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Full Length Article

Effects of Sewage Sludge Application on Yield, Yield Parameters and Heavy Metal Content of Barley Grown under Arid Climatic Conditions

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ABSTRACT

Environmental pollution can be minimized with reducing the amount of wastes emerged, harmonizing the wastes with environment and land use of waste materials. Sewage sludge, a by-product of wastewater treatment, can be used as a replacement and/or amendment for natural materials. However, it should be noted that sewage sludge contains heavy metals and soluble salts, which could be toxic to the soil and plants. This study was carried out to determine the effects of different sewage sludge application rates, which were 0, 4, 8 and 12 t da^{-1}, on yield, yield parameters, and heavy metal uptake of barley grown under arid climatic conditions. The experiment was conducted using a randomized complete block design with three replications in 12 plots, between years 2005-2007. Results obtained from this study have shown that sewage sludge is an effective way to improve yield, yield parameters and metal content of barley under arid climatic conditions. The most effective application rate was found as 12 t da^{-1} in this study. However, it should be noted that this situation depends on ecological conditions and species. Further studies should be conducted to evaluate the effects of sewage sludge on other plant species.

Key Words: Sewage sludge; Barley; Yield; Yield parameters; Heavy metal content

INTRODUCTION

Environmental pollution can be defined as the contamination of the ecosystem to such an extent that normal environmental processes are adversely affected. Environmental pollution due to release of air, water and soil pollutants is a problem both in developed and developing countries. Protection of environment requires reducing the amount of wastes emerged, harmonizing the wastes with environment (environment safe) and land use of waste materials. Use of wastes has been increasingly identified as an important issue for soil fertility, conservation and residual disposal in agriculture, forestry and land reclamation (Antolín *et al*., 2005). Using wastes in agriculture helps not only to dispose these materials economically, but also reduces negative effects on the environment. Therefore, protection of environment with proper waste management is of great concern both for nations and human being.

Sewage sludge is a concentrated suspension of solids, largely composed of organic matter and nutrient-laden organic solids. Sewage sludge contains not only major plant nutrients, but also trace elements that are essential for plant growth (Anonymous, 1996). Due to the presence of basic organic and mineral elements in its content, sewage sludge can be used as a replacement and/or amendment for natural materials. However, it should be noted that sewage sludge also contains heavy metals and soluble salts, which could be toxic to the soil and plants (McGrath *et al*., 2000; Vaca-Paulín *et al*., 2006). One of the major pathways by which land applied sewage sludge contaminants enters the food chain is plant uptake (Laturnus *et al*., 2007).

Several countries have regulated use of sewage sludge in agriculture, which are mainly based on heavy metal content of soil, regarding soil type and metal uptake by plants. Therefore, studies should be conducted to determine the possible effects of sewage sludge application on plant yield and their uptake by plants on different ecological conditions. Many studies have been conducted to determine the effects of sewage sludge application on crop and plant yield and soil properties (Navas *et al*., 1998; Aggelides & Londra, 2000; Holz *et al*., 2000; Tsadilas *et al*., 2005; Cheng *et al*., 2007). However, a study on yield, yield parameters and heavy metal uptake of barley with sewage sludge application has not been studied under arid climatic conditions, especially in Turkey. Therefore, this study was carried out to determine the effects of different sewage sludge application rates, which were 0, 4, 8, and 12 t da^{-1}, on yield, yield parameters, and heavy metal uptake of barley grown under arid climatic conditions.

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MATERIALS AND METHODS

This study was conducted for three years (2005-2007) in the Igdir plain, Turkey. The experimental region has an arid climate with long-term mean annual minimum and maximum temperatures of 5.8 and 19.2ºC, relative humidity of 55% and total precipitation of 259.1 mm.

The experiment was conducted using a randomized complete block design with three replications in 12 plots, each measuring 9 m^2 (3 x 3 m), with a separation strip of 1 m between them. Experimental site had a slight slope angle (<2%) so no run off 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), 4, 8, and 12 t da^{-1} dry weight and no sewage sludge application was made after this date.

Characteristics of sewage sludge are given in Table I. Soil properties prior to the application of sewage sludge are given in Table II. Barley (*Hordeum vulgare*) (Tokak-157/37) was sown to the plots in April of 2005, 2006 and 2007 (450 seed per m^2, Akten & Akkaya, 1986). Fourteen rows were seeded with sowing machine. Barley was irrigated three times; at the beginning of sowing time, stem elongation and heading stage. Harvesting was performed excluding side rows. At maturity the aerial parts of barley in each plot were harvested by hand and were dried for 5 days to estimate plant height, spike length, seed number/spike, spikes per m^2, thousand grains weight, grain and biological yield.

The nutrient and metal contents of barley were determined using HNO_3-$HClO_4$ acid mixture digestion (AOAC, 1990). K, Ca, Mg, Na, Fe, Cu, Zn, Mn, Ni, Pb, and Cd of the extraction solution were done by ICP (Perkin–Elmer Optima 2100 DV Optical Emission Spectrometer, Waltham, MA, USA). The Kjeldahl method and a Vapodest 10 Rapid Distillation Unit (Gerhardt, Konigswinter, Germany) were used to determine N.

The data were analyzed with sewage sludge (t da^{-1}) as main plot treatment and years (2005, 2006 & 2007) as 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).

Table I: Characteristics of sewage sludge used in study

Parameters (Unit) (Dry Matter)	Sewage Sludge
Organic matter (%)	34
Total N (%)	4.46
Total P (%)	1.1
CEC ($cmol_c$ kg^{-1})	62.43
Ca (%)	7.4
Mg (%)	1.9
Na (%)	0.2
K (%)	2.1
Fe (%)	0.10
Zn (mg kg^{-1})	873.53*
Cu (mg kg^{-1})	239.90*
Mn (mg kg^{-1})	903.99
Ni (mg kg^{-1})	57*
Pb (mg kg^{-1})	152.5*
Cd (mg kg^{-1})	8.5*
Hg (mg kg^{-1})	0.75*
Cr (mg kg^{-1})	168.5
pH	6.82
Electrical Conductivity (EC) (dS m^{-1})	6.54
Bulk density (g cm^{-3})	0.676
$CaCO_3$ (%)	17.3
Faecal coliform (unit g^{-1})	255
Salmonella (25 g)	Not found
Helmint egg (g)	Not found

*These values are lower than critical cumulative pollutant loading rates accepted by USEPA and Europe legislations

Table II: Soil properties prior to the application of sewage sludge

Properties		Values
Physical properties		
Texture	Sand (%)	41.16
	Silt (%)	23.30
	Clay (%)	35.54
Texture Class		Clay loam
Bulk density (g cm^{-3})		1.31
Particle density (g cm^{-3})		2.59
Porosity (%)		49.40
Permeability coefficient (cm h^{-1})		2.016
Aggregate stability (%)		47.82
Available water (AW) (P_w)	0-30 cm	7.42
	30-60 cm	6.89
	60-90 cm	7.76
Chemical Properties		
pH§		8.27
Electrical conductivity§ (EC) (dS m^{-1})		0.76
$CaCO_3$ (%)		10.98
Organic matter (%)		1.71
Cation exchange capacity (CEC) ($cmol_c$ kg^{-1})		35.19
Exchangeable cations ($cmol_c$ kg^{-1})	Na	1.07
	K	3.66
	Ca	32.08
	Mg	1.96
Total N (%)		0.11
DTPA-extractable metals (mg kg^{-1})	Fe	4.95
	Zn	0.51
	Cu	2.07
	Mn	5.87

§Determined in saturation extracts

RESULTS AND DISCUSSION

Effects of sewage sludge application on yield and yield parameters: Application of sewage sludge resulted in greater plant heights as compared with un-amended plots. In all application rates, sewage sludge increased plant heights (Table III). Variations among the years were obtained during the experimental period. The highest plant heights were observed in the first experimental year (2005). Increase in plant heights can be due to mineralization of organic matter, which released enough nutritional elements to enhance plant growth (Antolín *et al*., 2005). However, sewage sludge decreased plant height with time. In all of the years studied, the most effective application rate was found as 12 t da^{-1}. When compared with the control, sewage sludge application increased plant height in the ratios of 6.58, 5.75, and 8.39, at 4, 8, and 12 t da^{-1} rates, respectively. Although most effective application rate was 12 t da^{-1}, there were no statistical differences among 4, 8 and 12 t da^{-1} application rates. Decrease in the effectiveness of sewage sludge by time could be explained by the fact that organically bound N had a half-life of 1 year (Antolín *et al*., 2005).

Sewage sludge, due to its high organic matter content, increased spike lengths in all application rates (Table III), although this effect was not statistically significant. The highest increase was observed in 4 t da^{-1} application rate. When compared with the control, sewage sludge application increased spike length in the ratios of 4.78, 0.90 and 3.28, at 4, 8 and 12 t da^{-1} rates, respectively. Similar to plant height, the highest spike lengths were observed in the first experimental year (2005), and decreased with time.

Table III: Effects of sewage sludge on yield and yield parameters

Application rate (t da^{-1})	Years 2005	2006	2007	Mean
Plant Height (cm)				
Control	84.57±1.15bA[£]	80.39±1.83bA	75.37±1.54bB	80.11±1.03b
4	91.21±1.83aA	86.93±1.90aA	78.00±1.65bB	85.38±1.31a
8	87.07±1.23bA	88.07±1.50aA	79.03±1.32bB	84.72±0.98a
12	85.97±1.24bB	90.33±1.33aA	84.20±1.33aB	86.83±0.83a
Spike Length (cm)				
Control	7.95±0.19aA	6.06±0.16bB	6.10±0.16aB	6.70±0.16a
4	8.43±0.25aA	6.64±0.18aB	6.00±0.14aC	7.02±0.19a
8	7.79±0.21aA	6.37±0.13abB	6.13±0.19aB	6.76±0.15a
12	7.85±0.26aA	6.43±0.17abB	6.47±0.20aB	6.92±0.16a
Seed Number/Spike				
Control	19.60±0.66aA	17.13±0.45aB	14.80±0.47bC	17.18±0.42a
4	19.93±0.66aA	17.53±0.32aB	14.87±0.57bC	17.44±0.43a
8	18.80±0.38aA	17.67±0.27aA	15.80±0.37abB	17.42±0.27a
12	19.80±0.70aA	17.67±0.40aB	16.27±0.47aC	17.91±0.37a
Spikes per m^2				
Control	350.00±3.31dB	383.67±4.21dA	172.67±5.89dC	302.11±14.19d
4	417.00±3.27cA	422.00±5.36cA	213.33±1.44cB	350.78±14.80c
8	458.00±1.81bA	459.00±3.39bA	235.00±5.12bB	384.00±16.02b
12	515.33±3.25aA	480.67±5.28aB	268.00±2.84aC	421.33±16.63a
Thousand Grains Weight (g)				
Control	59.30±0.65aA	44.61±0.65bC	51.62±0.59abB	51.84±0.97a
4	59.99±0.62aA	45.21±1.17bC	53.30±0.78aB	52.83±1.04a
8	59.94±0.48aA	47.65±0.52aC	50.63±0.67bB	52.74±0.85a
12	56.62±0.39bA	49.52±0.54aC	51.61±0.40abB	52.58±0.52a
Grain Yield (kg da^{-1})				
Control	278.39±9.55dA	239.18±14.78bA	99.12±5.64cB	205.56±27.72d
4	377.39±4.70cA	293.47±5.59aB	151.14±5.50bC	274.00±33.12c
8	485.05±2.98bA	314.36±17.58aB	156.64±4.08abC	318.68±47.71b
12	508.41±3.11aA	341.17±20.66aB	168.87±6.01aC	339.48±49.41a
Biological Yield (kg da^{-1})				
Control	598.09±20.77cA	611.69±2.87dA	344.20±25.43bB	517.99±44.52c
4	900.78±7.59bA	712.01±5.36cB	362.23±2.63bC	658.34±78.93b
8	941.96±6.16bA	756.60±2.39bB	393.37±31.54bC	697.31±81.09b
12	1011.84±23.04aA	807.31±17.88aB	486.22±13.05aC	768.46±77.04a

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

Table IV: Effects of sewage sludge application on heavy metal content of barley (mean ± SD)

Application rate(t da^{-1})	Na (ppm)	K (ppm)	Ca (ppm)	Mg (ppm)	Fe (ppm)	Cu (ppm)
Control	1040±25ns[*]	12541±539ns	6059±518ns	1564±100ns	74.61±5.16ns	9.95±0.88ns
4	1055±29	13026±357	6988±476	1501±100	87.68±3.48	8.91±0.82
8	1081±44	12665±312	6628±508	1575±86	86.12±7.04	9.17±0.97
12	1061±24	13307±529	6092±606	1582±74	75.68±2.87	9.20±1.07
Threshold values (ppm)	-	-	-	-	50-100	5-20
Application rate (t da^{-1})	**Zn (ppm)**	**Mn (ppm)**	**Ni (ppm)**	**Pb (ppm)**	**Cd (ppm)**	**N (%)**
Control	71.75±2.58ns	16.26±0.51ns	0.37±0.07ns	3.67±0.26ns	0.12±0.02ns	2.90±0.12ab
4	72.80±3.09	17.19±0.75	0.42±0.08	3.48±0.39	0.10±0.02	2.62±0.11a
8	72.28±2.15	16.74±0.64	0.45±0.06	3.80±0.15	0.14±0.02	2.67±0.10ab
12	70.06±1.70	17.03±0.63	0.47±0.04	3.96±0.31	0.10±0.01	2.95±0.08b
Threshold values (ppm)	50-100	300	1-10	0.5-10	0.05-0.5	-

Mean differences were tested at the level of $P \leq 0.05$

[*]ns: Not significant

Application of sewage sludge increased seed number per spike (Table III). Except 8 t da^{-1} application rate in first year, sewage sludge increased seed number per spike in all application rates and years. The highest seed numbers per spike were observed in the first experimental year (2005) and decreased with time. In all of the years studied, the most effective application rate was found as 12 t da^{-1}. However, there were no statistical differences among the treatments. Increase in spike length and seed number per spike could be due to organic matter content of sewage sludge.

Sewage sludge, due to its high organic matter and N content, significantly increased spikes per m^2 values in all application rates (Table III). The highest spikes per m^2 were observed in the first experimental year (2005) and decreased with time. Among the rates tested, the highest increases were observed in the highest rate (12 t da^{-1}). Increase in spikes per m^2 can not only be attributed to the increase in available water content of soil (Seleiman *et al*., 2011) but also improvement in soil conditions (Navas *et al*., 1998). When compared with the control, sewage sludge application increased spikes per m^2 in the ratios of 16.11, 27.11, and 39.46, at 4, 8 and 12 t da^{-1} rates, respectively. Decrease in the effectiveness of sewage sludge by time could be explained by the fact that organically bound N had a half-life of 1 year and there was no additional sewage sludge and/or fertilizer application to the plots. Application of sewage sludge increased thousand grains weight (Table III), although this effect was not statistically significant. When means were compared, thousand grains weight varied between 51.84-52.83 g. Thousand grain weights of plots amended with sewage sludge were higher than those of un-amended ones.

Biological yield of barley increased in sludge amended plots in comparison to un-amended ones (Table III). According to the results of 3 years mean, biological yield was found as 517.99, 658.34, 697.31 and 768.46 kg da^{-1} for control, 4, 8, and 12 t da^{-1} application rates, respectively. When compared with the control, sewage sludge application increased biological yield in the ratios of 27.10, 34.62, and 48.35, at 4, 8, and 12 t da^{-1} rates, respectively. This increase in biological yield was not only due to increase in spikes per unit of area, but also by the supply of additional C from the sludge (Christie *et al*., 2001). The highest biological yields were observed in the first experimental year (2005). However, effect of sewage sludge on biological yield decreased with time. In all the years studied, the most effective application rate was found as 12 t da^{-1}. Decrease in the effectiveness of sewage sludge by time could be explained by the fact that organically bound N had a half-life of 1 year (Antolín *et al*., 2005). As in biological yield, grain yield of barley increased with sewage sludge application (Table III). According to the results of 3 years mean, grain yield was found as 205.56, 274.00, 318.68, and 339.48 kg da^{-1} for control, 4, 8, and 12 t da^{-1} application rates, respectively. When compared with the control, sewage sludge application increased grain yield in the ratios of 33.29, 55.03, and 65.15, at 4, 8, and 12 t da^{-1} rates, respectively. These results are higher than that of the Igdir plain (287.32 kg da^{-1}) (Anonymous, 2002). The highest grain yields were observed in the first experimental year (2005) and decreased with time, because of the fact that there was no additional sewage sludge and/or fertilizer application to the plots and no crop rotation. When results were analyzed, it was found that the highest biological and grain yield can be obtained by the application of 15.1 and 13.6 t da^{-1} sewage sludge, respectively (Fig. 1, 2). With the application of these rates it is expected that biological and grain yield will be gained as 772.43 and 341.14 kg da^{-1}, respectively.

Fig. 1: Estimation of maximum biological yield with sewage sludge application

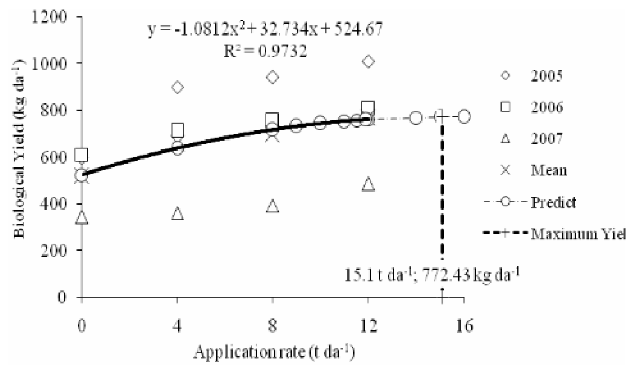
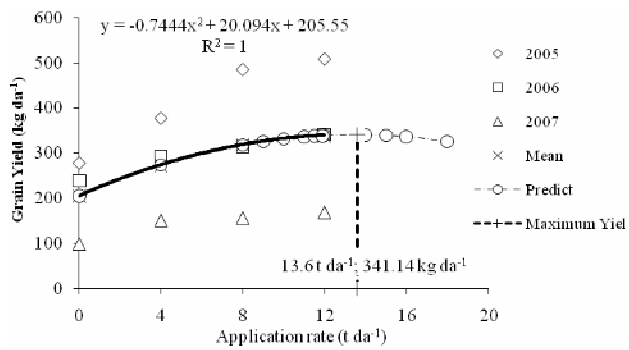


Fig. 2: Estimation of maximum grain yield with sewage sludge application



Effects of sewage sludge application on heavy metal content: Sewage sludge application increased Na, K, and Ca content of grain in all application rates (Table IV). However, this effect was not statistically significant. Concentrations of Fe, Cu, Zn, Mn, Ni, Pb and Cd in grain were unaffected by sewage sludge application (Table IV). These values remained almost same when 3 years means were evaluated. None of the values exceeded threshold values reported by Kabata-Pendias and Pendias (2001), which indicates that barley grain can be used safely. The highest increase in N content of grain was observed in 12 t da^{-1} application rate, due to N content of sewage sludge.

CONCLUSION

Sewage sludge is an effective way to improve yield, yield parameters, and metal content of barley under arid climatic conditions. The most effective application rate was found as 12 t da^{-1} in this study. Application of sewage sludge during plantation improved yield and yield parameters of barley. However, this situation depends on ecological conditions and species. In order to minimize negative effects of sewage sludge to soil, characteristics of sewage sludge should be taken into account according to the critical concentrations. Using sewage sludge as a fertilizer helps not only dispose these materials economically, but also improve yield. Further studies should be conducted to evaluate the effects of sewage sludge on yield, yield parameters, and heavy metal content on other plant species.

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