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Effects of Sewage Sludge Application on Some Physical and Chemical Properties of a Soil Affected by Wind Erosion

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ABSTRACT

Erosion is considered as a main problem for the loss of arable land around the world. As the world arable land is reaching its limit, marginal areas, such as those prone to wind erosion, have gained importance for agricultural use. A simple and effective way of restoring wind eroded soils is addition of organic materials. Sewage sludge can be an effective way to solve this problem. The effect of sewage sludge application on some physical and chemical properties of a soil affected by wind erosion was studied during 2004 - 2007 in Igdir plain (Aralik), Turkey. Sewage sludge was applied at the rates of 0, 40, 80 and 120 t ha^{-1} (dry weight). The experiments were conducted for three years using a complete randomized block design with three replications in 12 plots, where barley (*Hordeum vulgare*) was sown. Sewage sludge application not only improved the physical and chemical properties of the soil, but also increased barley yield. However, increased yield was not sufficiently high. In order to achieve satisfactory yields, annual application of sewage sludge at the rate of, at least, 40 t ha^{-1} is required.

Keywords: Barley yield, Sewage sludge, Soil physical and chemical properties, Wind erosion.

INTRODUCTION

Agriculture has a significant role in food supply and economy of all nations, regardless of their development. Increase in population growth and threats of global warming have made this sector much more important. With the reality that increase in food consumption is much greater than increase in agricultural productivity, people begin to think about how the world will be fed in future. Nowadays, many nations are facing food scarcity problems and hunger.

Of the 13.05 billion ha total land area of the world, only 3.19 billion ha are potentially arable. Currently, 1.47 billion ha (46.2%) of the arable lands are cultivated. In the last 25 years, arable land around the world has increased by less than 6 percent. Food and Agriculture Organization of the Unites Nations has reported that arable land per capita has decreased from 0.38 ha to 0.23 ha in the last 30 years, with a future estimation of 0.15 ha by 2050 and 0.14 ha by 2100 (FAO, 2000). Soil degradation processes including erosion, salinization, and non-agricultural uses cause at least ten hectare of arable land to be lost every minute (Abrol *et al.*, 1988). Considering that the world arable land is reaching its limit, problematic areas have gained much more importance for agriculture.

Wind erosion is a common and serious problem in arid and semiarid regions of the world, like North Africa and the Near East, Asia, Siberian Plains, Australia, northwest China, South and North America (Anonymous, 2003). Wind erosion removes soil constituents such as organic matter, clay, and silt, which are considered as the most fertile parts of the soil (Lyles, 1975). Wind erosion reduces soil productivity and increases economic costs. Therefore, productivity of

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such areas should be increased so that future food demands may be met.

In Turkey, soils affected by wind erosion cover approximately 0.51 million hectares and are not used for agricultural purposes; indeed, they constitute a threat for rural settlements around them (transportation of soil to settlements). Increase in soil productivity of these lands will improve economy and help local communities to meet future food demands.

Soils affected by wind erosion can be reclaimed by physical or cultural practices. These cultural practices are based on the improvement of land by adding organic materials such as compost and sewage sludge. Sewage sludge, due to its high content of organic matter and plant nutrient elements, is considered an effective material to improve soil physical and chemical properties (Sort and Alcañiz, 1999; Tsadilas *et al*., 2005; Weber *et al*., 2007).

The objective of this study was to investigate the impact of sewage sludge application on some physical and chemical properties of a soil affected by wind erosion.

MATERIALS AND METHODS

This study was conducted for three years (2005 – 2007) in Igdir plain (Aralik), Turkey. The experimental region has a semi-arid climate with long-term mean annual minimum and maximum temperatures of 5.8ºC and 19.2ºC, relative humidity of 55%, and annual precipitation of 259.1 mm. Climatic parameters during the experimental period are given in Table 1.

The experiment was conducted using a complete randomized block design with three replications in 12 plots, each measuring 9 m^2 (3 m x 3 m), with a separation strip of 1 m between them. Experimental site has a gentle slope (<2%), therefore, no runoff was observed during the study. Anaerobically digested sewage sludge, obtained from the wastewater treatment plant of the Municipality of Ankara, was added to the plough layer (0-25 cm) of the experimental site in July 2004 at rates of 0 (Control), 40, 80, and 120 t ha^{-1} dry weight. No sewage sludge was applied after this date. Characteristics of sewage sludge are given in Table 2. Soils in the experimental site are almost homogenous and classified as Entisol (Orthent) according to USDA Soil Taxonomy. Soil properties prior to the application of sewage sludge are given in Table 3. Three soil samples were collected from the top layer (0-25 cm) of each plot in July of 2005, 2006, and 2007, a total of 9 samples per treatment. A wind curtain 0.50 m high was placed between

Table 1. Meteorological parameters during the experimental period (Mean).

Months	Climatic parameters											
	Temperature (˚C)				Relative Humidity (%)				Precipitation (mm)			
	2005	2006	2007	Mean [a]	2005	2006	2007	Mean [a]	2005	2006	2007	Mean [a]
January	-4.0	-3.9	-9.4	-2.9	60.3	61.4	70.0	66	20.7	28.2	14.8	13.2
February	-0.9	-0.9	-1.2	-0.1	54.2	65.5	62.3	60	12.9	29.8	8.4	16.5
March	6.8	9.1	7.2	6.3	49.2	45.1	51.1	51	49.0	3.6	51.3	22.1
April	15.2	14.3	10.7	13.4	44.4	54.8	50.2	50	29.5	96.9	67.4	36.8
May	18.5	19.5	19.4	17.4	49.6	48.4	48.3	51	38.7	47.5	28.2	48.0
June	22.4	26.9	23.3	22.0	43.1	36.7	42.9	46	48.2	19.5	35.3	33.2
July	28.5	26.3	26.0	26.0	36.7	40.8	43.3	44	10.3	25.8	32.3	13.5
August	27.2	28.8	25.6	25.1	42.3	36.5	45.0	46	23.1	2.5	41.7	9.2
September	21.0	21.8	23.1	19.8	45.4	41.4	44.4	51	11.8	3.4	0.0	9.9
October	13.3	14.8	15.4	12.5	54.8	66.9	57.7	62	6.6	52.2	41.5	26.5
November	6.1	6.1	6.0	5.4	57.0	51.4	56.8	65	2.3	8.0	40.8	18.2
December	-0.4	-4.4	-0.3	-0.2	74.0	63.0	55.5	68	14.3	18.0	2.2	12.0

[a] 32 years mean.

Table 2. Characteristics of sewage sludge used in the study.

Parameters (Unit) (Dry Matter)	Sewage Sludge	Method Used
Organic matter (%)	34	Nelson and Sommers, 1982
Total N (%)	4.46	Bremner, 1996
Total P (%)	1.1	Watanabe and Olsen, 1965
CEC (cmol$_c$ kg^{-1})	62.43	Sumner and Miller, 1996
Ca (%)	7.4	USEPA, 1997
Mg (%)	1.9	USEPA, 1997
Na (%)	0.2	USEPA, 1997
K (%)	2.1	USEPA, 1997
Fe (%)	0.10	USEPA, 1997
Zn (mg kg^{-1})	873.53 [a]	USEPA, 1997
Cu (mg kg^{-1})	239.90 [a]	USEPA, 1997
Mn (mg kg^{-1})	903.99	USEPA, 1997
Ni (mg kg^{-1})	57 [a]	USEPA, 1997
Pb (mg kg^{-1})	152.5 [a]	USEPA, 1997
Cd (mg kg^{-1})	8.5 [a]	USEPA, 1997
Hg (mg kg^{-1})	0.75 [a]	USEPA, 1997
Cr (mg kg^{-1})	168.5	USEPA, 1997
pH	6.82	Demiralay, 1993
Electrical Conductivity (EC) (dS m^{-1})	6.54	Rhoades, 1996
Bulk density (g cm^{-3})	0.676	Blake, 1965a
$CaCO_3$ (%)	17.3	Nelson, 1982
Faecal coliform (unit g^{-1})	255	APHA, AWWA and WPCF, 1985
Salmonella (25 g)	Not found	
Helmint egg (g)	Not found	

[a] These values are lower than critical cumulative pollutant loading rates accepted by USEPA and Europe legislations.

plots to prevent soil (organic matter, silt, clay) and/or sewage sludge loss with wind, while preparing the plots. Barley (*Hordeum vulgare*) (Tokak-157/37) was sown to the plots in April of 2005, 2006, and 2007 (450 seed per m^2, Akten and Akkaya, 1986). Fourteen rows were seeded with sowing machine. At maturity, the aerial parts of barley in each plot were harvested and were dried for 5 days to estimate biomass yield. Irrigation water was applied at 587mm per year.

Particle size distribution was determined by the method proposed by Gee and Bauder (1986). Permeability coefficient was calculated by values recorded under saturated conditions with an ICW constant head permeameter (Eijkelkamp, Giesbeek, Netherlands) (Klute and Dirksen, 1986). Bulk and particle density were determined as described by Blake (1965a, b). Total porosity was calculated using bulk and particle density values. Field capacity (FC) and wilting point (WP) were determined at 0.33 atm. and 15 atm. pressures, respectively, using a membrane extractor (Soil Moisture, Santa Barbara, CA, USA) as described in Richards (1948, 1949). Available water (AW) was calculated by subtraction of WP from FC.

The pH and electrical conductivity (EC) were measured in saturation extracts according to Demiralay (1993) and Rhoades (1996). Soil organic matter was determined using the Smith-Weldon method as described in Nelson and Sommers (1982). $CaCO_3$ content of the soils was determined using "Scheibler Calcimeter" as described by Nelson (1982). Ammonium acetate buffered at pH 7 (Rhoades, 1982) was used to determine exchangeable cations. Cation exchange capacity (CEC) was determined with flame photometer (Jenway PFP-7, England) using sodium acetate – ammonium

Table 3. Soil properties prior to the application of sewage sludge.

Physical Properties		
Texture	Sand (%)	69.39
	Silt (%)	19.42
	Clay (%)	11.19
Texture Class		Sandy loam
Bulk density (g cm^{-3})		1.32
Particle density (g cm^{-3})		2.48
Porosity (%)		46.73
Permeability coefficient (cm h^{-1})		3.965
Field capacity (FC) (P_w)	0-30 cm	15.31
	30-60 cm	15.25
	60-90 cm	15.18
Wilting point (WP) (P_w)	0-30 cm	5.35
	30-60 cm	5.38
	60-90 cm	5.38
Available water (AW) (P_w)	0-30 cm	9.96
	30-60 cm	9.87
	60-90 cm	9.80
Chemical Properties		
pH [a]		8.18
Electrical conductivity[§] (EC) (dS m^{-1})		0.56
$CaCO_3$ (%)		2.83
Organic matter (%)		0.12
Cation exchange capacity (CEC) ($cmol_c$ kg^{-1})		22.58
Exchangeable cations ($cmol_c$ kg^{-1})	Na	1.06
	K	2.19
	Ca	4.44
	Mg	3.10
Total N (%)		0.09
DTPA-extractable metals (mg kg^{-1})	Fe	9.18
	Zn	1.47
	Cu	0.67
	Mn	4.87

[a] Determined in saturation extracts.

acetate buffered at pH 7 according to Sumner and Miller (1996). The Kjeldahl method (Bremner, 1996) and a Vapodest 10 Rapid Kjeldahl Distillation Unit (Gerhardt, Konigswinter, Germany) were used to determine total N. Micro elements in the soils were determined by DTPA extraction methods using a Perkin–Elmer 360 Atomic Absorption Spectrophotometer (Perkin-Elmer, Waltham, Massachusetts, USA) (Lindsay and Norwell, 1969).

The data were analyzed with sewage sludge (t ha^{-1}) as the main plot treatment and years (2005, 2006, and 2007) as the subplot treatments (SPSS Science, Chicago, IL). In the analysis of variance (GLM), the subplot treatments were analyzed as repeated measures in years. Mean differences were considered significant when $P \leq 0.05$ (Duncan's Multiple Range Test).

RESULTS AND DISCUSSION

Effects on Some Soil Physical Properties

In all application rates, sewage sludge decreased bulk density of the soil significantly (Table 4). However, its effectiveness decreased during the experimental period. In all of the years studied, the most effective application rate was 120 t ha^{-1}. Decrease in the effectiveness of sewage sludge could be attributed to the mineralization of sludge-borne organic matter with time, as suggested by Wong *et al.* (1998). The highest application rate of sewage sludge decreased bulk density by 8.89%, 7.91%, and 6.02% in 2005, 2006, and 2007, respectively, as compared to the control plot. The decrease in bulk density could be due to the low bulk density of sewage sludge (0.676 g cm^{-3}). Particle density also decreased with the application of sewage sludge (Table 4). In accordance with bulk density, the highest decrease in particle density was observed in the first year (2005). The positive effects of sewage sludge application were also observed in total porosity (Table 4). However, this effect was not significant throughout the experiment. Sewage sludge application increased total porosity by 3.27%, 4.75%, and 5.53%, at 40, 80, and 120 t ha^{-1} rates, respectively (2005-2007). Sort and Alcañiz (1999) and Weber *et al.* (2007) have also reported that the application of sewage sludge increased total porosity.

Sewage sludge also increased permeability coefficient significantly in all application rates (Table 4). This effect was much more pronounced in 2005 and 2006. Increase in permeability coefficient could be attributed to the amelioration of the aggregation and

Table 4. Effects of sewage sludge on some soil physical properties.

Application rate (t ha^{-1})	Years			Mean
	2005	2006	2007	
Bulk density (g cm^{-3})				
Control	1.35±0.02aAB [a]	1.39±0.02aA	1.33±0.01aB	1.35±0.01a
40	1.33±0.01aA	1.31±0.01bAB	1.28±0.01bB	1.31±0.01b
80	1.28±0.03abA	1.29±0.01bA	1.26±0.01bA	1.28±0.01bc
120	1.23±0.04bB	1.28±0.01bA	1.25±0.01bB	1.25±0.01c
Particle density (g cm^{-3})				
Control	2.480±0.01aB	2.507±0.00aA	2.519±0.00aA	2.502±0.01a
40	2.464±0.01aB	2.490±0.01bA	2.491±0.01bA	2.482±0.00b
80	2.432±0.01bB	2.472±0.00cA	2.472±0.01cA	2.459±0.01c
120	2.402±0.02bB	2.450±0.01dA	2.450±0.01dA	2.434±0.01d
Porosity (%)				
Control	45.75±0.74aAB	44.74±0.54bB	47.24±0.50bA	45.91±0.39b
40	46.07±0.43aB	47.52±0.41aAB	48.65±0.30aA	47.41±0.30a
80	47.47±1.32aA	47.94±0.54aA	48.85±0.43aA	48.09±0.49a
120	48.65±1.78aAB	47.57±0.34aB	49.12±0.24aA	48.45±0.60a
Permeability coefficient (cm h^{-1})				
Control	4.097±0.205cA [a]	4.608±0.215cA	4.149±0.195aA	4.285±0.122c
40	4.816±0.314bAB	5.217±0.072bA	4.201±0.461aB	4.745±0.198bc
80	5.353±0.290abAB	5.704±0.297abA	4.524±0.339aB	5.193±0.197ab
120	5.862±0.394aA	6.270±0.479aA	4.634±0.527aB	5.589±0.294a
Field capacity (P_w)				
Control	15.32±1.11bB [a]	17.46±0.36cA	17.53±0.48bA	16.77±0.45c
40	22.72±1.13aB	20.59±0.22bA	20.30±0.67aA	21.20±0.48b
80	22.87±1.33aA	22.10±0.53aA	20.72±0.33aB	21.90±0.50ab
120	23.65±0.79aA	23.00±0.38aA	21.00±0.19aB	22.55±0.36a
Wilting point (P_w)				
Control	5.53±0.22dA	5.47±0.08dA	5.00±0.30cA	5.33±0.13d
40	7.92±0.15cA	6.58±0.10cB	5.82±0.15bC	6.77±0.19c
80	10.44±0.48bA	7.86±0.14bB	6.67±0.15aC	8.33±0.35b
120	12.21±0.93aA	9.17±0.20aB	6.83±0.27aC	9.40±0.54a
Available water content (P_w)				
Control	9.80±0.95bB	11.99±0.37bAB	12.53±0.35bA	11.44±0.42b
40	14.80±1.15aA	14.02±0.28aA	14.47±0.74aA	14.43±0.45a
80	12.43±1.61abA	14.24±0.55aA	14.04±0.30aA	13.57±0.57a
120	11.44±1.40bB	13.83±0.51aA	14.17±0.33aA	13.15±0.55a

[a] Letters followed in each row (capital letters) show differences between years, while letters in columns (small letters) show differences between application rates (Mean±SE, n=9). Mean differences were tested at the level of $P \leq 0.05$.

decrease in bulk density (Aggelides and Londra, 2000; Tsadilas *et al*., 2005). However, the permeability class of the soil (2.00 – 6.25 cm h^{-1}, medium) was not changed. This might be due to the textural class (SL) of the soil.

Sewage sludge, due to its high organic matter content, significantly increased the field capacity values in all application rates (Table 4). The highest increase was observed in the highest rate (120 t ha^{-1}), due to the increase in adsorption surface and organic matter content (Navas *et al*., 1998; Holz *et al*., 2000; Veeresh *et al*., 2003). When compared with the control, sewage sludge increased field capacity by 26.42%, 30.59, and 34.47%, at 40, 80, and 120 t ha^{-1} rates, respectively. The same increases were recorded for wilting point (Table 4). In accordance with field capacity, the highest wilting point was found in the 120 t ha^{-1} rate. While field capacity has a significant role in the increase of available water content, increase in wilting point may minimize this effect. Because of the increase in wilting point at high sewage sludge rates, the highest available water content was found in the application rate of 40 t ha^{-1}. This situation could be not only due to the increase in field capacity, but also due to the increase in the wilting point as reported by Epstein (1975). These changes in the soil physical properties improved its quality.

Effects on Some Soil Chemical Properties

The effect of sewage sludge application on soil pH was found statistically significant (Table 5). Sewage sludge significantly decreased soil pH. This decrease could be due to low pH value (6.82) of sewage sludge and organic acids produced during mineralization (Veeresh *et al*., 2003). Soil pH is a critical soil parameter in sewage sludge applied lands, because it significantly affects the bioavailable forms of metals. Soil electrical conductivity (EC) increased with sewage sludge application (Table 5). Variations among the years were obtained during the experimental period. The highest EC value was recorded in 2005 in the 120 t ha^{-1} treatment. However, this effect decreased with time. Decrease in soil EC could be attributed to the loss of sewage sludge effectiveness and irrigation, which helped leaching (Perez-Murcia *et al*., 2006; Gascó and Lobo, 2007). Variations in pH and EC among the years of the same treatments can be due to the seasonal

Table 5. Effects of sewage sludge on some soil chemical properties.

Application rate (t ha^{-1})	Years			Mean
	2005	2006	2007	
pH				
Control	8.22±0.01aA[a]	7.42±0.02aC	7.63±0.01aB	7.76±0.07a
40	7.85±0.04bA	7.26±0.03bC	7.49±0.02bB	7.53±0.05b
80	7.59±0.02cA	7.12±0.03cC	7.34±0.01cB	7.35±0.04c
120	7.43±0.01dA	6.84±0.03dC	7.16±0.01dB	7.15±0.05d
EC (dS m^{-1})				
Control	0.62±0.01dC	2.96±0.15aA	0.85±0.03cB	1.48±0.21d
40	1.67±0.04cB	2.59±0.04bA	1.73±0.04bB	2.00±0.09c
80	2.65±0.04bA	2.41±0.08bB	1.75±0.06bC	2.27±0.08b
120	3.75±0.03aA	1.58±0.04cC	1.96±0.07aB	2.43±0.19a
$CaCO_3$ (%)				
Control	3.17±0.09dB[a]	3.87±0.10dA	0.85±0.03dC	2.63±0.26d
40	4.12±0.13cB	4.56±0.09cA	1.11±0.08cC	3.26±0.31c
80	5.46±0.23bA	4.84±0.08bB	1.71±0.06bC	4.00±0.33b
120	5.89±0.15aA	5.32±0.08aB	1.97±0.05aC	4.39±0.34a
Organic matter (%)				
Control	0.16±0.01dB	0.62±0.02dA	0.26±0.02dB	0.35±0.04d
40	1.27±0.03cA	1.23±0.04cA	0.81±0.05cB	1.10±0.05c
80	1.68±0.04bA	1.78±0.05bA	1.20±0.06bB	1.55±0.06b
120	2.38±0.07aB	2.60±0.07aA	1.45±0.04aC	2.14±0.10a
N (%)				
Control	0.11±0.00dA	0.03±0.00dB	0.02±0.00dB	0.05±0.01d
40	0.21±0.01cA	0.09±0.00cB	0.05±0.00cC	0.12±0.01c
80	0.29±0.00bA	0.17±0.00bB	0.10±0.01bC	0.19±0.02b
120	0.37±0.01aA	0.22±0.02aB	0.12±0.00aC	0.24±0.02a

[a] Letters followed in each row (capital letters) show differences between years, while letters in columns (small letters) show differences between application rates (Mean±SE, n=9). Mean differences were tested at the level of $P \leq 0.05$.

changes in soil moisture, temperature, microbial activity, and plant growth.

The high $CaCO_3$ content of sewage sludge (17.3%) caused a significant increase in $CaCO_3$ of the soils (Table 5). When means were compared, sewage sludge application in the rate of 40, 80, and 120 t ha^{-1} increased $CaCO_3$ content by 23.95%, 52.09%, and 66.92% as compared with the control. The lower $CaCO_3$ content of the soil in the last study season could be due to leaching and polymers added to sewage sludge at dewatering stage. Polymeric ions found in sewage sludge could have reacted with calcium. This hypothesis is consistent with Ca content of soil in the last study season. Sewage sludge application increased organic matter content of soils significantly (Table 5). Organic matter class of the soil was upgraded to low (1-2%) with sewage sludge application (Lindsay and Norwell, 1969; FAO, 1990). Similar results have been reported by other researchers (Albiach *et al*., 2001; Hernández-Apaolaza *et al*., 2005, and Tsadilas *et al*., 2005). Differences among the years could be due to mineralization during the experiment. As with organic matter, nitrogen (N) content of the soil increased with sewage sludge application (Table 5), a finding also reported by Hernández-Apaolaza *et al*. (2005), Mantovi *et al*. (2005), and Weber *et al*. (2007).

Cation exchange capacity (CEC) of the soils varied with sewage sludge application (Table 6). The highest CEC values were observed at the highest application rate (120 t ha^{-1}). This situation could be explained by the fact that the CEC of sewage sludge was high (62.43 cmol$_c$ kg^{-1}). Although the effectiveness of sewage sludge on soil CEC was found much more pronounced in 2005, soil CEC remained almost constant throughout the study. Considering all data, relationship between organic carbon and CEC is given in Figure 1.

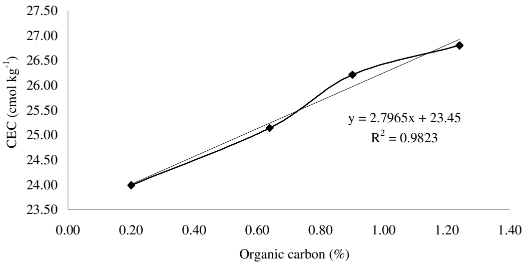

Figure 1. Relationship between organic carbon and CEC of the soil (all data).

Sewage sludge application increased soil exchangeable sodium (Na) content in all application rates. But, this increase does not make a difference for agricultural productivity. However, it could be a problem in the long-term usage because of its contribution to soil salinization or deflocculation. Potassium, calcium, and magnesium content of soils increased with sewage sludge application. Organic inputs are not only important for the increase of agricultural productivity, but also for the supply of some critical nutrient elements. However, organic inputs may vary widely depending on their production source. Sewage sludge, due to its high heavy metal content, might be a threat for soils and the environment, if it is used for a long time (Richards *et al*., 1998; Epstein, 2003; Gascó *et al*., 2005). Sewage sludge application increased DTPA-extractable Fe, Mn, Zn, and Cu concentrations of the soil significantly at all application rates (Table 6 and Figure 2). In spite of these increases, the contents of these metals in the soil did not exceed the critical values reported by Gascó and Lobo (2007), European and USEPA regulations (Table 7).

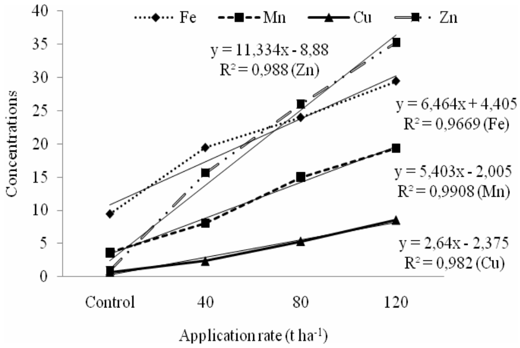

Figure 2. Changes in soil Fe, Mn, Cu and Zn with sewage sludge application.

Table 6. Effects of sewage sludge on some soil chemical properties.

Application rate ($t\ ha^{-1}$)	Years 2005	2006	2007	Mean
CEC (cmol$_c$ kg^{-1})				
Control	22.98±0.14dC[a]	23.57±0.26cB	25.42±0.24aA	23.99±0.24d
40	25.38±0.10cA	24.61±0.09bB	25.42±0.15aA	25.14±0.10c
80	28.02±0.17bA	25.15±0.26abB	25.47±0.24aB	26.21±0.28b
120	29.13±0.16aA	25.76±0.55aB	25.52±0.26aB	26.80±0.38a
Na (cmol$_c$ kg^{-1}) (Exchangeable Cations)				
Control	1.08±0.06bA	0.80±0.01bB	0.79±0.05aB	0.89±0.04b
40	0.93±0.02cA	0.81±0.00bB	0.75±0.01aC	0.83±0.02c
80	1.20±0.03aA	0.82±0.01abB	0.82±0.01aB	0.94±0.04a
120	1.26±0.06aA	0.83±0.00aB	0.82±0.02aB	0.97±0.05a
K (cmol$_c$ kg^{-1}) (Exchangeable Cations)				
Control	2.56±0.07cA	0.78±0.03cB	0.56±0.03bC	1.30±0.18c
40	2.68±0.05bA	0.95±0.01bB	0.58±0.02bC	1.40±0.18b
80	2.73±0.04abA	1.08±0.03aB	0.66±0.02aC	1.49±0.18a
120	2.81±0.06aA	1.10±0.03aB	0.64±0.02aC	1.52±0.19a
Ca (cmol$_c$ kg^{-1}) (Exchangeable Cations)				
Control	4.99±0.17cB	4.47±0.16cB	6.33±0.14cA	5.26±0.18c
40	6.87±0.20bC	8.11±0.29bA	7.62±0.14bB	7.53±0.16b
80	9.65±0.39aA	9.18±0.08aA	8.41±0.05aB	9.08±0.16a
120	9.35±0.30aA	9.38±0.14aA	8.58±0.07aB	9.10±0.13a
Mg (cmol$_c$ kg^{-1}) (Exchangeable Cations)				
Control	3.25±0.07cA	2.36±0.08cB	2.25±0.05cB	2.62±0.10c
40	3.56±0.05bA	2.91±0.04bB	2.44±0.03bC	2.97±0.09b
80	3.81±0.05aA	3.17±0.10aB	2.57±0.02aC	3.19±0.11a
120	3.66±0.14abA	3.19±0.08aB	2.64±0.03aC	3.16±0.10a
Fe (mg kg^{-1}) (DTPA-extracted)				
Control	9.18±0.13dA[a]	9.64±0.28dA	9.44±0.52cA	9.42±0.20d
40	25.74±0.53cA	22.79±1.29cB	9.73±0.78cC	19.42±1.46c
80	30.14±0.39bA	26.50±0.35bB	15.28±0.88bC	23.97±1.28b
120	33.84±0.31aA	28.82±0.24aB	25.70±1.96aC	29.45±0.92a
Mn (mg kg^{-1}) (DTPA-extracted)				
Control	5.90±0.05cA	3.31±0.30dA	1.67±0.09dB	3.63±0.36d
40	11.10±0.61bA	9.60±0.61cA	3.44±0.27cB	8.05±0.71c
80	19.66±1.69aA	17.87±0.31bA	7.49±0.72bB	15.01±1.21b
120	23.02±1.97aA	22.88±0.36aA	12.07±0.20aB	19.32±1.19a
Cu (mg kg^{-1}) (DTPA-extracted)				
Control	0.78±0.06dA	0.66±0.06dA	0.66±0.04dA	0.70±0.03d
40	3.40±0.17cA	1.62±0.06cC	2.05±0.14cB	2.36±0.17c
80	6.58±0.78bA	4.92±0.08bB	4.50±0.39bC	5.33±0.33b
120	11.11±0.41aA	7.76±0.07aB	6.67±0.21aC	8.51±0.40a
Zn (mg kg^{-1}) (DTPA-extracted)				
Control	1.49±0.29dA	0.51±0.05dB	0.83±0.10dAB	0.94±0.13d
40	16.49±0.27cA	15.47±0.42cB	14.93±0.49cB	15.63±0.26c
80	28.09±0.21bA	28.06±0.28bA	21.78±0.56bB	25.98±0.62b
120	35.60±0.27aA	35.87±0.33aA	34.34±0.85aB	35.27±0.33a

[a] Letters followed in each row (capital letters) show differences between years, while letters in columns (small letters) show differences between application rates (Mean±SE, n=9). Mean differences were tested at the level of $P \le 0.05$.

Table 7. Amounts of metals added to the soil with sewage sludge (kg ha^{-1}).

Application rate (kg ha^{-1})	Zn	Cu	Ni	Pb	Cd
40000	34.94	9.60	2.28	6.10	0.34
80000	69.88	19.19	4.56	12.20	0.68
120000	104.82	28.79	6.84	18.30	1.02
Critical soil concentration [a]	480	150	120	480	9.6
European regulations [a]	300	120	30	150	1.5
USEPA [a]	2800	1500	420	300	39

[a] Obtained from Gascó and Lobo (2007).

Effects of Sewage Sludge on Barley Yield

Barley yield significantly increased with increased levels of sewage sludge applied (Table 8). As seen in Table 8, there were no differences between the 40 and 80 t ha^{-1} treatments. This situation is similar to that of the organic matter and N content of the soil. Because of the textural class (SL) of the soil and wind erosion in this area, biomass yields were much lower than the average expected yield in Igdir Plain (2873.20 kg ha^{-1}). The highest yields were obtained in the first year (2005) of the study. Yields declined in 2006 and 2007, because of the fact that there was no additional sewage sludge and/or fertilizer application to the plots. The highest biomass yield was obtained in the 120 t ha^{-1} treatment in all seasons. The gradually lower biomass yields in the second and the third seasons could be explained by the decrease in organic matter and N content of soils (Table 5). Grain yield showed a trend similar to the biomass (Table 8), increasing with higher rates of sewage sludge application.

CONCLUSION

Results obtained in this study have shown that sewage sludge application is an effective way to improve some physical and chemical properties of soil affected by wind erosion. The effect of sewage sludge on soil properties was observed in all seasons of the experimental period. However, its effectiveness decreased during the study, while, in every season, the most effective sewage sludge rate was 120 t ha^{-1}. Sewage sludge not only improved soil properties, but it also increased yield of barley significantly

Table 8. Effects of sewage sludge application on biomass and grain yield of barley.

Application rate (t ha^{-1})	Years 2005	2006	2007	Mean
Biomass Yield (dry weight kg ha^{-1})				
Control	1342.5±25.3cA [a]	1424.1±49.9cA	-	922.2±231.4c
40	2189.6±39.7bA	1909.2±97.8bB	-	1366.3±345.3b
80	2292.4±27.4bA	2044.9±47.0bB	-	1445.8±363.5b
120	2669.2±95.9aA	2442.4±126.3aB	107.85±4.23C	2063.3±252.9a
Grain Yield (dry weight kg ha^{-1})				
Control	555.7±47.8cA	384.4±20.5cB	-	313.4±83.5c
40	807.3±49.2bA	581.9±42.7bB	-	463.1±121.7b
80	889.7±13.8bA	676.5±50.2bB	-	522.1±134.9b
120	1054.2±69.8aA	930.1±40.2aA	387.5±7.3B	790.6±105.0a

[a] Letters followed in each row (capital letters) show differences between years, while letters in columns (small letters) show differences between application rates (Mean±SE, n=9). Mean differences were tested at the level of $P \leq 0.05$.

compared with the control. However, the increased yield was not sufficiently high in comparison with yields expected for the Igdir Plain. In order to achieve higher yields, sewage sludge should be applied to the soil every year, at least at the rate of 40 t ha^{-1}, or fertilizer additions should follow in the subsequent years. Further studies should be conducted to determine the effects of sewage sludge application on erosion parameters.

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اثر کار برد لجن فاضلاب روی برخی ویژگی های فیزیکی و شیمیایی خاک باد فرسوده

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چکیده

در سراسر گیتی، فرسایش خاک به عنوان یکی از عوامل اصلی نابودی زمین های قابل کشت قلمداد می شود. از آنجا که مساحت اراضی قابل کشت به مرز نهایی آن نزدیک شده است، استفاده از اراضی حاشیه ای (مانند زمین های باد فرسوده) برای تولید محصولات کشاورزی اهمیت یافته است. یک روش موثر و ساده برای باز سازی خاک های باد فرسوده، افزودن مواد آلی به آنهاست. در این پیوند، کاربرد لجن فاضلاب می تواند موثر باشد. به منظور بررسی تاثیر استفاده از این مواد در یک خاک باد فرسوده آزمون هایی طی سالهای ۲۰۰۷-۲۰۰۴در دشت اژدر در ترکیه اجرا شد. در این تحقیق، لجن فاضلاب در مقادیر صفر (تیمار شاهد) ، ۴۰، ۸۰ و ۱۲۰تن (وزن خشک) درهکتار به خاک افزوده شد و آزمایش به مدت سه سال با طرح بلوک های کامل تصادفی در سه تکرار و در ۱۲ کرت که در آن ها جو (*Hordeum vulgare*) کاشت می شد ادامه یافت. کاربرد لجن فاضلاب نه تنها ویژگی های فیزیکی و شیمیایی خاک را بهبود بخشید بلکه عملکرد جو را نیز افزایش داد. با این همه، افزایش تولید به اندازه رضایت بخش نبود. برای دستیابی به عملکرد مطلوب، کار برد لجن فاضلاب به طور سالانه و دست کم به مقدار ۴۰ تن در هکتار ضروری است.