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Impact of Brewery Waste Sludge on Sorghum (*Sorghum bicolor* L. Moench) Productivity and Soil Fertility in Harari Regional State, Eastern Ethiopia

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ABSTRACT

The study was conducted on farmers' field in sofi district of Harari Regional State during 2013/2014 main cropping season, eastern Ethiopia, to investigate the impact of brewery sludge on sorghum production and soil fertility. The treatments comprised seven levels of brewery sludges (0, 2.5, 5.0, 7.5, 10.0, 12.5 and 15.0 t ha^{-1}) and NP inorganic fertilizer at recommended rate, arranged in randomized complete block design with four replications. Application of brewery sludge at 15 t ha^{-1} significantly increased the yield and biomass yield of sorghum by 79 and 85% over control and by 57 and 67% over NP application, respectively. There was no effect of brewery sludge application on heavy metals concentrations in soil after crop harvest, compared to international standard tolerable level. Co and Se levels were high in the control as well as in the soils treated with brewery sludge indicating the already high concentration of these heavy metals in the soils of the area. Plots, which received higher brewery sludge application, resulted in decreased or less percentage of grain nitrogen content showing the independence of grain protein content on lower brewery sludge level. The nitrogen uptake by sorghum grain, straw and the total was maximum (52.68, 44.25 and 79.03 kg ha^{-1}, respectively) with the application of brewery waste sludge at 10 and 15 t ha^{-1} which were significantly higher than the other brewery sludge and NP mineral fertilizer applications.

Introduction

Beer Brewery is among the industries known for production of by-products (spent grains, excess yeast) and sludge from the waste water treatment plant at different stages of the manufacturing process. Sludges are usually rich in organic matter and essential nutrients. As a result, they have great potential for use as fertilizers and soil conditioners, and when they meet the necessary requirements concerning the concentration of heavy metals and pathogens, can replace part or all of mineral fertilizers (Silva et al., 2002). There are scientific evidences of increase in productivity of different crops with the application of sludge (Silva et al., 2002; Basta et al., 2005; Bjuhr, 2007). According Bjuhr (2007), the benefits of application of biosolids can exceed those achieved with mineral fertilizers, especially in terms of productivity and economy with fertilizers, mainly nitrogen (N) and in some cases phosphorus (P) and metallic ions like calcium (Ca) and magnesium (Mg). In line with this, (Yohannes Gelan, 2011) reported an increment in maize crop yield from 2.70 t ha^{-1} in the control plot to 5.23 t ha^{-1} with the application of 8 t ha^{-1} of sludge of textile factory in Kombolcha town area, northern Ethiopia. However, studies on the viability of brewery sludge from industries for agricultural use are few and specific for certain industrial by-products such as tannery and coal (Korboulewsky et al., 2002; Ferreira et al., 2003). Nevertheless, brewery sludge wastes are diverse, with characteristics that vary according to the raw materials and manufacturing processes/processing systems followed (Ferreira et al., 2003). These justify the need for investigating the technical feasibility, determining the levels of application, evaluating agronomic performances and economic benefits, and/or assessing environmental safety of major industrial wastes.

The current daily sludge production of the Harar Brewery in the eastern Ethiopia has increased significantly along with the expansion and increase in its beer production. It is therefore inevitable to focus on the development of appropriate brewery sludge waste management strategy and management plan that enables to reutilize the industrial liquid waste for other purposes in an environmentally friendly manner. One way of reutilizing such byproducts is application on cultivated lands as fertilizer for improvements of soil fertility and crop production which is also a common practice in many countries. This practice stands out as a way to reduce soil fertility depletion and input cost for smallholder farmers. This also avoids final destination options such as incineration and disposal in landfills that involve higher production costs on the factory and greater impact on the environment (Abdousalam, 2010).

The fact that sorghum is the major crop cultivated continuously without crop rotation and/or fallowing followed by complete crop residue removal from the farmlands have exacerbated the process of soil fertility depletion and overall land degradation in Harari People Regional State (HPRS) (Heluf, 2003; Heluf, 2005; Heluf, 2006; Heluf and Mishra, 2006; Heluf and Yohannes, 2011). Some farmers in the Region have already started using the brewery sludge of the Harar Beer factory as a fertilizer input for crop production. However, there is no scientific study carried out yet to investigate the impact of brewery waste sludge on crop production and soil fertility. Keeping this in view, the present study was planned to investigate the impact of brewery waste sludge on sorghum yield components, yield, and soil fertility.

Materials and Methods

Description of the Study Area

The experiment was conducted at Daker in sofi district of Harari Regional State, eastern Ethiopia during the 2013/2014 main cropping season on farmers' field under rain-fed condition. The area is located at 09^0 18’ 43” North and 42^0 07’ 23” East and 515 km East of Addis Ababa. It represents a medium altitude and moderate rainfall (850 mm/annum).

Treatments and Experimental Design

The experiment consisted of eight treatments *viz*. applications of brewery sludge (BS) that collected from Harar Beer factory at seven levels (0.0, 2.5, 5.0, 7.5, 10.0, 12.5 and 15.0 t ha^{-1}) and recommended rate of NP mineral fertilizer: N (92 kg N ha^{-1}) and P (92 kg P_2O_5 ha^{-1}) laid out in a randomized complete block design (RCBD) in four replications. Sorghum variety “Teshale” was planted on a plot size of 3.5 m x 4.2 m (14.70 m^2) in rows of five per plot at a spacing of 70 by 25 cm and a row length of 4.2 m. All levels of brewery sludge were applied 2 weeks before planting and incorporated into the plow depth. Half of the N and the full rate of the P fertilizers on the plots of the fertilized treatments were applied 5 cm below the seed at time of planting as urea (46% N) and as triple super phosphate or TSP (20% P), respectively. The second half of the N fertilizer was applied 35th days after planting at 7-10 cm away from the plant as two side dressing at about 5 cm below the surface.

Data of Yield Components and Yield

Ten plants per experimental unit were tagged and data on plant height (cm), ear length (cm), ear width (cm) and stalk diameter were recorded based on their recommended procedures. The grain yield and total biomass (kg ha^{-1}) were calculated using the relevant variables.

Analytical Procedure for Plant Samples, Soil and Brewery Sludge Physico-chemical Properties

Plant samples collected at harvest were partitioned into vegetative and grain for the determination of N content in grain and straw. The straw and grain samples were ground and sieved through 0.5 mm sieve. The N content of the grain and straw samples were determined using the wet digestion method, which involved the decomposition of the plant tissues using various combinations of HNO_3, H_2SO_4 and $HClO_4$ by using Kjeldahl procedure. Total N uptakes in straw and grain were calculated by multiplying the N contents by the respective straw and grain yields per hectare. Physico-chemical properties of soil and brewery sludge (BS) used for experiment and their methods of analysis are reported in Table1.

Analytical Procedure for Accumulation of Heavy Metals in the Soil

Extractable heavy metals (Fe, Cu, Zn, Mn, Cr, Mo, Co, Pb, Se and Cd) were extracted by DTPA extraction method (Lindsay and Norvell, 1978) and all these heavy metals were measured by atomic absorption spectrophotometer. Concentration of heavy metals (mg kg^{-1}) in the soil (before application of treatments) and brewery sludge used for the experiment were given in Table 2.

Statistical Analysis

The data were subjected to analysis of variance (GLM procedure) using SAS software program version 9.1 (SAS, 2003). From the analysis of variance, treatment means were compared using the least significant difference (LSD) at p = 0.05 significance level following the procedure described by Gomez and Gomez (Gomez, 1984).

Results and Discussion

Yield Components

The analysis of variance revealed statistically significant ($P<0.05$) difference in plant height due to treatments applications (Table 7). Increasing sludge application from 0 to 2.5 t ha^{-1} increased plant height consistently. However, further increasing of sludge application from 2.5 to 15 t ha^{-1} not increased plant height significantly indicating that application of brewery sludge beyond 2.5 t ha^{-1} did not significantly increase plant height. However, as compared to the control and NP fertilized plots, brewery sludge application at all levels showed significance difference and the increment ranged from 23 to 27% and 8 to 11%, respectively. This increment in plant height due to sludge application may be due to the increase in crop cell elongation and cell division improved as a result of application of brewery sludge that might enhanced availability of essential nutrients for the growing plants.

Table 1 Physico-chemical properties of soil and brewery sludge used for experiment

Property	Values	Method used
Soil		
pH	8.55	Glass-calomel combination electrode (Agustina Branzini and Marta Susana Zubillaga, 2012).
Total N, %	0.09	Kjeldahl digestion, distillation and titration method as described by (Blake, 1965).
Organic Carbon, %	1.98	Wet digestion (Walkley and Black, 1934)
Available P, ppm	14.23	According to the standard procedure of (Olsen et al., 1954).
Cation exchange capacity (cmol (+)/kg)	28.7	Ammonium acetate (Chapman, 1965).
Soil Texture		Bouyoucas hydrometer method (Day, 1965).
Sand	39%	
Silt	23%	
Clay	38%	
Class	Clay loam	
Brewery Sludge		
pH	8.67	Glass-calomel combination electrode (Agustina Branzini and Marta Susana Zubillaga, 20120).
Total N, %	1.33	Kjeldahl digestion, distillation and titration as described by (Blake, 1965).
Organic Carbon, %	3.5	Rapid titration method (Walkley and Black, 1934)
Available P, ppm	39.75	According to the standard procedure of (Olsen et al., 1954).

Table 2 Mean concentration of heavy metals (mg kg^{-1}) in the soil before application of treatments and brewery sludge used for the experiment

Heavy metals	Concentration of Heavy Metals (mg kg^{-1})	
	Soil	Brewery Sludge
Zn	35.00	38.50
Fe	25.05	20.50
Cd	0.04	1.27
Ni	19.00	31.33
Mn	2.24	0.83
Co	9.50	33.00
Cu	42.50	40.00
Se	2.02	12.56
Mo	1.00	0.45
Cr	20.00	47.00

Ear width was measured after harvest and it showed statistically significant ($P<0.05$) difference due to treatments application (Table 7 and Table 3). In this respect, application of brewery sludge at 12.5 t ha^{-1} gave the maximum (16.5 cm) ear width, which was statistically at par with the application of sludge at 15 t ha^{-1} (16.4 cm), 7.5 t ha^{-1} (15.6 cm) and 10 t ha^{-1} (15.5 cm) (Table 3). On the other hand, the lowest (13.9 cm) ear width was recorded from the control plot. Increasing brewery sludge levels from 0 to 15 t ha^{-1} showed a consistent ear width increment ranging from 27 to 37% over the control and from 7 to 15% over NP fertilizer application.

On the other hand, the difference among sludge applications with respect to ear length of sorghum was found to be non-significant ($P>0.05$), however, the mean of separation revealed that application of brewery sludge from 2.5 to 15 t ha^{-1}, showed significantly increased ear length over control and NP fertilized plots (Tables 7 and 3).

Similar to ear width, the stalk diameter was found to vary significantly among brewery sludge levels, whereby sorghum stalk recorded the highest diameter (1 cm^2). In this line, the mean of stalk diameter (0.83 cm^2) of sludge treated plots were 46.6% and 6.4% thicker than that of the control and NP fertilized plots, respectively (Table 3). In this respect, application of sludge at 15 t ha^{-1} gave the thickest stalk whereas the thinnest was observed in control. The NP fertilizer application also recorded the fifth highest mean stalk diameter following application of sludge at 15, 5, 10 and 7.5 t ha^{-1}. Generally, on the average, larger stalk diameters were observed in BS treated plots compared to control and NP fertilized plots. Similarly, (Barriquelo et al., 2003) reported larger ear width and stalk diameters after sludge application, because of its contribution to greater availability of macro and micro nutrients in the soil.

Table 3 Mean performance of plant height, ear length and width, stack diameter and grain yield of sorghum as influenced by different levels of brewery sludge and NP at Daker during 2013/2014 cropping season

Sludge levels (ton ha^{-1})	Plant height (cm)	Ear length (cm)	Ear width (cm)	Total biomass (kg ha^{-1})	Stalk diameter	Grain Yield (kg ha^{-1})
2.5	134.1^{ab}	18.2	14.0^{c}	2961.5^{cd}	0.8^{b}	2074.8^{c}
5	137.0^{ab}	18.4	14.9^{abc}	3596.2^{bc}	0.9^{ab}	2993.2^{b}
7.5	140.6^{a}	19.3	15.6^{abc}	4211.5^{b}	0.8^{b}	3078.2^{b}
10	138.0^{ab}	17.8	15.5^{abc}	4576.9^{b}	0.8^{ab}	3282.3^{b}
12.5	136.3^{ab}	18.5	16.5^{a}	4250.0^{b}	0.7^{b}	3129.3^{b}
15	138.4^{ab}	18.1	16.4^{ab}	6230.8^{a}	1.0^{a}	4081.6^{a}
NP	126.6^{b}	17.9	14.7^{bc}	2038.5^{d}	0.8^{b}	1768.7^{d}
0	110.8^{c}	18.6	13.9^{c}	942.3^{e}	0.5^{c}	858.8^{e}
LSD (0.05)	13.7	NS	1.7	1005.9	0.2	746.6
CV (%)	7.0	9.2	7.7	19.0	16.7	19.1

CV= Coefficient of **V**ariation, LSD= Least Significant Difference, NS= Not Significant, Means in columns of same parameter followed by the same letter(s) are not significantly different from each other at 5% level of significance.

Table 4 Accumulation of heavy metals in the soil after sorghum harvest

Sludge levels (ton ha^{-1})	Mean concentration of heavy metals in mg/kg soil									
	Zn	Fe	Cd	Ni	Mn	Co	Cu	Se	Mo	Cr
Soil boundary Values*	100	5000	3.0	50	2000	20	80	2.0	-	150
2.5	40.00	25.37	0.045	26.67	3.00	10.00	45.00	2.20	1.16	69.00
5	45.00	25.82	0.17	26.77	3.19	13.00	45.50	2.52	1.25	76.00
7.5	48.00	26.50	0.89	27.00	3.28	16.00	47.50	2.84	1.31	88.00
10	51.00	26.93	1.07	27.33	3.37	17.00	50.50	3.25	1.45	93.00
12.5	58.00	27.24	1.15	27.67	3.47	18.00	63.00	3.79	1.55	100.00
15	58.00	29.24	1.24	27.90	3.54	33.00	72.50	3.85	1.65	110.00
NP	14.50	25.50	0.05	19.33	2.28	9.00	42.50	2.15	1.08	25.00
0	35.00	25.02	0.042	19.00	2.27	9.50	42.50	2.12	1.00	20.00

* ECS (European Committee for Standardization, 2010), NP: NP-fertilizer (recommended)

Grain Yield and Total Biomass

Total grain yield of sorghum crop in the present study, was significantly affected (P<0.01) by the application of brewery sludge, where sludge at 15 t ha^{-1} treated plot gave the highest (4081.6 kg ha^{-1}) mean grain yield followed by the application of 10 t ha^{-1} brewery sludge which was statistically at par with the application of brewery sludge at (12.5, 7.5, 5 t ha^{-1}) (Table 3). When averaged across the application levels, sorghum grain yield showed a significant variation due to the brewery sludge application. In this regard, sludge treated plots produced 261.7 and 75.6% more grain yield than that of control and NP applied plots, respectively (Table 3). The low response to NP might have been due to the fact that part of the applied NP would not be available to the plants; rather it tends to be fixed by the soil and existing available nutrients reserve of the soil might be very low.

The result of analysis indicated a highly significant (P<0.01) total biomass yield variation among treatments (Table 7). Increasing waste sludge from 0 to 15 t ha^{-1} showed a consistent total biomass yield increment. The average total biomass yield for different levels of brewery sludge ranged from 6230.8 to 942.3 kg ha^{-1} (Table 3). With this line, increasing sludge from 2.5 to 15 t ha^{-1} showed a consistent total biomass yield increment ranging from 214 to 561% and 45 to 205% over control and NP fertilized plots, respectively.

The mean of separation for the treatments showed that a significant total biomass yield difference was observed between 2.5 and 15 t ha^{-1} brewery sludge application indicating that application of brewery sludge beyond 15 t ha^{-1} may significantly increase sorghum total biomass yield. Though a highly significant (P<0.01) total biomass yield difference was observed due to the application of brewery sludge, however no significant total biomass yield difference was observed between 5 and 12.5 t ha^{-1} brewery sludge application indicating that application of brewery sludge from 5 to 12.5 t ha^{-1} did not significantly increase sorghum total biomass yield (Table 3). In agreement with this study, Oudeh (2002) and AlZoubi et al. (2008) reported that increasing BS applications, increased crop productivity. Alike some studies have shown a high yield after BS application, because it's content of macro/ micro nutrients (Barriquelo et al., 2003; Arslan et al., 2007). Also, (Berti and Jacobs, 1996) reported sludge may be used in agriculture for increasing crops yield.

Accumulation of Heavy metals in the Soil after Sorghum Harvest

There was no effect of brewery sludge application on heavy metals (Zn, Fe, Cd, Ni, Mn, Co, Cu, Se, Mo and Cr) concentrations in soil after sorghum harvest in Daker site, compared to international standard tolerable limits (ECS, 2010) except for Co under 15 t ha^{-1} (33.00 mg kg^{-1})

treated soil and Se under all treatments. Zn level was found to be higher in sorghum plots after harvest where sludge was applied at 15 t ha^{-1} (58 mg kg^{-1}) which was equivalent with Zn in the plots treated with 12.5 t ha^{-1} (58 mg kg^{-1}) whereas the lowest (14.5 mg kg^{-1}) concentration was observed in NP fertilizer plots (Alloway, 2008). The concentrations of other metal ions in the soil also increased after the harvest of sorghum with each brewery sludge applied (Table 4). It is well documented that sewage sludge application to soils substantially increases nutrient content and crop growth (Smith, 1996) as well as improves soil physical properties. John et al. (2009) noticed accumulation of heavy metals in the treated crops were under allowable limits. On the contrary, Korboulewsky et al. (2002) noticed that heavy metals were increased above allowable limits in soil and plant by increasing sludge applications.

Nitrogen Concentration in Grain and Straw of Sorghum

Analysis of variance showed significant differences (P<0.01) among brewery sludge levels for grain and straw N contents (Table 7). The mean values for grain and straw N content due to brewery sludge levels were reported in Table 5. Increased brewery sludge level progressively from 2.5 to 10 t ha^{-1}, increased sorghum grain N content from 1.39 to 1.61%. Hence, application of 10 t ha^{-1} brewery sludge resulted in significantly higher grain N content, and gave 10.84 % higher grain N content than the control treatment and 164.59% than the application of maximum brewery sludge (15 t ha^{-1}) level.

The grain N content of control treatment (1.45%) and NP mineral fertilizer (1.36 %) had statistically in parity with a grain N content of 2.5 t ha^{-1} BS (1.39%) and 5 t ha^{-1} brewery sludge. The highest level of brewery sludge (15 t ha^{-1}) produced the minimum level of grain N (0.61%) while the l0 t ha^{-1} brewery sludge application gave the maximum grain N content (1.61%), implying a negative response to brewery sludge application with the further increase of sludge level to 15 t ha^{-1}. Plots, which received higher brewery sludge application, resulted in decreased or less percentage of grain nitrogen content, which might be due to the independence of grain protein content on lower brewery sludge level (Table 5).

In contract with this, the studies by (Syrian Standardization Commission, 2002; AlZoubi et al., 2008) shown an increase in grain and straw N content by increasing sludge addition over control, because of the high content of N in the sludge.

Table 5 Nitrogen concentration (%) of sorghum in grain and straw as influenced by brewery sludge levels and NP application at Daker during 2013/2014 cropping season.

Sludge levels (ton ha^{-1})	Mean concentration (%) of Nitrogen in Sorghum	
	Grain	Straw
2.5	1.39^{d}	0.589^{a}
5	1.46^{bcd}	0.56^{ab}
7.5	1.55^{ab}	0.54^{ab}
10	1.61^{a}	0.54^{ab}
12.5	1.54^{abc}	0.52^{ab}
15	0.61^{e}	0.58^{a}
NP-fertilizer	1.36^{d}	0.54^{ab}
Control	1.45^{cd}	0.43^{b}
LSD (0.05)	0.099	0.141
CV (%)	4.11	15.04

CV= coefficient of **v**ariation, LSD= least significant difference, Means in columns of same parameter followed by the same letter(s) are not significantly different from each other at 5% level of significance.

Table 6 Nitrogen uptake (kg ha^{-1}) of sorghum grain and straw as influenced by brewery sludge levels and NP application at Daker during 2013/2014 cropping season.

Sludge levels (kg ha^{-1})	Mean Nitrogen uptake (kg ha^{-1}) by Sorghum		
	Grain	Straw	Total
2.5	28.84^{b}	17.01^{bc}	45.85^{b}
5	43.58^{a}	22.29^{bc}	65.87^{ab}
7.5	47.68^{a}	24.47^{bc}	72.15^{a}
10	52.68^{a}	26.35^{bc}	79.03^{a}
12.5	48.19^{a}	28.00^{b}	76.19^{a}
15	24.76^{b}	44.25^{a}	69.01^{a}
NP-fertilizer	24.10^{bc}	15.17^{c}	39.27^{c}
Control	12.42^{c}	4.80^{d}	17.22^{c}
LSD (0.05)	13.14	9.05	22.21
CV (%)	5.38	12.06	8.32

CV= coefficient of **v**ariation, LSD= least significant difference, Means in columns of same parameter followed by the same letter(s) are not significantly different from each other at 5% level of significance.

Table 7 Mean square values of plant height, ear length, stack diameter, total biomass, grain yield, nitrogen content (%) of grain and straw, nitrogen uptake (kg ha^{-1}) by grain, straw and total of sorghum as influenced by brewery sludge and NP fertilizers at Daker

SV	Df	pH	EL	SD	EW	TB	GY	Nitrogen content of sorghum		Nitrogen uptake of sorghum		
								Grain	Straw	Grain	Straw	Total
R	3	1174.5378	10.890	0.0713	5.398	1.351	1322883.89	0.0005	0.0056	187.32	44.076	231.40
T	7	385.763*	0.896ns	0.091**	3.752*	17.944**	4168810.08**	0.3055**	0.00679ns	1672.50**	393.53**	2066.03**
E	21	86.293	2.865	0.0169	1.392	0.7907	257741.28	0.0031	0.0065	113.43	26.69	140.12
C		6.99	9.22	16.70	7.77	18.99	19.09	4.11	15.04	5.38	12.06	8.32

SV: Source of Variation, R: Rep, T: Treatment, E: Error, C: CV(%), pH: Plant height (cm), EL: Ear length (cm), SD: Stalk diameter, EW: Ear width (cm), TB: Total biomass, GY: Grain yield (kg ha-1), ** = significant at P≤0.01, *= significant at P≤0.05, ns= not significant, CV = coefficient of variation, df= degree of freedom.,

Grain, Straw and Total N Uptake by Sorghum

The data in (Table 6) revealed that the effects of brewery sludge levels on grain, straw and total N uptakes were significant. The N uptake of sorghum exhibited an increasing trend with the increase in brewery sludge levels up to 10 t ha^{-1} but with the further increases of brewery sludge level to 15 t ha^{-1}, N uptake of sorghum showed a decreasing trend (Table 6). The nitrogen uptake by sorghum grain, straw and the total was maximum (52.68, 44.25 and 79.03 kg ha^{-1}, respectively) with the application of BS at 10 and 15 t ha^{-1} which were significantly higher than the other brewery sludge and NP mineral fertilizer applications. The results also showed that the highest (52.68 kg ha^{-1}) nitrogen uptake by the grain in 10 t ha^{-1} brewery sludge was followed by 12.5 t ha^{-1}, which did not differ significantly with the application of 7.5 t ha^{-1}. At recommended rate of NP mineral fertilizer, the nitrogen uptake by grains was statistically at par with the application of BS at 15 and 2.5 t ha^{-1}. However, statistically lowest nitrogen uptake by the grain was recorded with the control treatment (Table 6).

On the other hand, the result also showed that the maximum (44.25 kg ha^{-1}) nitrogen uptake by straw at 15 t ha^{-1} brewery sludge as in case of grain, which was significantly higher than the other brewery sludge application effect. Further, no significant difference existed between 5 and 7.5 t ha^{-1} brewery sludge applications (Table 6). In the absence of brewery sludge and NP mineral fertilizer application, nitrogen uptake by straw showed a significant reduction over all other treatments, which had statistically in parity with each other's. Analogous to nitrogen uptake by sorghum grain and straw (Tables 6), the total nitrogen uptake by sorghum was also significantly high (79.03 kg ha^{-1}) at application of brewery sludge at 10 t ha^{-1} compared to other treatments. This was followed by the brewery sludge application at 12.5 t ha^{-1}, which did not differ significantly with the application of 7.5 t ha^{-1} brewery sludge. It has been reported sludge content from total N can be directly used by plant after mixing sludge with soil (Oudeh, 2002; K€ut€uk et al., 2003).

Conclusions

Yield components and yield of sorghum improved significantly with the application of brewery waste sludge at 15 ton ha^{-1} over control as well as BS and NP fertilizer. Therefore, amending the soil properties and improvements of sorghum production with application of brewery waste sludge at 15 ton ha^{-1} proved to be the optimum BS level. However, under the condition of sludge constraint, application of brewery sludge at 12.5 ton ha^{-1} should be used to improve soil fertility and preclude the yield loss and ensure maximum benefits. In future, there is a need to explore the effectiveness of these and various levels of brewery waste sludge for cost effective and improve soil fertility and yield productivity in major crops production across different areas.

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