Original Research

The Effects of Sewage Sludge and Nitrogen Applications on Grain Sorghum Grown (*Sorghum vulgare* L.) in Van-Turkey

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Abstract

The research was conducted in Van, located in the eastern Anatolia region of Turkey. The purpose of this research was to assess environmental hazards to crops and soils from sludge-borne heavy metal; and the potential of using sludge as an alternative to commercial fertilizer, yield, N content and uptake of grain sorghum (*Sorghum vulgare* L. A-298). Sorghum plants were grown on sandy clay soils under irrigated conditions. Three levels of biosolids were topically applied at rates of 7, 14 and 21 Mg ha^{-1}; and two level of nitrogen were also applied at rates of 40 and 80 kg ha^{-1}. The experimental design was a randomized complete block with four replications.

Biosolids increased yields of dry matter and grain, plant length, N content of leaves, total N uptake and harvest index (HI). Grain yield was significantly correlated with plant length, N content of leaf and whole-plant, and total nitrogen uptake. Nitrogen harvest index (NHI) did not show significant correlation with any considered parameter other than harvest index. In contrast, nitrogen use efficiency (NUE) had a negative relationship with dry matter (DM) yield, N content of whole-plant, N content of grain and total N uptake. Diethylenetriamine pentaacetic acid (DTPA) extractable Cd, Pb and especially soil Zn concentrations increased with sewage sludge rates. In general, none of the heavy metals studied in both leaves and seed of crop reached either phytotoxic or toxic levels for humans or livestock [1]. The results showed that sewage sludge could be used as N fertilizer in grain sorghum production.

Keywords: biosolid, grain sorghum, yield, nutrient, heavy metal

Introduction

Sorghum and millet are valuable in the development of year-forage systems, particularly where quality is important. Akdeniz et al. [2] concluded that Ramada and A-298 varieties had the highest yield and adaptation for eastern Anatolian conditions, based on digestible dry matter and crude protein yields. Grain sorghum is grown all around the world under a wide range of climatic conditions. Sorghum is considered very efficient in utilizing nutrients from the soil because of a large fibrous root system.

Nitrogen (N) has traditionally been considered one of the most important nutrients for plants. It usually increases plant growth and crop yield. Because most soils are often deficient in the type of N that plants can readily use, therefore chemical fertilizers or organic "residuals" such as manure or biosolids are added annually to agricultural soils. The amount of N in biosolids is relatively high,

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

Properties	Soil	Properties	Sewage sludge
Sand (%)	34.3	pH	7.22
Silt (%)	25.6	EC (mS cm^{-1})	4.13
Clay (%)	40.1	Organic Matter (%)	57.2
Texture	Sandy Clay	NH_4-N (%)	0.18
$CaCO_3$ (%)	5.2	Organic N (%)	2.50
EC (mS cm^{-1})	2.41	Total N (%)	2.70
pH (1:2.5)	8.08	Total P (%)	0.58
Organic Matter (%)	2.08	Total K (%)	0.42
N-Kjeldahl (g kg^{-1})	0.095	Total Fe (%)	3.15
P-Olsen (mg kg^{-1})	10.8		
Exchangeable cations (mg kg^{-1})		Total metal concentrations (mg kg^{-1})	
K	1260	Mn	270
Ca	4970	Zn	660
Mg	1133	Cu	90
Fe	3.5	Cr	90
Mn	11.4	Cd	1.40
Zn	0.4	Pb	70
Cu	2.2	Ni	110
Cr	0.20		
Cd	0.04		
Pb	0.9		

making it an attractive fertilizer. In fact, biosolids application rates must be carefully calculated to avoid adding too much N, which leaches out of the soil in the form of nitrate and degrades the environment [3].

Sludge land application has proven to be an excellent substitute for inorganic fertilizer and is cost effective for both the municipality applying the sludge and the farmer who accepts it [4]. The benefits of using sewage sludge as fertilizer has been proven by numerous researchers. In most cases the application of sewage sludge improves the physical and chemical properties of infertility soils and increases their fertility [5]. Kresse and Naylor [6] have reported that sludge-treated plots produced corn yields equivalent to those to which commercial fertilizer was applied. In addition to nutrients, however, sludge contains a number of potentially harmful constituents such as heavy metals. The heavy metals in applied sludge create the potential for soil and water contamination, crop damage, and accumulation of heavy metals in the food supply. The magnitude of the problem depends on the composition of the sludge, rate of sludge application, soil properties, and crop species and cultivation [3]. In general, biosolids increase plant production and improve forage quality when application rates are not excessive relative to N requirements of treated plants and metal concentrations are not toxic [7].

The primary aim of this study was to evaluate the potential of using sludge as an alternative to commercial fertilizer, yield, N content, harvest index, N harvest index and N use efficiency for irrigated grain sorghum. The secondary aim was to evaluate the availability of other nutrients and heavy metal contents in seed and leaf sorghum.

Material and Methods

The study was performed as a field experiment on a research area at an altitude of 1725 m located in the Eastern Anatolia region of Turkey. Some characteristics of sewage biosolids used in the experiment and soils are given in Table 1. The soils at the experimental site are sandy clay, pH was 8.08, organic matter content was 2.08% and diethylenetriamine pentaacetic acid (DTPA) extractable of Mn, Zn, Cu, Cr, Cd and Pb in the upper 30 cm of soil were 11.44, 0.36, 2.19, 0.20, 0.036 and 0.88 (mg kg^{-1}), respectively (Table 1). The experimental design was completely randomized block design, with four replications. Plots consisted of five rows 5 m long and 40 cm row spacing. Plots were established by hand and seeding rate was 100 seeds per meter square, depth of sowing was a 2-3 cm and sowing date was 7 July 2003.

The experiment involves six treatments. Biosolids were applied at three rates: 4.5, 9, and 19 Mg ha^{-1}; corresponding ammonium nitrate rates were 40 and 80 kg ha^{-1} and a zero N-control, respectively. Additionally, 80 kg P_2O_5 ha^{-1} was applied on the plots that were not taken by sewage biosolid. Half of the nitrogen was applied during planting and the other was applied when the plants reached 20-30 cm. Sewage biosolids were topically applied to each experiment unit by hand using a shovel. Sewage biosolid and inorganic nitrogen application rates were based on the agronomic nitrogen requirement of sorghum, which is approximately 80 kg ha^{-1}. Nitrogen application rates equivalent to 50, 100 and 200 percent for sludge and 50 and 100 percent for inorganic nitrogen of the agronomic nitrogen requirement were used. Sludge application rates were chosen to supply the estimated 40, 80 and 160 kg ha^{-1} plant available nitrogen. We estimated plant available nitrogen in the sludge as 30% of the organic nitrogen plus 50% of the ammonium N [8]. Based on this estimate, we applied the biosolid rates. Plots were irrigated every week to adequate moisture for plant.

First of all, panicles of plants in the center of each plot were harvested by hand. Later, seeds were separated from panicles and weighed. Secondly, stems of plants in the center of each plot were harvested to determine fresh herbage weight. Then, approximately 1.5 kg fresh plants samples were taken and dried at 60°C for 24 hours. Samples were weighed and hay yield was determined by using dry sampling weight and fresh herbage yield.

Plant samples were taken at flowering stage; the plots were harvested at physiological maturity, by hand on 26 September 2003. Harvested grain sorghum center three from each plot weighed, sampled for dry matter (DM; about 1500 g whole plant corn). Yield and yield components (number of panicle-NP and Unit Grain Weight-UGW), harvest index was determined as the ratio grain yield to total above-ground biomass at harvest. Nitrogen Harvest Index was calculated as the ratio of N in grains (kg N ha^{-1}) on the whole plant N content (kg N ha^{-1}). The determination of nitrogen using efficiency (NUE) is kg grain increase kg^{-1} N applied.

The grain and leaves were analyzed to determine nutrient and heavy metal content of sorghum plants. Separately, the plant samples were washed with de-ionized water, dried at 60°C and finally ground. Samples were dissolved in 3 N HCl after the organic matter had been ashed at 500°C. N content of samples were determined by the Kjeldahl method [15]. Phosphorus content of samples was measured by spectrophotometer. The other nutrients and heavy metal contents of samples (K, Ca, Mg, Fe, Mn, Zn, Cu, Cr, Cd, Ni and Pb) were determined using acetylene plus flame atomic absorption spectrophotometer apparatus with graphite furnace (AAS). Additionally, the organic matter in sewage sludge was measured by the dry combustion method [9]. Sludge NH_4^+-N was determined by extraction in 2 M KCl [10]. Total P in sludge was measured spectrophotometrically. Total metals in sludge were determined using acetylene flame atomic absorption spectrophotometer apparatus following extraction by nitric-hydrochloric digestion [11].

Soil samples taken from plots amended sewage sludge were dried and sieved (2 mm) for analytical purposes. Textural analysis was performed by using the hydrometer method [12]. Soil pH was determined in a 1:2.5 soil water suspension [13]. Electrical conductivity (EC) was determined according to [14]. Total N was measured by the Kjeldahl method [15]. Available P was determined by the Olsen procedure for calcareous soil [16]. Calcium carbonate was measured with a calcimeter apparatus. Organic matter was analyzed colorimetrically using the modified Walkley-Black method [17]. Exchangeable K, Ca and Mg were measured by atomic absorption spectroscopy after an ammonium acetate extraction [18].

Statistical analyses were performed using the GLM procedure of SAS [19] and means were compared using Duncan's test [20].

Results and Discussion

Yield and Yield Components

Both sewage sludge and chemical fertilizers increased dry matter yield and grain yield of sorghum. The highest grain yield (12.28 t ha^{-1}) was obtained from the highest sewage sludge application (S3:18.0 Mg ha^{-1}). Although N fertilizer and sewage sludge applications caused a little increase in dry matter yield, these increases were not statistically significant compared to the control plots. Sorghum showed increases in plant length in the growing season, when treated with biosolids. Nitrogen contents of leaves increased with S3 treatment, and a significant difference was determined between S3 and the other treatments. Although S3 treatment increased the nitrogen content of whole-plant a little, there were not significant differences between the biosolid treatments and the N fertilizer (Table 2).

A positive effect of fertilizer application on the harvest index also was detected. Both grain nitrogen and N concentration of whole-plant treated and untreated plants did not differ significantly. There are many other studies indicating that plant length and DM yield of sorghum increases with increasing nitrogen doses [21-24]. The highest HI (66.0) was obtained with the highest sewage sludge application rate. Note that the N concentration of the seed did not increase at increasing nitrogen rates, as also pointed out by other authors [25-27]. Biosolids and nitrogen applications had a favorable effect on the crop N uptake. Total N uptake increased from 113.8 to 198.8 kg ha^{-1} with the highest biosolid application rate. Sludge application increased grain yield, N leaf content, total N uptake and HI more than inorganic fertilizer. There was not significant differ-

Table 2. Effect of fertilization treatments on dry matter, grain yield, plant length, number of panicles, unit grain weight and whole plant and grain, harvest index, total N uptake, N harvest index, nitrogen using efficiency.

Fertilization Treatment	Dry matter (t/ha)	Grain yield (t/ha)	Plant length (cm)	Number of panicle (m2)	Unit grain weight	Leaf-N (%)	Whole plant N (%)	Grain N (%)	Harvest Index	Total N uptake (kg/ha)	N Harvest Index	N using efficiency
Control	5.75 b	7.25 d	110.8 ab	52.0	13.9 b	1.60 c	0.52	1.13	57.5 c	113.8 c	76.0	66.1
N1	5.63 b	8.72 c	109.2 b	50.3	16.6 b	1.63 bc	0.58	1.16	59.8 b	129.3 c	74.7	64.7
N2	6.10 a	10.03 b	111.6 ab	53.2	18.9 ab	1.72 b	0.66	1.21	59.8 b	166.3 b	72.9	60.7
S1	5.16 b	7.84 cd	107.6 b	54.2	14.5 b	1.62 c	0.64	1.15	60.5 b	124.3 c	73.4	63.8
S2	5.19 b	8.30 c	107.1 b	51.7	16.0 b	1.68 bc	0.60	1.08	61.4 b	121.0 c	74.3	68.6
S3	6.58 a	12.82 a	116.8 a	57.8	22.2 a	1.93 a	0.67	1.20	66.0 a	198.8 a	77.7	64.8
Sig.level	**	**	*	ns	*	***	ns	ns	*	***	ns	ns

*Means with different letter within each column are significantly different between treatments at ($P < 0.05$) Duncan's test.

Table 3. Micronutrient and heavy metal concentrations (mg kg $^{-1}$) in soil (DTPA).

Fertilizer	pH	Fe	Mn	Cu	Cd	Cr	Ni	Pb	Zn
Control	8.08	3.46	12.00	2.19 b	0.038 b	0.24	1.04	0.88 b	0.36 c
S1	8.02	3.61	11.73	2.32 ab	0.045 a	0.26	1.03	1.03 a	0.92 c
S2	7.99	3.91	11.50	2.44 a	0.050 a	0.23	1.04	1.16 a	2.28 b
S3	7.84	3.70	12.00	2.35 ab	0.045 a	0.23	0.91	1.13 a	4.25 a
Sig. level	ns	ns	ns	*	*	ns	ns	*	***

*Means with different letter within each column are significantly different between treatments at ($P < 0.05$) Duncan's test.

ence between N sources (biosolid and chemical fertilizer) in respect to DM yield, plant length, and unit grain weight. Binder et al. [22] reported that nitrogen content of forage corn increased with nitrogen fertilization similar to these results. Buxton and Fales [28] also reported that only nitrogen fertilization affects nitrogen content, but also temperature and drought affects nitrogen content of forages. Mamo et al. [29] reported that plant N uptake increased with sewage sludge application and N fertilization. Effects of sewage sludge and N fertilizer rates on the N use efficiency were not significant. Binder et al. [22] stated that N use efficiency of biosolid-N and fertilizer-N decreased with increasing treatment rates in irrigated corn production.

There are certain observations to be made on the correlations noted between yield and yield components, harvest index, total N uptake and these are given in Table 6. Grain yield was significantly correlated with plant length, N content of leaf and whole-plant, total nitrogen uptake and unit of grain weight. Harvest index was correlated with grain yield, N content of leaf and total N uptake. Nitrogen harvest index did not show significant correlation with any considered parameter other than harvest index. Nitrogen use efficiency was significantly and negatively correlated with dry matter yield, N content of whole-plant and N content of grain, total N uptake.

Mineral Composition of Plant Leaf and Seed

Concentrations of the studied macronutrients, P, K, Ca, and Mg; and micronutrient and heavy metals Fe, Mn, Cu; Cd, Cr, and Pb in both leaf and grain of sorghum showed no differences with sewage biosolid and nitrogen applications (Tables 4, 5). Compared to control, sewage sludge slightly increased plant P, Mg, Cu, and Cr concentrations, but this increase was not significant. Conversely, the increase in the leaf Ni and Zn was found to be statistically significant. However, Ni did not increase in the grain in significant amounts. Reed et al. [4] reported that the concentration of Cu in the soil and Zn in the leaf increased with increasing sludge application. At the and of the experiment the Cr, Fe, Mn, and Ni concentrations did not increase significantly with sewage sludge applications and its concentrations are considered low [34].

The Ca, Mg, Cr, and Pb concentrations in leaves are relatively higher than the seed, while the P, K, Fe and Mn concentrations in seed are relatively higher than the leaves. However, there was a significant and positive correlation among P, K, Mg and Ca concentrations in seed. On the other hand, there was a relationship among Cr, Zn and P concentrations. In the leaf, there was a

Table 4. Macronutrient concentrations (%), micronutrient and heavy metal concentrations (mg kg^{-1}) dry weight in sorghum leaf.

Fertilizer	P	K	Ca	Mg	Fe	Mn	Cu	Cd	Cr	Ni	Pb	Zn
Control	0.15	1.31	0.50	0.41	13.53	3.40	4.15	0.13	0.93	1.05 b	0.49	11.63 b
N1	0.17	1.14	0.47	0.42	13.65	3.35	4.45	0.12	0.80	1.10 a	0.46	12.15 b
N2	0.15	1.03	0.51	0.47	13.63	3.15	4.40	0.13	0.82	1.18 a	0.56	11.80 b
S1	0.17	1.05	0.71	0.46	13.95	3.08	4.45	0.12	0.86	1.11 a	0.56	13.03 ab
S2	0.18	1.15	0.64	0.48	13.23	3.20	4.55	0.11	1.06	1.34 a	0.49	15.80 a
S3	0.19	1.14	0.57	0.48	14.48	3.60	4.60	0.11	1.01	1.15 a	0.49	15.18 a
Sig. level	ns	ns	ns	ns	ns	ns	ns	ns	ns	*	ns	*

*Means with different letter within each column are significantly different between treatments at ($P < 0.05$) Duncan's test.

Table 5. Macronutrient concentrations (%) micronutrient and heavy metal concentrations (mg kg^{-1}) dry weight in sorghum seed.

Fertilizer	P	K	Ca	Mg	Fe	Mn	Cu	Cd	Cr	Ni	Pb	Zn
Control	0.25	0.41	0.11	0.29	28.40	11.75	4.52	0.13	0.45	1.14	0.36	19.20
N1	0.26	0.43	0.11	0.30	23.95	12.56	4.46	0.12	0.40	1.22	0.41	20.73
N2	0.24	0.44	0.12	0.29	27.40	12.38	4.94	0.12	0.34	1.10	0.36	18.15
S1	0.25	0.39	0.11	0.29	29.28	12.44	4.09	0.13	0.39	1.13	0.44	20.05
S2	0.25	0.40	0.10	0.25	28.33	11.88	4.89	0.13	0.45	1.19	0.46	20.35
S3	0.26	0.38	0.11	0.29	27.15	12.25	4.03	0.11	0.41	1.01	0.45	19.78
Sig. level	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns

*Means with different letter within each column are significantly different between treatments at ($P < 0.05$) Duncan's test.

Table 6. Correlation coefficients (*r*) of yield components and Harvest Indexes, and N Harvest Indexes and Nitrogen use efficiency in grain sorghum.

	r												
	DM	GY	PL	NP	LP	NL	NWP	NG	TNU	HI	NHI	NUE	UGW
DM	-												
GY	0.535 **	-											
PL	0.775 **	0.576 **	-										
NP	0.445 **			-									
LP	0.462 **		0.627 **		-								
NL	0.480 *	0.796 **	0.516 **			-							
NWP	0.431 *	0.531 **					-						
NG							0.406 *	-					
TNU	0.651 **	0.944 **	0.565 **			0.742 **	0.964 **	0.545 **	-				
HI		0.666 **				0.484*				-			
NHI	-0.450 *								0.500 **	0.771 **	-		
NUE	-0.504 *						-0.581 **	-0.789 **				-	
UGW		0.833 **				0.617 **			0.757 **	0.729 **	0.500 *		-

*,**: Significant at the 0.05 and 0.01 probability levels, respectively.
DM: Dry matter yield (kg ha^{-1}); GY: Grain yield (kg ha^{-1}); PL: Plant length (cm); NP: number of panicle (m^2); LP: Length of plant (cm); NL: N content of leaf (%); NWP: N content of whole-plant (%); NG: N content of grain (%); TNU: Total N uptake (kg ha^{-1}); HI: Harvest index; NHI: N harvest index; NUE: Nitrogen using efficiency; UGW: Unit grain weight

significant relationship between Ni and Zn; Pb and Cd; but the relation between Mg and Cu concentrations was negative. Similarly, there was a significant and positive correlation for P, K, Mg and Ca concentrations in seed. The resulting data demonstrate that sewage biosolid applications did not cause any significant increase in heavy metal levels in leaf and seed of grain sorghum. Metals have toxic effects on living organisms when they exceed a certain concentration. However, the heavy metal levels in plants did by far not reach the limits of tolerance for plants [1]. Heavy metal content of leaves and grains never reached toxic levels because the sewage biosolid used in the experiment had fewer amounts of heavy metals.

Soil pH and DTPA Extractable Metals

None of the treatments examined had any significant influence on soil pH; the mean pH values were as follows: control=8.08, S1=8.02, S2=7.99, S3=7.84.

The amounts of DTPA extractable metals such as Fe, Mn, Cr and Ni did not change with the application of sewage biosolid. On the other hand, the amount of Cu, Cd, Pb ($P<0.05$), and Zn ($P<0.001$) changed significantly with biosolid applications. Similar findings also have been reported by other authors [4, 30, 31, 32]. Harrison et al. [33] recommend a more cautious approach to land application of biosolids. Some of their concerns include uptake coefficients used in the EPA's risk assessment were based on averages and do not take into consideration factors such as soil pH, influencing metal uptake by plants. The risk assessment also allows the cumulative load zinc to reach levels that would result in a 50% yield reduction**.**

Conclusion

Sewage sludge application positively affected grain yield, leaf nitrogen, harvest index, and total N uptake more than chemical fertilizer, except for dry matter yield. Moreover, biosolid applications did not cause the negative effect on heavy metal content of plant, seed as well as soil. The concentration of copper, cadmium, lead and zinc in the soil and Ni and Zn in the leaf increased with increasing sludge application; however, the increases were low. As a result, sewage sludge may be used as nitrogen source for grain sorghum production.

The short-term advantage of applying sewage sludge as a fertilizer is relatively determined based on a level economic return. Although a short-term economic advantage may be realized, the individual farmer may not be aware or the long-term disadvantage of phytotoxicity. Nevertheless, a continuous monitoring of heavy metal accumulation in the soil and plants should be established in areas of application of biosolids.

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