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

I. Angin¹*, and A. V. Yaganoglu¹

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 Iğdır plain (Aralık), Turkey. The experimental region has a semi-arid climate with long-term mean annual minimum and maximum temperatures of 5.8°C and 19.2°C, 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 m² (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>
<thead>
<tr>
<th>Months</th>
<th>Temperature (°C)</th>
<th>Relative Humidity (%)</th>
<th>Precipitation (mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>2005</td>
<td>2006</td>
<td>2007</td>
</tr>
<tr>
<td>January</td>
<td>-4.0</td>
<td>-3.9</td>
<td>-4.4</td>
</tr>
<tr>
<td>February</td>
<td>-0.9</td>
<td>-0.9</td>
<td>-1.2</td>
</tr>
<tr>
<td>March</td>
<td>6.8</td>
<td>9.1</td>
<td>7.2</td>
</tr>
<tr>
<td>April</td>
<td>15.2</td>
<td>14.3</td>
<td>10.7</td>
</tr>
<tr>
<td>May</td>
<td>18.5</td>
<td>19.5</td>
<td>19.4</td>
</tr>
<tr>
<td>June</td>
<td>22.4</td>
<td>26.9</td>
<td>23.3</td>
</tr>
<tr>
<td>July</td>
<td>28.5</td>
<td>26.3</td>
<td>26.0</td>
</tr>
<tr>
<td>August</td>
<td>27.2</td>
<td>28.8</td>
<td>25.6</td>
</tr>
<tr>
<td>September</td>
<td>21.0</td>
<td>21.8</td>
<td>23.1</td>
</tr>
<tr>
<td>October</td>
<td>13.3</td>
<td>14.8</td>
<td>15.4</td>
</tr>
<tr>
<td>November</td>
<td>6.1</td>
<td>6.1</td>
<td>6.0</td>
</tr>
<tr>
<td>December</td>
<td>-0.4</td>
<td>-4.4</td>
<td>-0.3</td>
</tr>
</tbody>
</table>

* 32 years mean.
Table 2. Characteristics of sewage sludge used in the study.

<table>
<thead>
<tr>
<th>Parameters (Unit) (Dry Matter)</th>
<th>Sewage Sludge</th>
<th>Method Used</th>
</tr>
</thead>
<tbody>
<tr>
<td>Organic matter (%)</td>
<td>34</td>
<td>Nelson and Sommers, 1982</td>
</tr>
<tr>
<td>Total N (%)</td>
<td>4.46</td>
<td>Brenner, 1996</td>
</tr>
<tr>
<td>Total P (%)</td>
<td>1.1</td>
<td>Watanabe and Olsen, 1965</td>
</tr>
<tr>
<td>CEC (cmol, kg⁻¹)</td>
<td>62.43</td>
<td>Summer and Miller, 1996</td>
</tr>
<tr>
<td>Ca (%)</td>
<td>7.4</td>
<td>USEPA, 1997</td>
</tr>
<tr>
<td>Mg (%)</td>
<td>1.9</td>
<td>USEPA, 1997</td>
</tr>
<tr>
<td>Na (%)</td>
<td>0.2</td>
<td>USEPA, 1997</td>
</tr>
<tr>
<td>K (%)</td>
<td>2.1</td>
<td>USEPA, 1997</td>
</tr>
<tr>
<td>Fe (%)</td>
<td>0.10</td>
<td>USEPA, 1997</td>
</tr>
<tr>
<td>Zn (mg kg⁻¹)</td>
<td>873.53⁴</td>
<td>USEPA, 1997</td>
</tr>
<tr>
<td>Cu (mg kg⁻¹)</td>
<td>239.90⁴</td>
<td>USEPA, 1997</td>
</tr>
<tr>
<td>Mn (mg kg⁻¹)</td>
<td>903.99</td>
<td>USEPA, 1997</td>
</tr>
<tr>
<td>Ni (mg kg⁻¹)</td>
<td>57⁷</td>
<td>USEPA, 1997</td>
</tr>
<tr>
<td>Pb (mg kg⁻¹)</td>
<td>152.5⁴</td>
<td>USEPA, 1997</td>
</tr>
<tr>
<td>Cd (mg kg⁻¹)</td>
<td>8.5⁴</td>
<td>USEPA, 1997</td>
</tr>
<tr>
<td>Hg (mg kg⁻¹)</td>
<td>0.75⁴</td>
<td>USEPA, 1997</td>
</tr>
<tr>
<td>Cr (mg kg⁻¹)</td>
<td>168.5</td>
<td>USEPA, 1997</td>
</tr>
<tr>
<td>pH</td>
<td>6.82</td>
<td>Demiralay, 1993</td>
</tr>
<tr>
<td>Electrical Conductivity (EC) (dS m⁻¹)</td>
<td>6.54</td>
<td>Rhoades, 1996</td>
</tr>
<tr>
<td>Bulk density (g cm⁻³)</td>
<td>0.676</td>
<td>Blake, 1965a</td>
</tr>
<tr>
<td>CaCO₃ (%)</td>
<td>17.3</td>
<td>Nelson, 1982</td>
</tr>
<tr>
<td>Faecal coliform (unit g⁻¹)</td>
<td>255</td>
<td>APHA, AWWA and WPCF, 1985</td>
</tr>
<tr>
<td>Salmonella (25 g)</td>
<td>Not found</td>
<td></td>
</tr>
<tr>
<td>Helminth egg (g)</td>
<td>Not found</td>
<td></td>
</tr>
</tbody>
</table>

⁴ 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 m², 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 587 mm 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). CaCO₃ 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.

<table>
<thead>
<tr>
<th>Physical Properties</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sand (%)</td>
<td>69.39</td>
</tr>
<tr>
<td>Silt (%)</td>
<td>19.42</td>
</tr>
<tr>
<td>Clay (%)</td>
<td>11.19</td>
</tr>
<tr>
<td>Texture Class</td>
<td>Sandy loam</td>
</tr>
</tbody>
</table>
| Bulk density (g cm
^{-3})     | 1.32           |
| Particle density (g cm
^{-3}) | 2.48           |
| Porosity (%)                 | 46.73          |
| Permeability coefficient (cm h
^{-1}) | 3.965          |
| 0-30 cm                      | 15.31          |
| 30-60 cm                     | 15.25          |
| 60-90 cm                     | 15.18          |
| Field capacity (FC) (P_w)    |                |
| 0-30 cm                      | 5.35           |
| 30-60 cm                     | 5.38           |
| 60-90 cm                     | 5.38           |
| Wilting point (WP) (P_w)     |                |
| 0-30 cm                      | 9.96           |
| 30-60 cm                     | 9.87           |
| 60-90 cm                     | 9.80           |
| Available water (AW) (P_w)   |                |
| 0-30 cm                      |                |
| 30-60 cm                     |                |
| 60-90 cm                     |                |

Chemical Properties

<table>
<thead>
<tr>
<th>Property</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>pH (a)</td>
<td>8.18</td>
</tr>
<tr>
<td>Electrical conductivity (EC)</td>
<td>0.56</td>
</tr>
<tr>
<td>CaCO3 (%)</td>
<td>2.83</td>
</tr>
<tr>
<td>Organic matter (%)</td>
<td>0.12</td>
</tr>
<tr>
<td>Cation exchange capacity (CEC)</td>
<td>22.58</td>
</tr>
</tbody>
</table>
| Exchangeable cations (cmol, 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 Vapodist 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.

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

*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>
<thead>
<tr>
<th>Application rate (t ha(^{-1}))</th>
<th>pH</th>
<th>Years</th>
<th>Mean</th>
</tr>
</thead>
<tbody>
<tr>
<td>Control</td>
<td>8.22±0.01aA</td>
<td>7.42±0.02aC</td>
<td>7.63±0.01aB</td>
</tr>
<tr>
<td>40</td>
<td>7.85±0.04bA</td>
<td>7.26±0.03bC</td>
<td>7.49±0.02bB</td>
</tr>
<tr>
<td>80</td>
<td>7.59±0.02cA</td>
<td>7.12±0.03cC</td>
<td>7.34±0.01cB</td>
</tr>
<tr>
<td>120</td>
<td>7.43±0.01dA</td>
<td>6.84±0.03dC</td>
<td>7.16±0.01dB</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>EC (dS m(^{-1}))</th>
<th>Control</th>
<th>0.62±0.01dC</th>
<th>2.96±0.15aA</th>
<th>0.85±0.03cB</th>
<th>1.48±0.21d</th>
</tr>
</thead>
<tbody>
<tr>
<td>40</td>
<td>1.67±0.04cB</td>
<td>2.59±0.04bA</td>
<td>1.73±0.04bB</td>
<td>2.00±0.09c</td>
<td></td>
</tr>
<tr>
<td>80</td>
<td>2.65±0.04bA</td>
<td>2.41±0.08bB</td>
<td>1.75±0.06bC</td>
<td>2.27±0.08b</td>
<td></td>
</tr>
<tr>
<td>120</td>
<td>3.75±0.03aA</td>
<td>1.58±0.04cC</td>
<td>1.96±0.07aB</td>
<td>2.43±0.19a</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>CaCO(_3) (%)</th>
<th>Control</th>
<th>3.17±0.09dB</th>
<th>3.87±0.10dA</th>
<th>0.85±0.03dC</th>
<th>2.63±0.26d</th>
</tr>
</thead>
<tbody>
<tr>
<td>40</td>
<td>4.12±0.13cB</td>
<td>4.56±0.09cA</td>
<td>1.11±0.08cC</td>
<td>3.26±0.31c</td>
<td></td>
</tr>
<tr>
<td>80</td>
<td>5.46±0.23bA</td>
<td>4.84±0.08bB</td>
<td>1.71±0.06bC</td>
<td>4.00±0.33b</td>
<td></td>
</tr>
<tr>
<td>120</td>
<td>5.89±0.15aA</td>
<td>5.32±0.08aB</td>
<td>1.97±0.05aC</td>
<td>4.39±0.34a</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Organic matter (%)</th>
<th>Control</th>
<th>0.16±0.01dB</th>
<th>0.62±0.02dA</th>
<th>0.26±0.02dB</th>
<th>0.35±0.04d</th>
</tr>
</thead>
<tbody>
<tr>
<td>40</td>
<td>1.27±0.03cA</td>
<td>1.23±0.04cA</td>
<td>0.81±0.05cB</td>
<td>1.10±0.05c</td>
<td></td>
</tr>
<tr>
<td>80</td>
<td>1.68±0.04bA</td>
<td>1.78±0.05bA</td>
<td>1.20±0.06bB</td>
<td>1.55±0.06b</td>
<td></td>
</tr>
<tr>
<td>120</td>
<td>2.38±0.07aB</td>
<td>2.60±0.07aB</td>
<td>1.45±0.04aC</td>
<td>2.14±0.10a</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>N (%)</th>
<th>Control</th>
<th>0.11±0.00dA</th>
<th>0.03±0.00dB</th>
<th>0.02±0.00dB</th>
<th>0.05±0.01d</th>
</tr>
</thead>
<tbody>
<tr>
<td>40</td>
<td>0.21±0.01cA</td>
<td>0.09±0.00cB</td>
<td>0.05±0.00cC</td>
<td>0.12±0.01c</td>
<td></td>
</tr>
<tr>
<td>80</td>
<td>0.29±0.00bA</td>
<td>0.17±0.00bB</td>
<td>0.10±0.01bC</td>
<td>0.19±0.02b</td>
<td></td>
</tr>
<tr>
<td>120</td>
<td>0.37±0.01aA</td>
<td>0.22±0.02aB</td>
<td>0.12±0.00aC</td>
<td>0.24±0.02a</td>
<td></td>
</tr>
</tbody>
</table>

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

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

<table>
<thead>
<tr>
<th>Application rate (t ha⁻¹)</th>
<th>Years</th>
<th>Mean</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>2005</td>
<td>2006</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>CEC (cmol kg⁻¹)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Control</td>
<td>22.98±0.14dC</td>
<td>23.57±0.26cB</td>
</tr>
<tr>
<td>40</td>
<td>25.38±0.10cA</td>
<td>24.61±0.09bB</td>
</tr>
<tr>
<td>80</td>
<td>28.02±0.17bA</td>
<td>25.15±0.26abB</td>
</tr>
<tr>
<td>120</td>
<td>29.13±0.16aA</td>
<td>25.76±0.55bB</td>
</tr>
<tr>
<td>Na (cmol c⁻¹ kg⁻¹)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Control</td>
<td>1.08±0.06bA</td>
<td>0.80±0.01bB</td>
</tr>
<tr>
<td>40</td>
<td>0.93±0.02cA</td>
<td>0.81±0.00bB</td>
</tr>
<tr>
<td>80</td>
<td>1.20±0.03aA</td>
<td>0.82±0.01abB</td>
</tr>
<tr>
<td>120</td>
<td>1.26±0.06aA</td>
<td>0.83±0.00aB</td>
</tr>
<tr>
<td>K (cmol c⁻¹ kg⁻¹)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Control</td>
<td>2.56±0.07cA</td>
<td>0.78±0.03cB</td>
</tr>
<tr>
<td>40</td>
<td>2.68±0.05bA</td>
<td>0.95±0.01bB</td>
</tr>
<tr>
<td>80</td>
<td>2.73±0.04abA</td>
<td>1.08±0.03aB</td>
</tr>
<tr>
<td>120</td>
<td>2.81±0.06aA</td>
<td>1.10±0.03aB</td>
</tr>
<tr>
<td>Ca (cmol c⁻¹ kg⁻¹)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Control</td>
<td>4.99±0.17cB</td>
<td>4.47±0.16cB</td>
</tr>
<tr>
<td>40</td>
<td>6.87±0.20cB</td>
<td>8.11±0.29bA</td>
</tr>
<tr>
<td>80</td>
<td>9.65±0.39aA</td>
<td>9.18±0.08aA</td>
</tr>
<tr>
<td>120</td>
<td>9.35±0.30aA</td>
<td>9.38±0.14aA</td>
</tr>
<tr>
<td>Mg (cmol kg⁻¹)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Control</td>
<td>3.25±0.07cA</td>
<td>2.36±0.08cB</td>
</tr>
<tr>
<td>40</td>
<td>3.56±0.05bA</td>
<td>2.91±0.04bB</td>
</tr>
<tr>
<td>80</td>
<td>3.81±0.05aA</td>
<td>3.17±0.10aB</td>
</tr>
<tr>
<td>120</td>
<td>3.66±0.14abA</td>
<td>3.19±0.08aB</td>
</tr>
<tr>
<td>Fe (mg kg⁻¹) (DTPA-extracted)</td>
<td>9.18±0.13cA</td>
<td>9.64±0.28aC</td>
</tr>
<tr>
<td>Control</td>
<td>25.74±1.29cB</td>
<td>22.79±1.29cB</td>
</tr>
<tr>
<td>40</td>
<td>30.14±0.39bA</td>
<td>26.50±0.35bB</td>
</tr>
<tr>
<td>80</td>
<td>33.84±0.31aA</td>
<td>28.82±0.24aB</td>
</tr>
<tr>
<td>Mn (mg kg⁻¹) (DTPA-extracted)</td>
<td>5.90±0.05cA</td>
<td>3.31±0.30dA</td>
</tr>
<tr>
<td>Control</td>
<td>11.00±0.61bA</td>
<td>9.60±0.61cA</td>
</tr>
<tr>
<td>40</td>
<td>19.66±1.69bA</td>
<td>17.87±0.31bA</td>
</tr>
<tr>
<td>80</td>
<td>23.02±1.97aA</td>
<td>22.88±0.36aA</td>
</tr>
<tr>
<td>Cu (mg kg⁻¹) (DTPA-extracted)</td>
<td>0.78±0.06dA</td>
<td>0.66±0.06dA</td>
</tr>
<tr>
<td>Control</td>
<td>3.40±0.17cA</td>
<td>1.62±0.06cC</td>
</tr>
<tr>
<td>40</td>
<td>6.58±0.78bA</td>
<td>4.92±0.08bB</td>
</tr>
<tr>
<td>80</td>
<td>11.11±0.41aA</td>
<td>7.76±0.07aB</td>
</tr>
<tr>
<td>Zn (mg kg⁻¹) (DTPA-extracted)</td>
<td>1.49±0.29dA</td>
<td>0.51±0.05dB</td>
</tr>
<tr>
<td>Control</td>
<td>16.49±10.27cA</td>
<td>15.47±10.27cB</td>
</tr>
<tr>
<td>40</td>
<td>28.09±10.21bA</td>
<td>28.06±10.28bA</td>
</tr>
<tr>
<td>120</td>
<td>35.60±10.37aA</td>
<td>35.87±10.33aA</td>
</tr>
</tbody>
</table>

\( a \) 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 \( P \leq 0.05 \).
Restoration of Wind Eroded Soil by Sewage Sludge

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

<table>
<thead>
<tr>
<th>Application rate (kg ha(^{-1}))</th>
<th>Zn</th>
<th>Cu</th>
<th>Ni</th>
<th>Pb</th>
<th>Cd</th>
</tr>
</thead>
<tbody>
<tr>
<td>40000</td>
<td>34.94</td>
<td>9.60</td>
<td>2.28</td>
<td>6.10</td>
<td>0.34</td>
</tr>
<tr>
<td>80000</td>
<td>69.88</td>
<td>19.19</td>
<td>4.56</td>
<td>12.20</td>
<td>0.68</td>
</tr>
<tr>
<td>120000</td>
<td>104.82</td>
<td>28.79</td>
<td>6.84</td>
<td>18.30</td>
<td>1.02</td>
</tr>
</tbody>
</table>

Critical soil concentration \(^{a}\) 480 150 120 480 9.6
European regulations \(^{a}\) 300 120 30 150 1.5
USEPA \(^{a}\) 2800 1500 420 150 1.5

\(^{a}\) 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.

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

<table>
<thead>
<tr>
<th>Application rate (t ha(^{-1}))</th>
<th>Years</th>
<th>Mean</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>2005</td>
<td>2006</td>
</tr>
<tr>
<td>Biomass Yield (dry weight kg ha(^{-1}))</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Control</td>
<td>1342.5±25.3cA(^{a})</td>
<td>1424.1±49.9cA</td>
</tr>
<tr>
<td>40</td>
<td>2189.6±39.7bA</td>
<td>1909.2±97.8bB</td>
</tr>
<tr>
<td>80</td>
<td>2292.4±27.4bA</td>
<td>2044.9±47.0bB</td>
</tr>
<tr>
<td>120</td>
<td>2669.2±295.9a</td>
<td>2442.4±126.3a</td>
</tr>
<tr>
<td>Grain Yield (dry weight kg ha(^{-1}))</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Control</td>
<td>555.7±47.8cA(^{a})</td>
<td>384.4±20.5cB</td>
</tr>
<tr>
<td>40</td>
<td>807.3±49.2bA</td>
<td>581.9±42.7bB</td>
</tr>
<tr>
<td>80</td>
<td>889.7±13.8bA</td>
<td>676.5±50.2bB</td>
</tr>
<tr>
<td>120</td>
<td>1054.2±69.8a</td>
<td>930.1±40.2a</td>
</tr>
</tbody>
</table>

\(^{a}\) 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 \(P \leq 0.05\).

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.
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.

ACKNOWLEDGEMENTS

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REFERENCES

Restoration of Wind Eroded Soil by Sewage Sludge


ارث کار برد لجن فاضلاب روی برخی ویژگی‌های فیزیکی و شیمیایی خاک باد

ی. آنجین و و. یاگان اوقلو

چکیده

در سراسر گیتی، فرسایش خاک به عنوان یکی از عوامل اصلی ناپدیدی زمین‌های قابل کشت قلمداد می‌شود. از آنجا که مساحت اراضی قابل کشت به مرز نهایی آن تنها بکشیده است، استفاده از اراضی حاشیه‌ای (مانند زمین‌های باد فرسوده) برای تولید محصولات کشاورزی اهمیت بسزایی داشته است. یک روش مؤثر و ساده برای باز سازی خاک‌های باد فرسوده، افزودن مواد آلی به آنهاست. در این پژوهش، کاربرد لجن فاضلابی می‌تواند مؤثر باشد. به منظور بررسی تاثیر استفاده از این مواد در یک خاک باد فرسوده آزمون هایی طی سال‌های 2007-2008 در دشت ازور در ترکیه اجرا شد. در این تحقیق، لجن فاضلاب در مقادیر صفر (تیمار شاهد)، 1، 3 و 4 درصد (وزن خشک) در هر کهرم خاک افزوده شد و آزمایش به‌مدت سال با طرح پلک‌های کامل تصادفی در سه تکرار و در 16 کرت که در آن ها جو کشت می‌شده ادامه یافت. کاربرد لجن فاضلابی نتیجه ویژگی‌های فیزیکی و شیمیایی خاک را بهبود بخشید بلکه عملکرد جو را نیز افزایش داد. با این‌همه، افزایش تولید به اندازه رضایت بخش نیست. برای دستیابی به عملکرد مطلوب، کار برد لجن فاضلاب به طور سالانه و دست کم به مقدار 40 تن در هکتار ضروری است.