Fly Ash and Sewage Sludge Application on an Acid Soil and Their Influence on Some Soil Properties and Wheat Biomass Production

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Abstract: A pot experiment was conducted with wheat on an acid soil (pH 5.0) amended with fly ash and sewage sludge. The experimental design was complete randomized blocks with seven treatments each replicated four times. The treatments were: C, control - soil alone, IF - soil with inorganic fertilizers, T1 - soil plus 30 g fly ash/2.5 kg soil, T2 - soil plus 90 g fly ash/2.5 kg soil, SS1 - soil plus 2.65 g sewage sludge/2.500 kg soil, SS2 - soil plus 5.25 g sewage sludge/2.5 kg soil, SS3, soil plus 10.5 g sewage sludge/2.5 kg soil. All the treatments included sewage sludge, included also fly ash, at the amount of the treatment T1. The results showed that fly ash alone didn't increase significantly wheat biomass as did inorganic fertilization and sewage sludge application at the higher levels. Fly ash addition increased soil pH, electrical conductivity, hot water extractable boron and total Cu, Pb, Ni, and Zn while decreased available forms of these heavy metals. Sewage sludge increased wheat biomass along with soil pH, and ammonium and nitrate N in soil. However, it also increased heavy metal content especially their total concentration but not their available forms.
Keywords: fly ash, sewage sludge, acid soil, heavy metals

1 Introduction

Fly ash is a by-product of combustion of lignite being used as fuel by power stations of electric power production. It is the portion of the ash stream with small size (0.001 mm—0.1 mm) so that is carried from the boiler in the flue gas. Chemically, it is consisted mainly of the essential to plant growth elements Ca, Fe, Mg, K, and some other elements such as Si, Al, Na, and Ti. However, fly ash contains also many trace elements (B, Se, and Mo) that in excess may be toxic to the plants (Korcak, 1995). Fly ash may be acidic (pH 3—4) or alkaline (pH 10—12) due to carbonate salts of Ca and Mg. In addition fly ash soluble salt content is usually high giving a value of the electrical conductivity of saturation extract from 0.63—55 dS/m (Aitken *et al*., 1984). Most of the amount of fly ash produced in the USA (80%) is disposed while about 20% is recycled (USEPA, 1988) both in non agricultural uses such as cement additives, road and construction fills, asphalt amendment stabilization of hazardous wastes or in agriculture (Korcak, 1995). The latter use has been found beneficial since fly ash may enhance soil fertility but at the same time it may has adverse effects on plants if its application is not based on a prescription according to the need and soil composition. In Greece there are several electric power plants using coal as a fuel that produce considerable amounts of fly ash. Recent research (Matsi and Keramidas, 1999) has shown that fly ash use as liming agent in acid soils in definite amounts increases dry biomass yield of rye grass and cumulative uptake of B and P.

Land disposal of sewage sludge expanded during the last decades after it appeared to be an advantageous and environmentally sound method. From a great number of studies it was very well documented that sewage sludge application to the soils, substantially increases nutrient content and crop growth (Smith, 1996) as well as soil physical properties. Generally, sewage sludge application increases water retention capacity (Hall and Coker, 1983), reduces the soil bulk density and consequently increases total porosity (Chang *et al*., 1983), increases the number and size of water-stable aggregates through increase of soil organic matter content (Tisdal and Oades, 1982), and increases hydraulic conductivity (Epstein, 1975) However, sewage sludge contains a number of potentially toxic substances and may cause environmental pollution such as heavy metal contamination or nitrate pollution of ground water if it is applied in higher than the recommended rates which usually are needed for improvement of physical properties. Improvement of soil physical properties is especially important for intensively cultivated soils under conditions enhancing a rapid decomposition of soil organic matter like Mediterranean environments leading to a considerable deterioration of soil physical status and erosion. In such cases application of sludge, is a very effective method to maintain sufficient organic matter content in soils. Recent studies in Greece (Tsadilas *et al.*, 1995) have proved that municipal sewage sludge may be beneficial for agricultural use in Greek soils without causing detrimental effects on soil quality if it is used in the appropriate quantities. The purpose of this study, that is a part of a research project financed by the EU, was to continue the research on the possibility of using fly ash and sewage sludge as soil amendments in acid Greek soils.

2 Materials and methods

A pot experiment was conducted with an acid soil (pH 5.0) from Agia area Central Greece classified as Typic Haploxeralf. Selected properties of the soil used specified according to procedures described by Page *et al.* (1982) are presented in Table 1.

Table 1 Selected properties of the soil used in the experiment

pH	Lime requirements (Adams method)	Clay	Organic matter	N total	Cation exchange capacity	Base saturation
H_2O 1:1	kg $CaCO_3$/ha	%	%	%	cmol(+)/kg	%
4.73	6530	15.2	1.8	0.101	13.02	36
HwsB*	EC (1:5)**	P_{Olsen}	Total Zn	Total Cu	Total Ni	Total Pb
ppm	mmhos/cm	ppm	ppm	ppm	ppm	ppm
0.48	0.107	69	43.21	4.12	33.85	48.32

* Hot water extractable boron, ** Electrical conductivity in water suspension 1:5 soil:water.

Fly ash was collected from the electrostatic precipitator of a lignite-fired electric power plant in northern Greece. It was artificially aged for three months before its use by maintaining in an open air and leaching periodically with deionized water. It was strongly alkaline with a pH 12.1. Its heavy metal content and other selected properties are shown in Table 2.

Table 2 Selected properties of the fly ash used

pH (H_2O 1:1)	Zn	Cu	Ni	Pb	HwsB	Available P	EC_{se}	$CaCO_3$
	ppm	ppm	ppm	ppm	ppm	ppm	mmhos/cm	%
12.1	116.25	30.25	378.75	9.0	2.75	15.3	2.8	15.8

Sewage sludge was selected from the waste water treatment plant of the city of Tirnavos, Central Greece. Its composition specified according to Leschber *et al.* (1984) is presented in Table 3.

Table 3 Some characteristics of the sewage sludge used

pH (H_2O 1:1)	$CaCO_3$, %	EC, mmhos/cm	Organic mater, %	N-total, %	P-total, %
6.5	1.1	2.87	32.0	4.45	1.69
K-total, %	Zn, ppm	Cu, ppm	Ni, ppm	Pb, ppm	Cd, ppm
0.38	1320	285	45.2	185.0	1.46

The experimental design was complete randomized blocks including seven treatments each replicated four times. The treatments were (in all the pots were placed 2.5 kg of soil):

C, control, 2.5 g soil alone,
IF, soil with inorganic fertilizers, 160 kg N/ha, 80 kg P_2O_5/ha,
T1, soil plus 30 g fly ash/pot,
T2, soil plus 90 g fly ash/pot,
SS1, soil plus 2.65 g sewage sludge/pot plus 30 g fly ash/pot,
SS2, soil plus 5.25 g sewage sludge/pot plus 30 g fly ash/pot,
SS3, soil plus 10.5 g sewage sludge/pot plus 30 g fly ash/pot.

Fly ash and sewage sludge were thoroughly mixed with the soil, the mixtures were wetted up to the field capacity and left for equilibration for 1 month. Then 15 seeds/pot of durum wheat were planted in the pots and grown for two months in a non-heated greenhouse. The plants were then harvested, dried and weighted. As wheat biomass was considered the dry weight of the whole above ground plant part. At the same time soil samples were selected from all the pots, aired dried, crushed and sieved with a 2 mm sieve. Soil samples were analyzed for pH, organic matter content, electrical conductivity, ammonium and nitrate nitrogen, hot water extractable boron, total content of Cu, Pb, Ni, and Zn as well as DTPA extractable Cu, Pb, Cd, and Zn according to the procedures described by Page *et al*. (1982). Analysis of variance of the mean values of the treatments applied was performed using the LSD test (P<00.05) as well as regression analysis where necessary.

3 Results and discussion

3.1 Influence of fly ash and sewage sludge on wheat biomass production

Wheat biomass production was slightly affected by the treatments applied. Only the treatment received inorganic fertilization (IF) gave higher yield in comparison to all the rest treatments (Fig.1). Fly ash addition (T1, T2) had no significant effect on the wheat biomass in comparison to the control treatment. Sewage sludge (SS1, SS2, SS3) significantly affected wheat biomass that was increased from 4.65 g/pot in the control treatment to above 6.0 g/pot in the treatments included the higher sewage sludge rates (Fig.1). This increase may be attributed to the increase caused by the sewage sludge to the ammonium and nitrate nitrogen (Table 4). Different results were reported by Matsi and Keramidas on the influence of fly ash application on rye grass yield. They found that fly ash significantly increased rye grass biomass. From all the properties studied, only total Zn and Cu content were significantly correlated in a positive way with wheat biomass (r = 0.41**, r = 0.44** respectively).

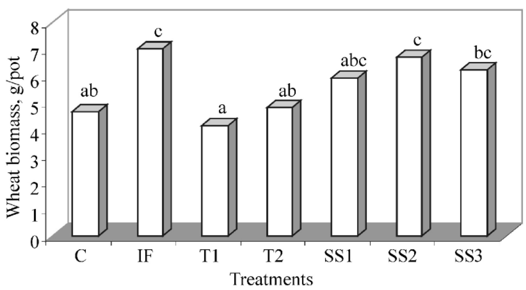

Fig.1 Influence of the treatments applied on the wheat biomass

3.2 Influence of fly ash and sewage sludge on soil properties

Soil pH was significantly increased by the application of both fly ash and sewage sludge. Fly ash at the rate 30 g/2.5 kg soil (T1) increased soil pH from 5.02 in the control to 6.62 and up to 7.49 at a rate 90 g/2.5 kg soil (T2) (Table 4). Similar but slighter effect had also sewage sludge addition on the soil pH that was increased up to 6.54 (Table 4). Similar influence on soil pH by fhy ash on the soil pH in two acid red soils from northern Greece was reported by Matsi and Keramidas (1999).

Table 4 Influence of fly ash and sewage sludge on wheat biomass production and some soil properties

Treatments	pH	EC*	HwsB**	NH_4-N	NO_3-N	Org. mat.
	water(1:1)	mmhos/cm	ppm	ppm	ppm	%
C	5.02b***	0.082a	0.45b	7.19bc	2.00a	1.83a
IF	4.81a	0.109a	0.17a	2.72	3.14a	1.93a
T1	6.62e	0.163ab	0.84cd	5.20ab	3.07a	1.88a
T2	7.48f	0.63d	1.38e	5.64ab	4.47a	1.81a
SS1	6.54de	0.204b	0.58b	8.12bc	4.15a	1.88a
SS2	6.39c	0.25c	0.69bc	9.56c	16.55b	1.77a
SS3	6.43cd	0.221bc	0.96c	16.62d	13.28b	1.78a

Treatments	Cu_{DTPA}	Pb_{DTPA}	Cd_{DTPA}	Zn_{DTPA}	Total-Cu	Total-Pb	Total-Ni	Total-Zn
	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm
C	11.41c	0.78b	0.14b	2.44d	34.95a	4.16a	48.95a	43.95a
IF	9.36b	0.42a	0.10b	1.71c	75.31c	7.87c	105.37cd	89.68c
T1	9.19b	0.42a	0.10b	1.26ab	64.06b	6.93bc	91.03b	74.84b
T2	7.84a	0.39a	0.07a	1.09a	74.67c	7.33bc	110cd	102.92c
SS1	9.35b	0.38a	0.09b	1.80c	73.87c	7.31bc	106cd	98.12c
SS2	9.49b	0.84b	0.09b	1.64bc	76.69c	6.94bc	104c	99.06c
SS3	11.30c	0.65ab	0.12c	2.65d	79.06c	6.62b	118d	95.94c

*Electrical Conductivity, **Hot water soluble Boron, ***numbers in the same columns followed by different letters, differ significantly at the probability level $P<0.05$ according to the LSD test.

Fly ash and sewage sludge significantly also increased electrical conductivity. The higher increase was recorded in the case of the higher fly ash rate (T2) i.e from 0.086 to 0.64 mmhos/cm (Table 4) in agreement with those reported previously by others (Matsi and Keramidas, 1998; Elseewi *et al*., 1980). It was strongly correlated with soil pH (R^2=0.84***). These rates of electrical conductivity may be harmful especially for sensitive crops.

Application of fly ash and sewage sludge resulted in a considerable increase in hot water soluble boron (HwsB). However fly ash's effect was stronger than that of sewage sludge. It increased HwsB from 0.45 ppm in the control treatment up to 1.38 in the treatment with the higher fly ash rate (T2) while sewage sludge increased HwsB up to 0.96 ppm in the treatment including the higher rate (SS3). These rates are considered harmful to sensitive crops. Hot water soluble boron was strongly correlated with electrical conductivity (Fig. 2).

Ammonium and nitrate nitrogen were increased significantly as it was expected only in the treatments included sewage sludge (Table 4). Unexpectedly organic matter content did not increase because of the sewage sludge application as it was reported by others (Tsadilas *et al*., 1995).

Fly ash addition significantly affected heavy metal content of soils. Total Cu increased from about 35 ppm in the control to 75 ppm in the treatment T2, total Pb from about 4 to 7 ppm, total Ni from 49 ppm to 110 ppm, and total Zn from 44 ppm to 103 ppm in the treatment T2 (Table 4). However, available forms of these metals as they estimated by DTPA method (Page *et al*., 1982) decreased in the treatments included fly ash (Table 2). It is attributed to the pH increase because of the fly ash application. DTPA extractable heavy metals and pH were negatively correlated. The respective correlation coefficients were r = –0.56** for Cd, r = –0.43* for Zn, and r = –0.51** for Cu. So, although fly ash increases heavy metal content of soils, they are not in available form and it is not expected to increase heavy metal uptake by plants. Sewage sludge addition had similar effect with the fly ash to the heavy metal content of soils. It increased significantly total heavy metal content like fly ash but it did not affect significantly their available forms (Table 4).

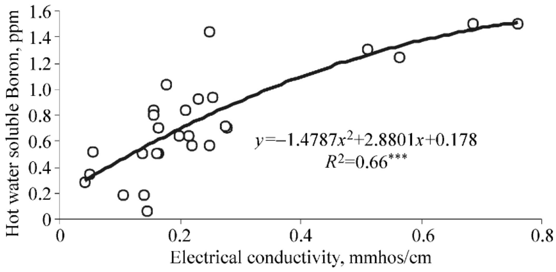

Fig. 2 Relationship between hot water soluble boron and electrical conductivity

4 Conclusions

Fly ash addition increases soil pH, electrical conductivity, hot water extractable boron and total heavy metal content of acid Typic Haploxeralfs. However, it does not increases wheat biomass production in these soils. Sewage sludge increases wheat biomass along with soil pH, and inorganic nitrogen forms. Sewage sludge also increases heavy metal content especially their total concentration but not their available forms.

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