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Sewage Sludge as Nitrogen Source for Irrigated Silage Sorghum

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Abstract: Field experiment was conducted in clay loam soil in Van, located in the eastern part of Turkey, to study sewage sludge and ammonium sulphate as nitrogen sources for sorghum. Silage and dry matter yield, plant height, stem, leaf and panicle ratio, plant nitrogen content, total N uptake, leaf nutrient and heavy metal content, soil DTPA-extractable nutrient and heavy metal content were quantified. The experimental design was a randomized complete block with four replications. Two rates of ammonium sulphate (50, 100 kg ha^{-1}) and three rates of sewage sludge (5.95, 11.90 and 23.80 Mg ha^{-1}) were applied to plots. Sorghum plant was irrigated once a week until soil water content reached to field capacity. Silage and dry matter yield, plant height and total N uptake increased with application of chemical N fertilizer and sewage sludge as compared to control. The yield results revealed that, 100 kg ha^{-1} nitrogen rate and 23.80 Mg ha^{-1} sewage sludge rate caused to produce almost the same amount of silage and dry matter yield. Leaf N, P, Ca, Mg, Fe and Mn content of sorghum increased with application of N fertilizer and sewage sludge. Mentioned nutrients in leaf were found pretty similar with application of 100 kg ha^{-1} N rate and 23.80 Mg ha^{-1} sludge rate. Besides, Potassium content of sorghum leaf was not affected by either treatment. Leaf Zn content increased with application of N fertilizer and sewage sludge and it reached the highest level at 23.80 Mg ha^{-1} sludge rate. Leaf Cu content increased only with application of sewage sludge. Also, Fe, Zn, Cu and Ni contents in experiment soil increased with application of sewage sludge and their levels reached to the highest at 23.80 Mg ha^{-1} sludge rate. None of heavy metal reached toxic level either in plant or in soil. Results indicated that sewage sludge, produced in Van region, could be used as a fertilizer nitrogen source for sorghum, without risks associated with toxic heavy metals.

Key words: Sewage sludge, biosolid, heavy metal, nitrogen fertilizer, silage sorghum

INTRODUCTION

Sewage sludge application to agricultural land has been a widely accepted practice during recent years. Its use in agricultural land is promoted; because it is considered that it will solve not only the problem of disposal but also will increase productivity in agriculture. However, negative effects of sewage sludge such as elevated heavy metal levels resulting from the usage of sewage sludge must also be taken into consideration (Smith, 1996).

Different factors affect the rate, at which sewage sludge may be applied to land such as concentrations of heavy metals, pathogens, toxic organic compound and nutrients. To determine application rates, matching crop N needs with the plant available N in the sewage sludge is often used (Gilmour and Skinner, 1999). On the other hand, Nitrogen has been recognized as a major nutrient limiting yield of silage sorghum. The low efficiency of nitrogen is due to increased N losses from the soil by denitrification, ammonia volatilization, leaching, etc., under different environmental conditions (Mikkelsen *et al*., 1995; Savant and Datta, 1982). Reed *et al*. (1991) and Cogger *et al*. (2001) reported that 30-40% of sewage sludge organic nitrogen could be assumed to mineralize during the 1st year of application. Therefore, when sewage sludge applied to soil, it provides nitrogen to crops >1 year because mineralization will take place for long period and also nitrogen losses will be limited. Kresse and Naylor (1983) reported that sewage sludge treated plots produced corn yields equivalent to those to which commercial fertilizer was applied. However, sludge contains a number of potentially harmful constituents such as heavy metals. For his reasons, proper application rate should determined for different climatic conditions and different crops.

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This study was conducted in alkali soils with the following objectives to: Determine the potential of using sewage sludge as an alternative to nitrogen fertilizer, determine adequate application rate which, provide nitrogen requirement of sorghum, determine the contents of heavy metals in the crop and soil.

MATERIALS AND METHODS

Site characteristics and experimental design: This study was conducted in the field of Van Agricultural High School, in East Anatolia Region of Turkey, on a clay loam soil. Aerobically digested sewage sludge obtained from Van Waste Water Treatment Plant was used in experiment. Characteristics of experimental site soil and sewage sludge used in the experiment are given in Table 1.

In the experiment area, long term average annual precipitation is 385 mm and the mean temperature is 8.8°C. Precipitation and temperature in experiment year were 430 mm and 10.5°C, respectively.

The experimental design was a randomized complete block with 3 replications. Six treatment was applied, sewage sludge applied at three rates, ammonium sulphate applied at 2 rates and a zero N control. Sewage sludge and inorganic nitrogen rates were based on the agronomic nitrogen requirement of sorghum, which is approximately 100 kg N ha^{-1}. About 50, 100 and 200% of this nitrogen requirement was applied as sewage sludge. Besides, 50 and 100% of sorghum nitrogen requirement was applied as ammonium sulphate. Cogger *et al*. (2001) reported that plant available nitrogen in sewage sludge as 30% organic nitrogen plus 50% of the ammonium N. Based of this estimate; we applied sewage sludge at rates of 5.95, 11.90 and 23.80 dry sludge t ha^{-1}.

Experimental unit size was 5×2 m = 10 m^2 (6 rows, 40 cm row spacing). Sorghum was planted at a rate of 100 seed m^{-2}. In the experiment, Grazer hybrid sorghum cultivar (*Sorghum bicolor × Sorghum sudanense)* was used. Sorghum plants were irrigated once per week with a sprinkler until soil water content reached field capacity.

Sewage sludge was applied to plots by using a shovel at 0-15 cm depth. Besides, 50% of chemical nitrogen fertilizer (ammonium sulphate) was applied to each plot during planting and rest of nitrogen was applied when plants reached 25-30 cm height. Also, triple superphosphate at 80 kg P_2O_5 was applied by banding to plots and control plots had neither sewage sludge nor mineral fertilizer.

The sorghum hybrid plants were harvested at milk stage and harvested plant was weighted. Then, 20 plants were taken to determine plant height, leaf ratio, stem ratio and panicle ratio. Besides, about 1.5 kg plant material was taken to determine dry matter rate.

Table 1: Characteristics of soil and sewage sludge (dry weight basis)

Properties	Soil	Properties	Sewage sludge
Sand	41	pH	7.22
Silt	19	EC (mS cm^{-1})	4.13
Clay	39	Organic matter (%)	57.20
Texture	Clay-loam	NH_4^+-N (%)	0.18
$CaCO_3$ (%)	6.3	Organic N (%)	2.50
EC (mS cm^{-1})	2.43	N (%)	2.70
pH (1:2.5)	8.25	P (%)	0.58
Organic Matter (%)	1.83	K (%)	0.44
N-Kjeldahl (g kg^{-1})	0.95	Fe (%)	3.15
P-Olsen (mg kg^{-1})	8.5	Mn (mg kg^{-1})	270.00
K Ex. (mg kg^{-1})	911	Zn (mg kg^{-1})	661.00
Ca Ex. (mg kg^{-1})	4969	Cu (mg kg^{-1})	90.00
Mg Ex. (mg kg^{-1})	1133	Cr (mg kg^{-1})	63.00
Fe Ex. (mg kg^{-1})	2.69	Cd (mg kg^{-1})	1.39
Mn Ex. (mg kg^{-1})	14.1	Pb (mg kg^{-1})	71.30
Zn Ex. (mg kg^{-1})	0.32		
Cu Ex. (mg kg^{-1})	2.23		
Ni Ex. (mg kg^{-1})	0.99		
Cr Ex. (mg kg^{-1})	0.32		
Cd Ex. (mg kg^{-1})	0.036		
Pb Ex. (mg kg^{-1})	1.02		

Leaf samples were taken to determine N, P, K, Ca, Mg, Fe, Mn, Cu, Zn, Ni, Pb, Cd and Cr in each experimental unit. The N content of leaf samples was determined by the Kjeldahl method (Kacar, 1984). Phosphorus was measured by spectrophotometer. Also, K, Ca, Mg, Fe, Mn, Cu, Zn, Ni, Pb, Cd, Cr content were determined using flame atomic absorption spectrophotometer.

After harvest soil samples were taken from all treated plots and from control plots to determine Fe, Mn, Zn, Cu, Ni, Cr, Cd, Pb contents of soil. Soil nutrients and heavy metals contents were also determined by using flame atomic absorption spectrophotometer.

The SPSS for Windows program was used for the statistical analysis. Treatment means were compared with Duncan test at $p<0.05$.

RESULTS AND DISCUSSION

Sorghum yield, nitrogen content and uptake: Silage yield, dry matter yield, nitrogen content, total N uptake, plant height, stem ratio and leaf ratio were greatly affected from N fertilizer or sewage sludge (Table 2). Silage yield, total N uptake, dry matter yield and plant height of sorghum increased with increasing either N fertilizer or sewage sludge application as compared with the control. The highest sewage sludge rate (23.80 t ha^{-1}) and 100 kg ha^{-1} inorganic N fertilizer caused similar silage yield, dry matter yield and plant height. Therefore, we can conclude that the highest sewage sludge rate (23.80 Mg ha^{-1}) supplied

Table 2: Effect of sewage sludge and N fertilizer on yield, N content and uptake of sorghum

Treatment	Rate	Plant height (cm)	Silage yield kg ha^{-1}	Dry matter yield kg ha^{-1}	Stem ratio (%)	Leaf ratio (%)	Panicle ratio (%)	Plant nitrogen content (%)	Total N uptake (kg ha^{-1})
Control	0	215.1c	35791b	10322b	71.4b	17.8a	10.8	0.71c	73.6d
N-fertilizer	50	220.2bc	40500b	12267b	71.9ab	17.1b	10.9	0.88ab	108.0bc
(kg ha^{-1})	100	246.2a	51675a	15999a	73.2a	14.5b	12.1	0.99a	158.1a
Sewage	5.95	221.0bc	41166b	11852b	72.7ab	16.3ab	11.0	0.76bc	89.7cd
Sludge	11.90	221.9bc	39666b	12457b	72.5ab	15.3b	12.2	0.74bc	91.8bcd
(Mg ha^{-1})	23.80	232.8ab	51375a	15966a	72.5ab	15.1b	12.4	0.78bc	124.8b

*Means with a column followed by a different letter are significantly different at $p<0.05$

Table 3: Effect of sewage sludge and N fertilizer on leaf nutrient contents of sorghum

Treatment	Rate	N (%)	P (%)	K (%)	Ca (%)	Mg (%)	Fe (mg kg^{-1})	Mn (mg kg^{-1})
Control	0	1.55bc	0.153b	0.670	0.620c	0.510c	125.0b	41.05b
N-fertilizer	50	1.40c	0.153b	0.675	0.675bc	0.570b	134.5ab	41.10b
(kg ha^{-1})	100	1.69ab	0.173a	0.640	0.770a	0.750a	137.5a	40.41b
Sewage	5.95	1.51bc	0.148b	0.695	0.670bc	0.530c	134.5ab	40.10b
Sludge	11.90	1.40c	0.146b	0.663	0.665bc	0.535c	143.0a	41.40b
(Mg ha^{-1})	23.80	1.84a	0.169a	0.656	0.715a	0.675a	135.5ab	45.40a

*Means with a column followed by a different letter are significantly different at $p<0.05$

nitrogen as much as 100 kg ha^{-1} chemical nitrogen rate. We hypothesized that 11.90 t ha^{-1} sludge treatment could supply the N requirement of sorghum equivalent to 100 kg ha^{-1} inorganic N treatment. However, we determined that 11.90 t ha^{-1} sludge rate was insufficient to achieve the highest sorghum silage yield, probably due to slow N mineralization. Binder *et al*. (2002) reported that maize and sorghum yield increased due to biosolid application. Also, Cogger *et al*. (2001) showed that tall fescue yields increased with biosolid application rates similarly to our results. In contrast, Shober *et al*. (2003) showed that both biosolid and commercial N fertilizer application increased the yield of sorghum hybrid, but no significant differences in yield due to N fertilizer or biosolid applications were found.

Sewage sludge and N-fertilizer rates caused slight increase in stem ratio. Contrary, treatments caused slight decrease on leaf ratio. Panicle ratio was not affected from treatments. The highest plant nitrogen content was obtained from 100 kg ha^{-1} N fertilizer rate. There were no significant differences among sewage sludge applications for plant nitrogen contents.

Guixin *et al*. (2004) reported that total dry mass of forage sorghum was found to be significantly higher for the sewage sludge treated plots compared to the untreated plots. Excessive application rates did not show further increases in dry mass of forage sorghum production and resulted in significant increases in soil residue nitrate and P, which in the cases of heavy rainfall or irrigation could result in loses through leaching and runoff. Therefore, we can conclude that excessive amount of sewage sludge is not recommended, but we can increase sludge application up to 23.80 t ha^{-1} in order to supply sorghum N requirement and reach to maximum silage yield.

Nutrient and heavy metal content of sorghum: Leaf nutrient content (N, P, K, Ca, Mg, Fe, Mn) of sorghum hybrid was given at Table 3. Leaf nitrogen, phosphorous, Ca and Mg content were higher in both N fertilizer and sewage sludge treated soil compared to control. Total 100 kg ha^{-1} N fertilizer rate and 23.80 sewage sludge rate caused almost the same amount N, P, Ca and Mg content in sorghum leaves. However, concentration of K in leaves did not change with N fertilizer and sludge application. Similarly, Cogger *et al*. (2001) found that N, P, Ca, Mg contents of tall fescue plant tissue increased with sewage sludge application; while, K levels of plant tissue was not affected from sludge application. In contrast, Shober *et al*. (2003) indicated that biosolids application did not affect plant tissue concentrations of N, P, K, Ca and Mn. On the other hand, leaf Fe content increased with application of N fertilizer and sewage sludge. But, leaf Mn content is only increased with the application of 23.80 t ha^{-1}sewage sludge rate contrary to the findings of Shober *et al*. (2003).

A heavy metal content of sorghum leaves was presented at Table 4. Treatments significantly affected Cu and Zn content of sorghum leaves. In contrast, Cd, Cr, Ni and Pb content of leaves was not affected from not only sewage sludge but also inorganic N fertilizer. Sewage sludge applications increased leaf Cu content, but chemical nitrogen did not affect leaf Cu content. It reached the greatest value (5.29 mg kg^{-1}) with application of 11.90 Mg ha^{-1} sewage sludge rate. On the other hand, Zn concentration of leaves increased with increased sewage sludge and N fertilizer rates. The highest sewage sludge rate caused the highest Zn content (20.35 mg kg^{-1}). Logan *et al*. (1997) found that Cd, Cu, Zn concentrations in corn increased significantly with sludge application. Reed *et al*. (1991) and Simon *et al*. (2000)

Table 4: Effect of sewage sludge and N fertilizer on leaf heavy metal contents of sorghum (mg kg^{-1})

Treatment	Rate	Cu	Zn	Cd	Cr	Ni	Pb
Control	0	3.94bc	14.45b	0.120	0.702	0.860	0.256
N-fertilizer	50	3.23c	18.70a	0.120	0.680	0.885	0.253
(kg ha^{-1})	100	3.88bc	17.50ab	0.095	0.695	0.805	0.257
Sewage	5.95	4.95a	14.85b	0.100	0.691	0.975	0.278
Sludge	11.90	5.29a	14.45b	0.095	0.860	1.080	0.340
(Mg ha^{-1})	23.80	4.54ab	20.35a	0.125	0.720	0.900	0.307
Phytotoxic levels(1)		20-100	100-400	5-30	5-30	10-100	30-300

*Means with a column followed by a different letter are significantly different at $p<0.05$, (1) Lopez *et al.* (2000)

Table 5: Effect of sewage sludge on the soil pH and DTPA-extractable nutrient and heavy metal concentration of experimental soil (mg kg^{-1})

Sewage sludge Rates (Mg ha^{-1})	pH	Fe	Zn	Cu	Ni	Mn	Cr	Cd	Pb
Control	8.25	2.85b	0.290b	2.40b	0.946b	14.70	0.340	0.037	1.05
5.95	8.13	2.87b	0.883b	2.53ab	0.923b	14.53	0.370	0.041	1.06
11.90	8.01	3.12b	0.850b	2.54ab	0.970b	13.93	0.343	0.041	1.10
23.80	7.94	4.08a	2.84a	2.68a	1.090a	15.06	0.383	0.044	1.13

*Means with a column followed by a different letter are significantly different at $p<0.05$

showed that the increase in leaf Zn concentration of corn was observed with increasing sludge application. Cogger *et al.* (2001) reported that Cu and Zn contents of tall fescue plant tissue increased with biosolid application. Akdeniz *et al.* (2006) stated that none of the heavy metals studied in both leaves and seed of grain sorghum and silage corn reached either toxic levels of humans or livestock. Bozkurt *et al.* (2006) reported that sewage sludge application increased leaf Pb and Zn but it was pretty lower than toxic level. But, some other studies showed that sludge did not affect leaf heavy metal content of plant tissue (Shober *et al.*, 2003; Dowdy *et al.*, 1994; Mcgrath *et al.*, 1995). In present study, leaf Cu and Zn concentration increased with sewage sludge application, but none of the heavy metal content in plant tissue reached to toxic level.

Soil pH and DTPA-extractable metals: Soil pH level decreased with increasing sewage sludge addition. Soil pH level decreased from 8.25-7.95 in 23.80 sewage sludge t ha^{-1} (Table 5). Decreases in soil pH after sewage sludge application have been observed in other studies (Reed *et al.*, 1991; Cogger *et al.*, 2001; Bozkurt and Cimrin, 2003).

DTPA-extractable Fe, Zn, Cu, Ni content of soil increased by sewage sludge application. Extractable Fe, Zn, Cu, Ni content increased from 2.85-4.08, 0.290-2.84, 2.40-2.68 and 0.946-1.090 mg kg^{-1} at highest sludge rate (23.80 t ha^{-1}), respectively. But DTPA-extractable Mn, Cr, Cd and Pb contents of soil were not affected from sewage sludge application. The greatest changes were observed in extractable Zn. It was approximately, 10 times higher in sludge amended soil than in the control soil. Many researchers reported similar results to our findings. For example, Nyamangara and Mzezewa (1999) reported that sewage sludge significantly increased the DTPA-extractable Zn, Cu and Pb contents in surface soil compared to the control. Datta *et al.* (2000) showed that DTPA-extractable Cu, Zn, Fe, Mn, Ni and Pb contents were increased by long term use of sewage sludge application. Shober *et al.* (2003) found that soil concentration of Cu, Cr, Mn, Pb, Zn were higher in biosolid-treated fields than in control fields. Cogger *et al.* (2001) and Silva *et al.* (2000) found that sewage sludge applications increased DTPA-extractable Cu, Zn and Cd in the surface soil. Bozkurt *et al.* (2001) reported that sewage sludge applications caused an increase on DTPA-extractable Cu and Zn contents of soil. Moreover, Mbila *et al.* (2001) and Wong *et al.* (2001) reported that Cu and Zn were more mobile and bioavailable in the sludge applied soil compared to the other heavy metals. Toxicities are seen when Cu exceeds 20 mg kg^{-1} and when Zn exceeds 80 mg kg^{-1} with the DTPA test (Wallace and Wallace, 1994). In present study, none of extractable heavy metals exceeded the toxic level in soil even treated with high sewage sludge rate.

CONCLUSION

In present study, 50, 100 and 200% of nitrogen requirement of silage sorghum were applied as sewage sludge. Besides, 50 and 100% of sorghum nitrogen requirement was applied as ammonium sulphate. As a result of study, we determined that 11.90 t ha^{-1} sewage sludge rate was insufficient to achieve the highest sorghum silage yield, probably due to slow N mineralization. Therefore, to reach the highest silage and dry matter yield, 23.80 t ha^{-1} sludge rate should be applied to silage sorghum and this rate will supply nitrogen to sorghum as much as 100 kg N ha^{-1} chemical fertilizer rate, which is agronomic nitrogen requirement of sorghum. When, this sewage sludge rate (23.80 t ha^{-1}) was applied to sorghum, heavy metal content either in plant tissue or in soil will not reach the toxic level. Therefore, we can conclude that sewage sludge can be used as an alternative to inorganic N fertilizer, without considering any environmental problem.

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