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Response of fodder sorghum (*Sorghum bicolor* (L.) to sewage sludge treatment and irrigation intervals in a dryland condition

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Abstract

A field experiment was conducted in the Experimental Research Farm of Omdurman Islamic University, Sudan to determine short-term effect of irrigation intervals (7 and 10 days) and sun-dried or composted sewage sludge, recommended mineral fertilizer on straw dry matter yield (SDMY) and N, P and K content of fodder sorghum and soil properties. In the 7 and 10 days irrigation intervals, composted, sun-dried sludge and mineral fertilizer have significantly increased SDMY over the control by 51, 98, 67 and 78, 19, 33%, respectively. Apparent N use efficiency (ANUE) in composted and sun dried plots irrigated at either 7 or 10 days was 9 - 36 and 16 - 74%, respectively. Reducing the irrigation interval has significantly increased salinity by 13%. Increasing irrigation interval has decreased bulk density by 5%. It could be concluded that, application of composted sludge is a useful practice for improvement of soil properties and consequent yield increase.

Keywords: Compost, cultivation, fresh, soil chemical and physical properties, yield.

Introduction

Soil degradation is quite serious problem in Sudan which is one of the largest countries in the North Africa and Near East region with high agricultural potential (Ayoub, 1999). In the last 35 years, the 46 million ha lying in the semi-arid zone which is the centre of production of field crops, the gum Arabic tree (*Acacia senegal* L.) and cattle region has encountered intensive soil degradation (Abdalla, 2015). Restoration of soil productive capacity in this region is largely based on increasing the soil organic carbon content. Some authors have studied the changes of physical characteristics of soils by additions of urban organic wastes (Diaz et al., 1994; Spaccini et al., 2002).

Use of chemical fertilizers was most crucial input for enhancing crop yield, but intensive application of these fertilizers has adversely affected the environment. Moreover, the production of chemical fertilizers, in both monetary and energy terms and the need for conservation of resources, forced the third world countries, including Sudan, to look for alternatives. Hence, organic fertilizers assumed great importance compared to mineral fertilizer, although they contain relatively low concentration of nutrients. Using organic amendments can be an important component of a strategy for achieving sustainable agricultural practices.

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Manure, compost and other organic amendments can be added to soil in order to increase soil organic matter content (Sneh et al., 2005) especially in arid, semi-arid and marginal lands.

Sewage sludge is the solid product of the municipal wastewater treatment process. This material can be a useful source of nutrients for the soil environment by turning wastes into valuable resources (Ghoniem, 2007; Dawi, 2014) that contained total N ranging from 1.5% in air-dried lime treated biosolids to 7.5% in liquid mesophilic anaerobic digested biosolids (Rigby et al., 2016). On the other hand, increasing doses of municipal solid wastes could be associated with sharp decrease in soil NO_3-N and as a result inhibition of plant growth (Giannakis et al., 2014) or soil properties may not improve or even worsen beyond 40 t ha^{-1} of sewage application (Roig et al., 2012).

Composting is a mean of biologically degrading organic materials while stabilizing a residual organic fraction as humus (Schnitzer and Kahn, 1987). The negative impact on plant growth may be caused by reduction in oxygen and available nitrogen or the presence of phytotoxic compounds (Zheljazkova and Warman, 2002). Furthermore, composting is of great significance in reducing the hazards of weed seeds, plant pathogens, public hygiene, pollution, thus, better environment (Lampkin, 1990; Rynk et al., 1992). Composting of sewage sludge is recommended as a technique to turn a less stabilized waste into a material that is no longer classified as a waste (Alvarenga et al., 2015) while others indicated that turning a less stabilized waste (e.g. sewage sludge) into a non waste material necessitates composting (Alvarenga et al., 2015). Additionally, fresh sludge has many problems, namely its high water content, contamination with pathogenic microorganisms, lack of stability, and even, in some cases, contributing to a lowering of the availability of heavy metals in amended soils (Smith, 2009).

In the capital, Khartoum State, there are enormous quantities of sewage sludge that can be recycled for cultivation and amelioration of desert soils. However, fresh use of compost is not advisable as many pathogens are reported and requires removal through composting. Therefore, our main objective was to determine the effects of incorporation of composted or air-dried sewage sludge on some soil properties and performance of fodder sorghum (*Sorghum bicolor*) under semi-arid conditions.

Material and Methods

Site

The experiment was conducted in the Experimental Research Farm, Faculty of Agriculture, Omdurman Islamic University (Latitude 15°19.9´N Longitude, 32°39´E and 381 m above the sea level). The area falls in the semi-arid tropics with mean annual rainfall of about 67.5 mm and mean monthly temperature ranges from 21°C (in winter) to 40°C (in summer). The soil of the study site belongs to the order Aridisols and classified according to the National Research Centre (1994) as sandy clay loam, hyperthermic, mixed, gypsic Cambiorthid (Table 1).

Table 1. Some physico-chemical properties of the top soil

pH (past)	SP	OC	TN	$CaCO_3$	Sand	Silt	Clay	ECe dSm^{-1}
				g kg^{-1}				
8.9	19.0	3.6	0.23	126	460	250	290	1.33
Ca^{2+}	Mg^{2+}	Na^{+}	K^{+}	HCO_3^{-}	Cl^{-}	P	Bd	SAR
			meq l^{-1}			ppm	g cm^{-3}	
3.5	0.5	9.3	12.6	1.9	3.4	1.8	1.82	6.6

Compost preparation

Air-dried sewage sludge was collected from Khartoum State-Soba Station for treatment of sewage sludge. For compost preparation (21/05/2012 to 21/08/2012), four pits were dug in the ground with dimensions of 2m x 2m and a depth of 0.5 m (i.e. 2 m^3). A plastic sheet (6 m x 4 meter) was placed on the bottom of each pit to prevent seepage. About 250 kg of sludge was placed in each pit, watered (135 l) to 75-80% of the water holding capacity (WHC) and finally covered with the same the plastic bag. After one week the pits were opened, the temperature was measured every two weeks using digital thermometer, mixed and covered. The compost was considered mature (temperature used as quality parameter) when the inside temperature was the same as ambient temperature. Then after, the compost was air dried under the sun and about 1 kg of the final material was taken to the laboratory for characterization (n=4). Initial and final composition of the air-dried and final compost is shown in Table 2.

Table 2. Chemical analysis of the air-dried sludge and the final compost (Mean ± standard deviation)

Type	pH (1:10)	ECe dSm^{-1}	OC	TN	Lignin	PP	WHC	SP	C/N
				g kg^{-1}					
Initial	7.43±.05	11.5±0.2	112±0.1	14±0.1	133.8	48.6±0.2	625±5	980±13	7.9±0.1
Final	7.37±0.2	4.29±0.2	248±2.9	68±2	nd	nd	nd	331±10	3.6±0.4
P≤0.05	0.03	0.001	0.003	0.001				0.005	0.001
	P ppm	Ca^{++}	Mg^{++}	K^{+}	Na^{+}	HCO_3^-	Cl^-	SAR	
				meq l^{-1}					
Initial	2.36±0.1	9.37±0.6	5.06±0.1	1.72±0.5	3.38±0.2	9.37±0.4	10.67±0.2	1.26±0.09	
Final	0.34±0.1	13.68±4	6.85±1.2	2.46±0.8	3.38±0.2	5.60±0.5	16.19±2.5	0.24±0.01	
P≤0.05	0.002	0.05	0.23	0.36	0.25	0.02	0.002	0.003	

nd= not determined

P: Probability ≤ *0.05*, LSD: Least Significant Difference

Compost application for sorghum production

In April 16th 2012, an area was disc-ploughed, leveled and 32 plots (6 m x 7 m) were prepared. Treatments include two factors:

1) Amendments: Control (C), recommended dose (55 kg N ha^{-1} and 100 kg P_2O_5 ha^{-1} as triple super phosphate) of mineral fertilizer (IN), sun dried sewage sludge (AD) and composted sludge (CS) applied at rates of 15.7 (1.4% TN) and 3.2 (6.8% TN) t ha^{-1}, respectively.

2) Irrigation: 10 and 7 days irrigation interval (i.e. 8 treatments and replicated 4 times). Sludge was manually incorporated (7 days before sowing) into the top 0-30 cm depth and irrigated twice a week before sowing. Plots were arranged in a randomized complete block design (RCBD). At sowing, 119 kg ha^{-1} of fodder sorghum (*Sorghum bicolor* L.) was scattered in each plot and mineral N was applied at sowing to relevant treatments. Plots were immediately irrigated (1000 m^3 ha^{-1}) from a canal with pH and electrical conductivity (ECi) of the irrigation water were 7.5 and 0.56 dSm^{-1}, respectively. Then after, irrigation was applied according to treatments (7 or 10 days interval).

At physiological maturity (70 days), plants were cut by sickle at about 5cm above the soil surface. For determination of straw dry matter (SDM) yield, 5 plants were randomly harvested from each plot, chopped to 10-15 cm, weighed in the field and oven dried (at 70-80 ^oC for 48 hrs) and moisture content was determined. Then after, each plot was totally harvested, weighed in the field and SDM (t ha^{-1}) was calculated using previous moisture content of each plot. The five plants (leaves and stem) were crushed (0.5 mm sieve) and analyzed for TN (Bremner and Mulvaney, 1982), P and K content (Chapman and Pratt, 1961). From each plot, soil samples were taken from the top 0-30 cm depth using 5 cm diameter auger, air dried (one part was used to determine field moisture content), crushed (2.00 mm) and analyzed for pH (McLean, 1982), TN (Bremner and Mulvaney, 1982), SOC (Nelson and Sommers, 1982), ECe (Richard, 1954), available P (Olsen and Sommers, 1982), soluble Ca^{2+}, Mg^{2+}, Na^+ (Chapman and Pratt, 1961), SAR and $CaCO_3$ (Goh et al., 1993). Undisturbed soil samples from the top 0-30 cm were also taken from each plot for determination of bulk density (Blake and Hartge, 1986). Apparent N use efficiency (ANUE) was calculated as follows:

%ANUE = (straw N content in sludge plots kg ha^{-1}- TN straw in C plots)/ TN added x100

The software of SAS (1999) was used to determine significant differences between treatment means (ANOVA).

Results and Discussion

Effects of sludge on dry matter yield (DMY) and straw nutrient content

The highest SDM yield (12.5 and 11.2 t ha^{-1}) was recorded in AD7 and CS10, respectively (Table 3). Main effects of fertilizer source showed that, irrespective of irrigation interval, percent increase over the control was in the order of CS (68%) > AD (62%) > IN (53%). On all sources of fertilizer added, reducing irrigation interval to 7 days has increased yield over the 10 days by 18%. Similar to yield, plants in AD7 plots recorded the highest (248 kg ha^{-1}) N content whereas those in C10 plots recorded the lowest (69 kg ha^{-1}) N content (Table 3). On average, 7 days irrigation interval increased N content over 10 days by about 25%. The ANUE in FS plots with reduced irrigation interval was exceptionally high and almost more than two fold that recorded in plots with compost application whereas ANUE of the mineral N was averaged 65% (Figure 1).

Table 3. Effects of sludge treatment on straw dry matter in yield and N, P, K content of sorghum (Mean ± standard deviation)

Treatments	SDMY (t ha^{-1})	TN	P	K
			kg ha^{-1}	
			7 days	
C	06.3±0.5	85.7±19.7	4.88±0.7	88.99±38.7
IN	10.5±0.5	137.1±53.6	8.3±2.6	134.7±12.5
AD	12.5±3.0	248.3±94.2	9.6±1.9	155.2±9.2
CS	9.5±1.0	105.8±30.6	9.78±1.9	161.15±10.8
			10 days	
C	06.1±0.7	69.8±9.7	6.1±0.4	90.0±8.6
IN	08.4±1.6	89.6±4.7	6.9±1.5	111.7±7.2
AD	07.5±0.8	104.9±9.2	5.8±0.5	87.9±5.9
CS	11.2±1.9	147.7±7.5	9.1±2.2	113.45±8.9
P value	0.0002	0.0007	0.07	0.7
LSD	2.3	76.4	3.77	94.6

P: Probability ≤ *0.05*, LSD: Least Significant Difference

Increasing irrigation interval reduced ANUE by 100%. The ratios of N uptake from mineral fertilizer, sun dried sludge and composted sludge to that of the soil ranged from 1.29-1.5, 1.5-2.88 and 1.23-2.11, respectively. Generally, application of air-dried compost increased plant N content over the control, mineral fertilizer and compost by almost 128, 49 and 39%, respectively. Regardless of irrigation interval, plants supplied with mineral fertilizer and composted sludge has very similar N content. Although P content in the straw was not significantly affected by fertilizer source or irrigation interval (CV of 34%), incorporation of sun dried sludge produced plants with P content similar to those supplied with mineral fertilizer. Irrigation interval (on all sources of P) has no effect on plant P content. However, P content in composted plots was not affected by irrigation interval and recorded an increase over the control and both mineral and sun dried sludge of 72 and 23%, respectively. The content of straw K was not significantly (CV of 55%) affected by treatments where on average fresh sludge and mineral fertilizer has similar straw K content. It was observed that application of composted sludge has resulted in an increase of K content over mineral source by almost 43%.

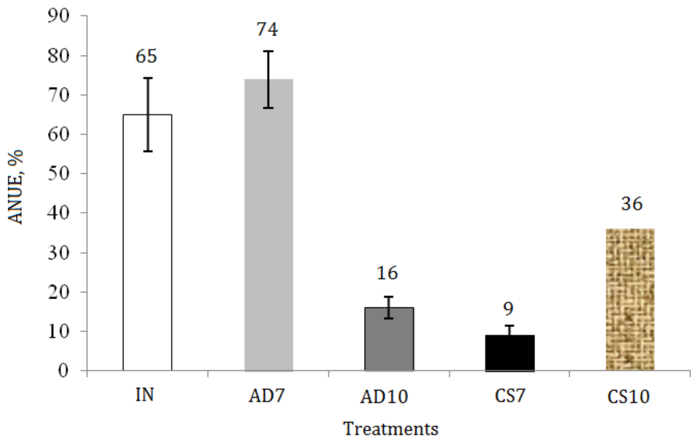

Figure 1. Effect of sludge treatment on ANUE ($P \leq 0.04$, LSD=44.7)

Effects of sludge treatment on soil properties

The effects of application of sewage sludge and irrigation interval on soil properties is shown in Table 4. The application of sludge whether sun dried or composted has generally increased pH over plots without sludge by 0.3 units whereas irrigation interval showed no significant effects.

The highest soluble salts were found in the control and plots with mineral fertilizer (with reduced irrigation interval) and all plots treated with sun dried sludge. The lowest EC values were recorded in plots treated with composted sludge. Interestingly, it was observed that on all levels of fertilizer source, increasing irrigation interval from 7 days to 10 days has decreased soluble salts by about 14%.

Table 4. Effects of sludge treatment on soil properties (Mean ± standard deviation)

Treatments	$pH_{(paste)}$	ECe dSm^{-1}	TN	OC	$CaCO_3$	P ppm	Ca^{2+}	Mg^{2+}	K^+	Na^+	SAR
			g kg^{-1}					meq l^{-1}			
					7 days						
C	8.07±0.16	1.7±0.34	0.14±0.07	17.33±4.7	4.6±0.15	1.33±0.12	3.53±0.46	2.9±0.4	0.25±0.09	25.9±1.50	14.4±1.40
IN	8.43±0.33	1.6±0.09	0.23±0.07	22.33±6.4	5.7±0.83	1.56±0.01	3.33±0.47	1.6±0.5	0.32±0.16	26.5±0.92	16.9±1.40
AD	8.33±0.21	1.6±0.19	0.20±0.05	27.73±3.2	4.7±0.45	1.28±0.25	5.08±1.05	1.1±0.1	0.39±0.31	21.4±1.59	12.2±0.78
CS	8.33±0.22	1.4±0.22	0.18±0.09	22.90±1.7	5.87±3.1	1.38±0.11	6.60±0.94	7.3±1.3	0.20±0.06	20.9±1.30	07.9±1.72
					10 days						
C	8.38±0.33	1.34±0.22	0.13±0.01	18.18±3.2	5.1±0.87	1.29±0.09	4.7±0.73	0.7±0.17	0.19±0.03	22.42±1.39	13.6±1.6
IN	7.98±0.13	1.34±0.23	0.15±0.01	28.18±3.7	4.9±1 .00	1.26±0.15	4.3±0.90	0.9±0.48	0.22±0.08	20.39±2.20	12.7±0.9
AD	8.33±0.46	1.56±0.41	0.13±0.02	30.50±3.6	4.5±0.63	1.32±0.35	3.4±0.33	1.5±0.13	0.27±0.13	18.78±2.81	12.0±0.6
CS	8.16±0.05	1.38±0.09	0.43±0.01	41.43±3.2	4.3±0.43	1.26±0.15	5.8±0.62	4.0±0.30	0.17±0.03	21.64±1.30	09.8±0.6
P Value	0.03	0.04	0.04	0.0001	0.63	0.83	0.0001	0.000	0.25	0.0002	0.0001
LSD	0.34	0.31	0.06	0.86	1.89	0.27	1.13	1.02	0.21	2.63	1.6

P: Probability ≤ 0.05, LSD: Least Significant Difference

The highest TN was found in plots treated with composted sludge (CS10) followed by mineral N (IN7). On average for all irrigation intervals application of composted sludge has increased soil N over the control, mineral fertilizer and air dried sludge by 126, 61 and 85%, respectively. Also, on average for all N sources, plots irrigated in 10 days interval contained significantly higher N than those irrigated in 7 days by 27%.

On average for all irrigation intervals the content of SOC was in the order of composted sludge > sun dried sludge > mineral fertilizer > control. The highest SOC content was found in the CS10 plots while the lowest was found in the C7 plots. Accordingly, on average SOC content in composted plots was higher than C, IN and AD plots by 81, 27 and 11%, respectively. Additionally, increasing irrigation interval to 10 days has increased SOC by 39%. The content of P, soluble K and $CaCO_3$ in the soil was not significantly changed along with addition of either air-dried or composted sludge. Both soluble Ca^{2+} and Mg^{2+} were significantly higher in plots treated with composted sludge than treated with air-dried sludge by 46 and over 300%, respectively. The content of soluble Na^+ in the soil solution was significantly reduced by composted and air-dried application by about 17 and 12%, respectively. Unexpectedly on average for all fertilizer sources, decreasing irrigation interval to 7 days has significantly increased soluble Na^+ by 12%. The lowest SAR values were found in plots treated with compost sludge whereas the highest values were found in control and plots with mineral fertilizer. Accordingly, application of composted and air-dried sludge has reduced initial SAR values by 37 and 14%, respectively. However, on average irrigation interval has not significant effects on SAR values.

The soil moisture content after harvest (Figure 2) was not significantly different among treatments. Application of sun dried sludge and composted at short irrigation interval has significantly increased bulk density of the sandy clay loam soil from 1.35 to a maximum of 1.43 g cm^{-3} (i.e 6%) whereas compost application and increasing irrigation interval has significantly decreased bulk density by 5% (Figure 3).

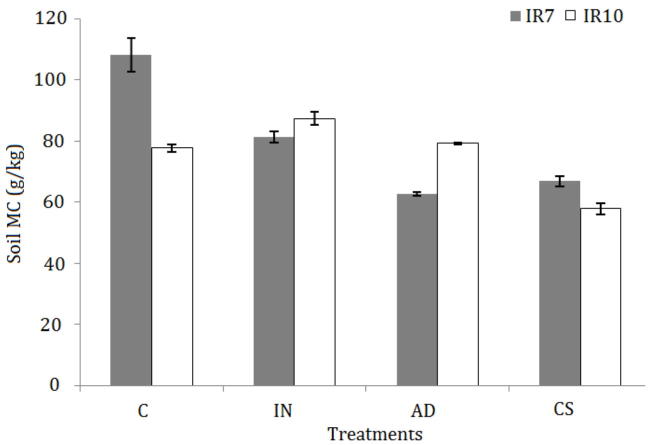

Figure 2. Effect of sludge treatment on soil MC after harvest ($P \leq 0.2$, LSD=35.3)

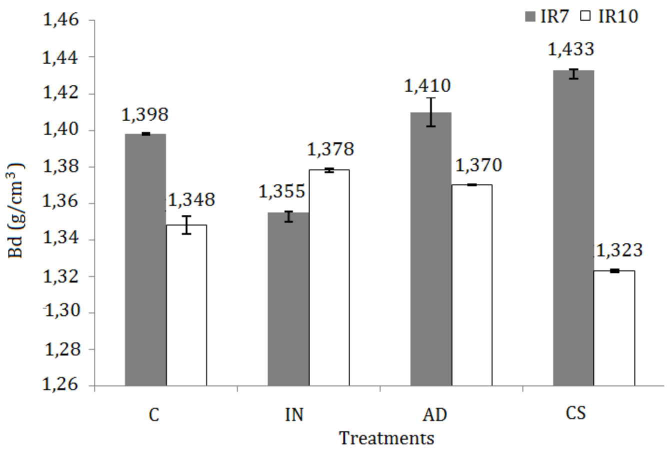

Figure. 3. Effect of sludge teratment on soil bulk density after harvest ($P \leq 0.0001$; LSD=0.009)

Effects of sludge treatment on dry matter yield (DMY) and straw nutrient content

In our study we aimed to determine the differences in effect of applying either air dried or composted sludge on crop-soil systems. It was also important to economize water through determining whether we can extend irrigation interval with organic amendments. Many studies have shown that sewage sludge is a good source of plant nutrients and it contains most of the essential nutrients for plant growth. On the contrary, we found that 10 days irrigation interval has significantly reduced yield over 7 days. Application of sewage sludge enhances soil fertility through increasing soil organic matter (Casado-Vela et al., 2006; Rezig et al., 2013) and consequently have positive effects on both the quantity and the quality of the biomass produced by crops (Seleiman et al., 2013; Mañas et al., 2014). Recently, Lag-Brotons et al. (2014) found that application of composted sludge at a rate of 70 t ha^{-1} to soils with poor physical structure, calcareous and with low organic matter has increased above ground yield of *Cynara cardunculus* L. (cynara) by 68% over the control. Although mineral N (NH_4-N + NO_3-N) in air dried compost was not determined, we expect that initial content to be high (Alvarenga et al., 2015) rendering it available for plant uptake. Therefore, plants supplied with fresh compost showed significantly high N content. Many previous studies have indicated that fresh sludge contains beside sanitary risk (Sidhu and Toze, 2009), extra mineral N that could be leached downwards and threatens pollution of water with NO_3-N. During composting, soluble mineral N decreased due to consumption by decomposing organisms that convert this portion into organic N (immobilization). Accordingly, N release from added compost is known to be slow and environmentally acceptable. This process is very important in nutrients cycling especially N turnover and it improves N synchrony between application and absorption. Fresh application of organic materials provides the soil with different types of organic compounds than composted materials. For instance, fresh residues are rich in polysaccharides and low molecular weight compounds (Said-Pullicino et al., 2007), which contribute to the initial stages of aggregate formation (Roldán et al., 1996; Abiven et al., 2009). In contrast, composted residues exert influence due to humic substances and are related to long-term aggregate stabilization (Abiven et al., 2009). Therefore, we assume that there was immediate soluble mineral N from sun dried sludge and could possibly increased ANUE. However, average ANUE from composted sludge (22.5%) seemed to be lower than that reported in air-dried sludge (average of 45%). The low ANUE from composted sludge may possibly indicates slow release of N during the growing season. In a glasshouse experiment, Asagi and Ueno (2008) reported NUE by *Brassica campestris var. perviridis* to be 19.7 and 12.1% for mineral N and sewage sludge, respectively. They also reported similar ratios of N to soil uptake for mineral fertilizer and sewage sludge of 3.1 and 1.88, respectively. Application of sewage sludge sun dried or composted has significantly increased N content of fodder sorghum plants (*Sorghum bicolor*). Composting of sewage sludge has resulted in N content in plants lower than the sun dried sludge which was also interpreted in low ANUE in composted plots. This may be attributed to either volatilization of NH_3 during composting or leaching of soluble nitrate at early stage of growth**.** On the contrary**,** significant increase in N content in plants after application of sewage sludge was reported by Kabirinejad and Hoodaji (2012). They also reported that application of sewage sludge increased significantly P and K content in the plant. The low content of P and K in sludge treatments may possibly be due to their initial low content. Also, the alkalinity of the soil may negatively affect the uptake of P content in the soil. These differences in results may be attributed to their high application rates (25 and 50 t ha^{-1}) and also the study of previous authors was carried out under controlled conditions (pot experiment).

Effects of sludge treatment on soil properties

In this study, the alkaline nature and presence of considerable salts (Table 2) used in sludge may justify the increase in soil reaction. It was stated by Alvarenga et al. (2015) that "typically, pH values for mature composts are close to 8.0, which identify its basic nature, usually due to compounds of calcium and sodium. This value leads to admit that the product has, at least in the short term, a certain mineral alkalizing effect when applied to soils, especially when they have low buffering capacity". However, the effect of sewage sludge application on soil reaction was not significant. For example, because of acidity, sewage sludge was generally reported to decrease soil pH (e.g. Veeresh et al., 2009; Latare et al., 2014) but application of up to 90 t ha^{-1} was reported not to be significantly changed soil pH (Delibacak et al., 2009). Additionally, application of stabilized municipal sewage sludge to a degraded acid mine soil for 45 days was reported to slightly increase soil pH (Mingorance et al., 2014). The increase in total salts with air-dried sludge could possibly be due to high initial ECe values. However, compared to the control plots, application of stable compost in this study decreased soluble salts that might be due to the formation of macro-aggregates and therefore increasing leaching of salts. Our results are inconformity with several workers who reported that application of sewage sludge improves soil physical properties such as bulk density, aggregate stability, water holding capacity, total porosity, and saturated hydraulic conductivity (Sort and Alcañiz, 1999; Aggelides and Londra, 2000; Mondal et al., 2015). In this study, compost application and reducing irrigation interval have positive effects on soil TN. The content of nitrogen in composted sludge used in our experiment (Table 2) is almost five folds more that of air-dried sludge. Accumulation of TN in plots treated with composted sludge is in line with several earlier studies (e.g. Jin et al., 2011; Roig et al., 2012; Latare et al., 2014). However, increasing irrigation interval may delay decomposition and N release due to less available moisture content for biological activity and may consequently result in N compositions build up. The order of increase in SOC found in our study supports earlier studies that composting sludge is a useful practice to obtain stable material that provides soil with organic matter. Many studies have reported positive effects from application of composted sludge on soil C in semi-arid regions. Many previous studies found increase of SOC up to six folds more, 36% higher than control or increase linearly with sludge dose (Salazar et al., 2012; Jin et al., 2015; Peña et al., 2015). The relatively high content of Ca^{+2} and Mg^{+2} in the composted sludge as compared to air-dried sludge may justify the accumulation of such elements in amended plots. On the contrary, Wen et al. (1999) did not find change in concentration of Ca^{+2} and Mg^{+2} in the bean pods due to application of 10, 20, 30 and 40 t ha^{-1} of composted sludge for two years. Our results showed that application of composted sludge could be a useful management practice for amelioration of sodic soils since SAR was significantly reduced. Application of composted sludge elsewhere was reported to reduce exchangeable sodium percentage from initial values of a saline sodic soil by 51% (Ors et al., 2015).

It is not known from our research why application of air-dried and composted sludge at a reduced irrigation interval has increased bulk density of the sandy clay loam soil. The only possible interpretation is that based on readily dissolved organic materials that brought together single fine sand grains, thereby increasing weight of soil particles per unit volume area. The decrease in bulk density with compost application found in this study is in line with other studies (Aggelides and Londra, 2000; Celik et al. 2004; Mondal et al., 2015). However, many long term experiments indicated contrasting effects of soil density with biosolids application. For example, Jin et al. (2011, 2015) reported that application of either 22 t ha^{-1} for 25 years or up to 67 t ha^{-1} of biosolids for 8 years has little or no effects on bulk density of the 0-10 cm depth of a silty loam to silty clay loam soil. Haney et al. (2015) found that in fields receiving annual application of 20 t ha^{-1} for 8 years consequently, soil bulk densities (0–30 cm) increased linearly with biosolids application rate and consistent with soil compaction due to wheel traffic. In a sandy soil (87, 9 and 4% sand, silt and clay, respectively), Glab (2014) reported positive decrease of bulk density with increase in compost application rate (R^2=0.991).

Conclusion

In general, application of composted sewage sludge has improved soil conditions which have been reflected in yield increase of fodder sorghum (*Sorghum bicolor*). The combination of composted sludge and increasing irrigation interval had resulted in increasing yield by more than 47% in comparison with air-dried sludge treatment with similar irrigation interval.

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