 b	28.52±1.07 b	10.23±0.30
	4	7.56±0.15	12.14±0.65 a	32.98±0.79 a	10.08±0.54
	8	7.71±0.05	8.36±0.96 b	33.50±0.30 a	10.63±0.50
Soil II	2	7.50±0.04 a	4.44±0.25 b	10.87±2.08 b	15.40±0.93
	4	7.23±0.08 b	3.76±0.66 b	9.30±2.91 b	15.48±1.19
	8	7.55±0.08 a	11.44±1.24 a	45.25±3.80 a	16.53±0.30
Soil III	2	7.48±0.01	5.22±0.46 b	17.76±2.21 b	10.93±0.75
	4	7.47±0.01	5.33±0.91 b	18.47±3.61 b	12.05±0.85
	8	7.39±0.12	7.57±0.11 a	28.35±0.96 a	12.36±0.11

Values followed by same letter in same soil types are not statistically different ($P \leq 0.05$).

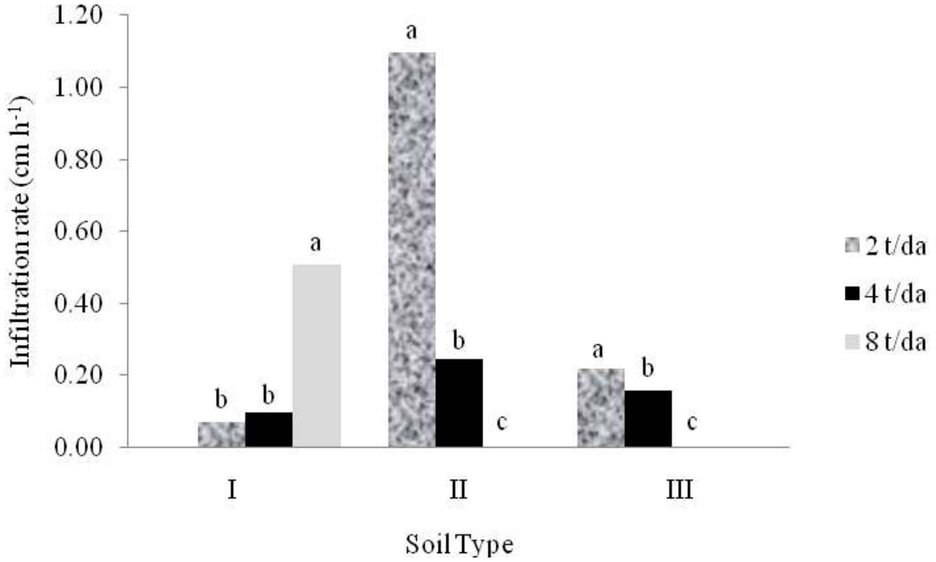

Figure 1 Effects of fly ash on infiltration rate of soils (Letters followed by same letter are not statistically different for same soil type)

This can be due to some properties of soil I and high solubility of Ca^{+2} in water. USSL (1954) has stated that texture, surface area and type of clay mineral, potassium status and soluble silicate and organic matter of soil effects ESP.

Improvement of water infiltration rate is one of the most essential requirements for reclamation of saline-sodic soils (Sahin et al., 2002). Therefore, providing a source of Ca^{2+} has great importance for amelioration of saline-sodic soils. Application of fly ash has increased infiltration rate in all of the application rates of soil I (Fig. 1). The ability of fly ash to increase infiltration rate has followed the order of 8 t da^{-1}>4 t da^{-1}>2 t da^{-1}, in soil I. Increase in the infiltration rate of soil I can be not only due to initial EC value of the soil (which helped aggregation) but also textural class of soil I and thus, caused interaction of fly ash with whole soil profile during leaching period. In contrast to soil I, the most effective application rate was found as 2 t da^{-1} in soil II and III, and followed the order of 2 t da^{-1}>4 t da^{-1} (Fig. 1). Infiltration was not seen in 8 t da^{-1} application rates of soil II and III, due to clogging of pores with fine graded material (0.075 mm sieve opening<50%), which also caused relatively high ESP values (Table 2).

4. CONCLUSION

This study showed that fly ash can be used for reclamation of saline-sodic soils and that fly ash can decrease soil ESP but that its effectiveness in enhancing reclamation depends on the initial organic matter and lime content, EC and ESP value, soil texture, the amount of fly ash applied and the acidity of the leaching water. Results obtained from this study have shown that for heavy textured soil 2 and 4 t da^{-1} application rate is much more effective in reducing ESP and EC value, with regard to soil infiltration rate. However, application of fly ash in the rate of 8 t da^{-1} decreases infiltration rate, thus does not make any sense on soil ESP value. For soils with high lime, organic matter and EC values use of 4 t da^{-1} can be much more effective, in contrast to use 2 t da^{-1} for soils with low high lime, organic matter and EC values. Use of fly ash as a reclamation material for saline-sodic soils will not only help to reclaim these soils but also help prevention of environmental pollution. Field studies are needed to further test and quantify the effectiveness of fly ash addition in enhancing reclamation of saline-sodic soils.

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