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Research Paper

# The Application of Brewery Sludge for Maize Production

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## Abstract

In this study, brewery sludge was evaluated in comparison with the recommended NP mineral fertilizer rate to elucidate a potential source of nutrients for maize crop. Randomized complete block design (RCBD) was laid out in three blocks at the experimental site. Physicochemical properties of the experimental soil and brewery sludge (BS) were evaluated in the soil laboratory. The N content of the grain and straw samples were determined using the wet digestion method. Heavy metals (Fe, Cu, Zn, Mn, Cr, Mo, Co, Pb, Se, and Cd) were extracted by DTPA extraction method and measured by atomic absorption spectrophotometer. The application of a 15 t ha$^{-1}$ sludge rate showed the highest grain yield that exceeds the value recorded from NP-treated and control plots by 3.15 t ha$^{-1}$ and 4.42 t ha$^{-1}$, respectively. Similarly, the application of 12.5 t ha$^{-1}$ sludge rate significantly increased the total nitrogen uptake of the crop (grain and straw) by 146.13% and 223.16% over the NP and control plots, respectively. There was 93.23%, 57.14%, and 76.78% higher significant difference of total nitrogen, organic carbon, and available phosphorus (mg kg$^{-1}$) in BS than the composition found in experimental soil before the application of treatments, respectively. The application of sludge maintained most of the heavy metal concentrations to the level of safety for health following the recommended ranges by World Health Organizations (WHO). In conclusion, future long-term study is required to elucidate the effect of the sludge on soil biology, the chemical property of soil (pH and salinity), and pathogen contaminations on soil and crop production.

## 1. Introduction

The brewing industry is one of the largest agricultural-based industries that produce a vast amount of residues every year. Industrial waste is defined as an unwanted byproduct of industrial processes that includes mining and manufacturing activities. Currently, a world concern is to find alternative options for disposal of untreated agro-industrial wastes rather than disposing of them through burning, unplanned landfilling, or releasing to a water body (Okonko et al., 2009; Sadh et al., 2018). In the majority of developing countries like Ethiopia, agro-industry releases a tremendous amount of wastewater which is untreated, and its effluents are mostly released into water bodies and soils (Ermias Alayu and Seyoum Leta, 2020; Temesgen Oljira et al., 2017).

Disposal of industrial waste through landfilling is the primary causal agent for methane production which comes from the decomposition of organic matters in the anaerobic process (Bailey, 2019). In addition to this, methane is considered as very short-lived gas but can cause long-lasting climate impact than $CO_2$ in thousand folds for more than two decades period. There is no question that sustainable brewery sludge management has a significant potential to mitigate climate change.

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Currently, improper disposal of industrial waste, climate change, and unsustainable agricultural production are unsurpassable world problems (Mbow et al., 2017; Kumar et al., 2017).

The residues of agro-industries that are disposed of spontaneously to the soil and water body have adverse effects on organisms and the environment (Sadh et al., 2018). Brewery sludge, as with any organic matter, improves soil fertility and can be used as an alternative way of reducing the cost of crop production. Nowadays, the accumulations of heavy metals in the terrestrial ecosystem are changing the chemical properties and composition of the soil, which can cause a significant loss in the agricultural sector (Satashiya, 2017).

Ermias Alayu et al. (2018) conducted a field trial in Amhara Regional State, the northern part of Ethiopia during the 2017 main cropping season on the farmers' field under the normal rain-fed condition to evaluate the effects of BS and mineral fertilizer on maize production. Results revealed that the addition of the sludge led to significant changes in soil pH reduction and soil electrical conductivity, total phosphorus, total nitrogen, and total potassium increment as compared to others and background concentration. Hence, rather than improperly dumping industrial waste, the recycling of brewery sludge has many advantages; reduce greenhouse gases, control groundwater pollution, and protect humans from health hazards. Furthermore, the utilization of industrial waste for crop production as input is environmentally safe, economically low cost and provides high essential elements for plant growth and development.

Maize can be consumed raw and in processed form by human beings and animals in addition to their advantages as raw materials in making beverages, ethanol, and starch in industries (Ranum et al., 2014). Soils are the heart of terrestrial ecosystems that help non-living things and living organisms to function as a source of the necessities for life.

This paper evaluated and answered two questions: 1) Can the reuse of brewery sludge be an alternative option that may replace mineral fertilizer in maize production? 2) Is the application of BS to agricultural soil ecofriendly to reduce environmental pollution?

## 2. Materials and Methods

### 2.1. Description of the Brewing Industry

The brewery sludge was collected from Harar brewing industry located at Harari city, Eastern Ethiopia. The industry was established in 1984 and it produces both alcoholic (Harar Beer and *Hakim Stout* Beer) and non-alcoholic (*Sofi* Beer) beverages.

### 2.2. Description of the Experimental Site

The collected brewery sludge in solid form was analyzed to evaluate their physicochemical properties at Haramaya University soil laboratory, Ethiopia. Farmer's field located in proximity to the brewing industry (Sofi district) was used as an experimental farm during 2013/2014 under the rained condition to assess the effects of sludge on maize growth attributes and grain yield. The area is geographically located between latitude 09° 18′ 43″ N and longitude 42° 07′ 23″ E. It represents a medium altitude and moderate rainfall (850 mm/annum).

### 2.3. Treatments, Experimental Design, and Procedures

In this study, seven rates of brewery sludge's (0.0; 2.5; 5.0; 7.5; 10.0; 12.5 and 15.0 t $ha^{-1}$) and a recommended rate of NP mineral (92 kg N $ha^{-1}$ and P 92 kg $P_2O_5$ $ha^{-1}$) were used to evaluate their cost-benefit in maize crop production. Improved maize variety, BH-661, was used as an experimental crop at the spacing of 70 cm between rows and 25 cm between plants at the depth 7-10 cm. Field plots (5 m × 6 m) were used for BS, commercial fertilizer (i.e., NP), and control treatments for the study purpose with 100 cm paths separating between blocks. Randomized complete block design with three blocks was used to carry out this field experiment.

The recommended doses of each brewery sludge were applied on experimental plots fourteen days in advance to crop seed sowing, while NP fertilizer was applied according to the recommended time and method by HURC (1996). Brewery sludge can be incorporated into the soil before sowing any crop. BS is a slow-release organic fertilizer that can provide macro and micronutrients to crops. Incorporating BS before planting the maize crop can benefit the plant because the brewery sludge may provide necessary nutrients to microorganisms that fix nitrogen from the air and increase the nutrient availability in the soil.

Additionally, the physicochemical properties of experimental soil were also analyzed to elucidate the change that occurred after the application of brewery sludge rates.

## 2.4. Physicochemical Data Collections and Experimental Procedures

Soil samples were collected from all experimental plots and selected soil chemical parameters were analyzed in Haramaya University soil chemistry and central laboratories. The pH of the soils suspension in a 1:2.5 (soil: liquid ratio) was measured potentiometrically using a glass-calomel combination electrode (Van Reeuwijk, 1992). The Walkley and Black (1934) wet digestion method was used to determine soil carbon content. Total N was analyzed using the Kjeldahl digestion, distillation, and titration method as described by Black (1965) by oxidizing the organic matter in concentrated sulfuric acid solution (0.1N $H_2SO_4$). Since the pH of the soil in the study area ranges from 8.49 to 8.67, available P of soils and brewery sludge was analyzed according to the standard procedure of Olsen et al. (1954).

Extractable heavy metals (Fe, Cu, Zn, Mn, Cr, Mo, Co, Pb, Se, and Cd) were extracted by diethylene triamine pentaacetic acid (DTPA) extraction method of Lindsay and Norvell (1978) and all these heavy metals were measured by atomic absorption spectrophotometer. Extractions were performed with three replications. Metals recovered at each extraction were separately analyzed and the cumulative metal recovery and cumulative volume of extractants used for the extractions were recorded.

The DTPA extracting solution was prepared to contain 0.005M DTPA, O.OIM $CaCl_2$, 0.1M TEA (triethanolamine), adjusted to pH 7.30, and shaken for 2 hours. To prepare 10 liters of the solution, 149.2 g of reagent grade $(HOCH_2CH_2)_3N$ (TEA), 19.67 g of diethylene triaminepenta acetic acid (DTPA), and 14.7 g of $CaCl_2$-$2H_2O$ were dissolved in approximately 200 ml of distilled water. Thereafter, sufficient time was allowed for the DTPA to be dissolved and diluted to approximately 9 liters. It was then adjusted to 7.30 ± 0.05 pH and 1N HC1 while stirring and diluting to 10 liters. This solution is stable for several months. Another commonly designated name and formula for DTPA is [(carboxymethyl) imino] bis (ethylenenitrilo) tetraacetic acid with the formula $[(HOCOCH_2)2NCH_2]$ $2NCH_2COOH$ with a formula weight of 393.35. Extracting Procedure Ten grams of air-dried soil was placed in a 125-ml conical flask, and 20 ml of the DTPA extracting solution was added. Each flask was covered with stretchable Parafilm and secured upright on a horizontal shaker with a stroke of 8.0 cm with a speed of 120 cycle $min^{-1}$. After 2 hr of shaking, the suspensions were filtered by gravity through Whatman no. 42 filter paper. The filtrates were analyzed for Fe, Cu, Zn, Mn, Cr, Mo, Co, Pb, Se, and Cd using atomic absorption spectrophotometry and appropriate standards.

The 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 1. Physicochemical properties of soil and brewery waste were evaluated in the soil laboratory.

## 2.5. Agronomic Data Collections and Procedures

A total of ten plants per experimental plot were randomly selected from the inner rows and were tagged, from which data on plant height (cm), ear length (cm), ear width (cm), and thousand kernels weight (g) were recorded based on their recommended procedures by HURC (1996). The grain yield (t $ha^{-1}$) and total cobs weight (kg $plot^{-1}$) were calculated using the relevant procedures.

The grain yield (air-dried) was computed in t $ha^{-1}$ based on the total population of plants (32,000) per hectare using the relevant variables.

$$GYha = Y_p \times Pha$$

Where, GYha = grain yield per hectare, *Y*p = average grain yield per plant, and *P*ha = plant population per hectare.

Plant samples collected at harvest were partitioned into vegetative and grain form for the determination of N content in grain and straw. The straw and grain samples were ground and sieved through a 0.5mm 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.

In the recent past, concentration is used in place of Nitrogen content as it is preferred to nitrogen concentration. The nutrient concentration multiplied with dry matter $100^{-1}$ gives uptake either in grain or straw. Dry matter is expressed in tonnes or kgs ha$^{-1}$. For calculating uptake, it is convenient to express a dry matter of grain or straw in kg ha$^{-1}$. So the formula used to calculate the uptake of the nutrient is:

N% in grain or straw*dry matter of grain or straw in kg ha$^{-1}$ ÷100 = uptake in kg ha$^{-1}$ in grain or straw (Rao, 2015).

If % N in the grain is 1% and %N in straw is 0.2%, grain yield is 5000kg ha$^{-1}$ and straw yield is 6000kg ha$^{-1}$ then uptake in grain and straw is:

$1\times5000\div100=50$kg ha$^{-1}$ N in grain

$0.2\times6000\div100=12$kg ha$^{-1}$ N in straw

### 2.6. Data Analysis

The data were subjected to analysis of variance (ANOVA) as applicable to RCBD in factorial arrangements for each location using the general linear model of Genstat 16th edition updated version. Treatment means that were significantly different were separated using the Tukey test at a 5% level of significance.

## 3. Results and Discussions

### 3.1. Physicochemical Data

### 3.1.1. Physicochemical characteristics of BS and background soil samples before application of treatments

The analysis of physicochemical characteristics of experimental soil (background soil samples) and BS before application of treatments revealed that the pH values obtained from the BS and background soil were 8.67 and 8.55, respectively. This indicated that the brewery sludge used for field experiments had a 1.38% increase over the pH result obtained from background soil (Table 1). The value is in the range of slightly alkaline. This result is In contrast to Ajmal and Khan (1984) who carried out field trials and reported that the effluent was found to be acidic, and had high biological oxygen demand (BOD) and chemical oxygen demand (COD) due to the presence of large amounts of solids. Moreover, these authors claimed that the effluent was rich in ammonia-nitrogen, nitrate-nitrogen, phosphorus, and potassium so that its application to the soil increased the values of available nutrients in the soil.

The comparison of background soil and BS indicated that the potential nutrient content was available in sludge that was added to agricultural soil for crop production. Similarly, the analysis of brewery sludge quality showed that the sludge had a high content of total nitrogen, organic carbon, total phosphorus; slightly high pH level, and high heavy metals (Zn, Fe, Ni, Co, Cu, and Se) (Table 1). However, the levels of these heavy metals did not exceed that is considered a safe level for health as per World Health Organization (WHO) standard (Table 1). However, the biological impact on soil microorganisms needs to be studied for sustainable use of the brewery sludge (Alayu et al., 2018).

**Table 1**: Physicochemical characteristics of experimental soil (background soil samples) and BS before the application of treatments.

| Parameters | Background soil samples | BS | Difference in percentage |
|---|---|---|---|
| pH | 8.55 | 8.67 | 1.38 |
| Total N, % | 0.09 | 1.33 | 93.23 |
| Organic Carbon, % | 1.50 | 3.50 | 57.14 |
| Available P, mg kg$^{-1}$ | 9.23 | 39.75 | 76.78 |
| Zn (mg kg$^{-1}$ soil) | 7.50 | 28.50 | 73.68 |
| Fe (mg kg$^{-1}$ soil) | 23.39 | 20.50 | -12.36 |
| Cd (mg kg$^{-1}$ soil) | 1.31 | 1.27 | -3.05 |
| Ni (mg kg$^{-1}$ soil) | 9.67 | 31.33 | 69.14 |
| Mn (mg kg$^{-1}$ soil) | 3.61 | 0.83 | -77.01 |
| Co (mg kg$^{-1}$ soil) | 18.00 | 33.00 | 45.45 |
| Cu (mg kg$^{-1}$ soil) | 2.50 | 20.00 | 87.50 |
| Se (mg kg$^{-1}$ soil) | 11.94 | 12.56 | 4.94 |
| Mo (mg kg$^{-1}$ soil) | 1.00 | 0.45 | -55.00 |
| Cr (mg kg$^{-1}$ soil) | 1.63 | 0.47 | -71.17 |

The high content of nutrients and other chemical properties like pH of brewery sludge indicate that its application to the soil can improve the organic matter and soil fertility of the production area. This indicates that mineral fertilizer can be substituted by brewery sludge for their positive effect of risk-free heavy metals level, low cost in comparison with mineral fertilizers (Bulti Merga et al., 2020), and keep our environment clean area.

### 3.1.2. Heavy Metal Accumulation in the Soil after Maize Crop Harvest

Zinc (Zn), cadmium (Cd), nickel (Ni), copper (Cu), and chromium (Cr) of treated sludges were laid within the allowed soil health boundaries. Data in various rates of brewery sludge application were compared with the maximum permissible concentration of potentially toxic elements (PTE) derived from the European Union Code of Practice (EUCP) (EC, 2001).

These values have been produced to protect food quality and the environment (Lester & Edge, 2001). Comparatively, the highest concentration for Zn was observed under application of brewery sludge at 5 t ha$^{-1}$ (17.5 mg kg$^{-1)}$ compared to the application of 15 t ha$^{-1}$ (11.5 mg kg$^{-1}$), 12.5 t ha$^{-1}$ (17 mg kg$^{-1}$), 10 t ha$^{-1}$ (15 mg kg$^{-1}$), 7.5 t ha$^{-1}$ (5 mg kg$^{-1}$) and NP (14 mg kg$^{-1}$) which all were below the international standard tolerant limit (Table 2). The BSs are dynamic in characteristics which vary widely by original waste composition and solid waste treatment courses, along with sludge treatment processes; hence, sludge may contain additional toxic substances that cause harmful effects to soil microbial activities through the transfer of antibiotics in the soil environment (Chen et al., 2016) and humans through transmission in the food chain (Arthurson, 2008) when they are applied for agricultural uses. Therefore, the characterization of the BS quality is vital to conclude on its viability for recycling it for agricultural application to promote waste resource utilization besides environmental protection.

**Table 2**: Heavy metal accumulation in the soil after maize crop harvest.

| Treatments | Mean concentration of heavy metals in mg kg$^{-1}$ soil | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Zn | Fe | Cd | Ni | Mn | Co | Cu | Se | Mo | Cr |
| Soil boundary Values (EU) | 100 | - | 3 | 50 | - | 20 | 80 | 2.0 | - | 150 |
| Sludge boundary Values (EU) | 2500 | - | 30 | 300 | - | - | 1000 | - | - | 1000 |
| **Background soil** | **7.5** | **23.39** | **1.31** | **9.67** | **3.61** | **18** | **2.5** | **11.94** | **1** | **1.63** |
| 2.5* | 7.00 | 25.79 | 1.14 | 28.33 | 3.99 | 25.00 | 7.00 | 13.06 | 0.91 | 1.63 |
| Change (%) | -6.67 | 9.31 | -12.98 | 65.87 | 9.52 | 28 | 64.29 | 8.58 | -9.00 | 0.00 |
| 5* | 17.50 | 25.58 | 1.25 | 8.67 | 3.77 | 8.00 | 3.50 | 12.19 | 0.73 | 1.44 |
| Change (%) | 57.14 | 8.56 | -4.58 | -10.34 | 4.24 | -55.56 | 28.57 | 2.05 | -27 | -11.66 |
| 7.5* | 5.00 | 25.66 | 1.28 | 15.00 | 4.22 | 30.00 | 5.50 | 13.12 | 0.27 | 1.25 |
| Change (%) | -33.33 | 8.85 | -2.29 | 35.53 | 14.45 | 40.00 | 54.55 | 8.99 | -73.00 | 23.31 |
| 10* | 15.00 | 25.55 | 1.02 | 30.33 | 3.93 | 36.00 | 6.00 | 12.31 | 0.73 | 1.34 |
| Change (%) | 50.00 | 8.45 | -22.14 | 68.12 | 8.14 | 50 | 58.33 | 3.01 | -27.00 | -17.79 |
| 12.5* | 17.00 | 25.29 | 1.08 | 28.67 | 3.09 | 34.00 | 4.50 | 12.25 | 0.45 | 0.72 |
| Change (%) | 55.88 | 7.51 | -17.56 | 66.27 | -14.40 | 47.06 | 44.44 | 2.53 | -55.00 | -55.83 |
| 15* | 11.50 | 25.89 | 1.18 | 17.00 | 4.28 | 32.00 | 9.00 | 13.25 | 1.36 | 1.13 |
| Change (%) | 34.78 | 9.66 | -9.92 | 43.12 | 15.65 | 43.75 | 72.22 | 9.89 | 26.47 | -30.67 |
| NP-fertilizer* | 14.00 | 25.39 | 1.25 | 22.33 | 3.93 | 32.00 | 4.50 | 13.37 | 1.82 | 0.34 |
| Change (%) | 46.43 | 7.88 | -4.58 | 56.70 | 8.14 | 43.75 | 44.44 | 10.70 | 45.05 | -79.14 |
| 0** | 13.50 | 25.84 | 0.83 | 18.33 | 3.69 | 11.00 | 4.00 | 12.69 | 1.55 | 0.66 |
| Change (%) | 44.44 | 9.48 | -36.64 | 47.24 | 2.17 | -38.89 | 37.5 | 5.91 | 35.48 | -59.51 |

EU = European Union standard, 2001; * = after application of brewery sludge; ** = without application of brewery sludge, and change (%) = the change in percentage for heavy metal accumulation in the soil before and after application of BS.

Similarly, the soil that was treated with brewery sludge at the rate of 10 t ha$^{-1}$ was found to contain the highest accumulation cobalt (Co) concentration of (36 mg kg$^{-1}$). Furthermore, the application of brewery sludge at the rate of 12.5 t ha$^{-1}$ accumulated cobalt (Co) concentration of 34 mg kg$^{-1}$ in crop soil that exceeded the maximum tolerable values. The accumulated cobalt in the soil after the crop harvest was due to the application of various rates of brewery sludge that were higher than the permitted soil boundary values adopted from European Union Standard (EU), except for the plots that received 0 t ha$^{-1}$ and 5 t ha$^{-1}$ t. This is because of the dynamic characteristics of the brewery sludge (Chen et al., 2016).

In comparison with the amount of cobalt that was available before brewery sludge application, the use of brewery sludge increased the level of heavy metal in soil by the range of 28 to 50% after maize crop harvest. This revealed the proportional increase of cobalt, heavy metal, accumulation in the grain of maize.

Although varied, the concentrations of all other elements especially Zn (5-17.5 mg kg$^{-1}$); Ni (8.67-30.33 mg kg$^{-1}$), and Cu (3.5-9 mg kg$^{-1}$) were below the maximum tolerable limits of 100, 50, and 80 mg kg$^{-1}$, respectively (Table 2). In this study, it was observed that the concentrations of Co and Se and all the heavy metal ions investigated exceeded the background tolerable limits; yet the concentrations of each element varied with each treatment. The result obtained from the plots that were treated with zero brewery sludge rate (control treatment) was also higher than the maximum tolerable value in context to selenium (Se). This indicated that the concentration of this element was already high in the soil of the study area. Moreover, there was no proportional increase of heavy metals with the increasing levels of BS rates.

## 3.2. Yield and Yield Components of Maize

### 3.2.1. Growth Performance

Plant height was measured at 50% physiological maturity. The analysis of variance revealed a statistically significant ($P<0.05$) difference in plant height due to levels of sludge applications. Increasing brewery sludge application (BS) from 0 to 15 t ha$^{-1}$ increased plant height consistently. The Maize plant height significantly increased with the application of BWSS as compared to NP mineral fertilizer. The calculated differences between BS treatment with the control treatment and recommended NP fertilizer rate ranged from 66 to 89% and 13 to 28%, respectively (Table 3).

The increase of plant height could be due to the increased plant cell elongation and division that occurred from the availability of essential nutrients by the applied BS. Plants must obtain the following mineral nutrients from their growing medium:- the macronutrients: nitrogen (N), phosphorus (P), potassium (K), calcium (Ca), sulfur (S), magnesium (Mg), carbon (C), oxygen (O), hydrogen (H); the micronutrients (or trace minerals): iron (Fe), boron (B), chlorine (Cl), manganese (Mn), zinc (Zn), copper (Cu), molybdenum (Mo), nickel (Ni) (Allen et al., 2007).

The essential nutrients investigated in this research is not only nitrogen (N) and phosphorus (P) because the following nutrients also included: the essential micronutrients (or trace minerals): iron (Fe), manganese (Mn), zinc (Zn), copper (Cu), molybdenum (Mo), and nickel (Ni). Similarly, Szymanska et al. (2016) reported that there was a trend of an increase in the height of maize plants, with the application of sewage sludge when compared to control treatment. Outhman and Firdous (2016) also reported the significant effect of sewage sludge on plant height of wheat and barley crop at 40, 80, and 120 days after sowing.

The results of maize growth attributes, ear length and ear width (Table 3), revealed that the highest corn ear length (14.63 cm) was obtained in experimental plots that received sludge at a rate of 10 t ha$^{-1}$ while the highest corn ear width (13.57 cm) recorded in the plots treated with lowest BS rate (2.5 t ha$^{-1}$).

In the corn ear width parameter, the statistical analysis revealed that the experimental plots to which BS was applied at the rate of 2.5 t ha$^{-1}$ were 8.11 and 15.62% higher than the NP fertilizer and control treatments, respectively. However, the highest corn ear height was recorded in the treatment that received 10 t ha-1 BS that exceeded NP fertilizer and control treatments by 13.53 and 27.00%, respectively. The higher yield attributes were recorded in the treatments that received sludge than both recommended NP mineral fertilizer and control treatment.

The statistical analysis of corn ear length and ear width of maize plants revealed a non-significant difference in all levels of brewery sludge. But all levels

**Table 3**: The effect of different rates of Brewery sludge application on growth attributes and grain yields of maize.

| Treatments | Plant height (cm) | Total cobs weight (kg plot$^{-1)}$ | Ear width (cm) | Ear length (cm) | Thousand kernels weight (g) | Grain yield (t ha$^{-1}$) |
|---|---|---|---|---|---|---|
| 2.5 | 137.8$^{c}$ | 0.98$^{c}$ | 13.57$^{a}$ | 13.63$^{ab}$ | 30.18$^{ab}$ | 3.16$^{c}$ |
| 5 | 145.22$^{bc}$ | 1.28$^{bc}$ | 12.77$^{ab}$ | 14.28$^{ab}$ | 31.25$^{ab}$ | 4.13$^{bc}$ |
| 7.5 | 147.80$^{b}$ | 1.315$^{b}$ | 12.92$^{ab}$ | 13.58$^{ab}$ | 30.28$^{ab}$ | 4.31$^{bc}$ |
| 10 | 151.97$^{ab}$ | 1.555$^{ab}$ | 13.32$^{ab}$ | 14.63$^{a}$ | 32.18$^{a}$ | 4.35$^{b}$ |
| 12.5 | 150.72$^{ab}$ | 1.492$^{ab}$ | 13.25$^{ab}$ | 13.73$^{ab}$ | 31.10$^{ab}$ | 4.37$^{b}$ |
| 15 | 156.92$^{a}$ | 1.610$^{a}$ | 13.05$^{ab}$ | 14.53$^{ab}$ | 31.43$^{ab}$ | 5.19$^{a}$ |
| NP fertilizer | 121.72$^{d}$ | 0.610$^{d}$ | 12.47$^{b}$ | 12.65$^{b}$ | 26.80$^{b}$ | 2.04$^{d}$ |
| 0 | 82.90$^{e}$ | 0.280$^{e}$ | 11.45$^{c}$ | 10.68$^{c}$ | 22.58$^{c}$ | 0.77$^{e}$ |
| LSD (0.05) | 10.08 | 0.222 | 0.81 | 1.50 | 3.51 | 0.82 |
| CV (%) | 5.01 | 13.25 | 4.33 | 7.60 | 8.10 | 15.71 |

of BS showed a significant difference when compared with NP fertilizer and control treatments on corn ear length and ear width of maize food crop. The statistical analysis revealed the improvement of maize plant growth attributes with sludge applications to crop soil.

The result of the analysis indicated a highly significant ($P<0.01$) difference in total cobs weight per plot. The mean separation showed that the highest cobs weight (1.61 kg plot$^{-1}$) was obtained from the highest brewery sludge (15 t ha$^{-1}$) rate (Table 3). Similarly, the application of 10 t ha$^{-1}$ brewery sludge rate to crop soil revealed 1.55 kg plot$^{-1}$ maize cobs weight, and plots treated with zero BS rate (control treatment) was produced the lowest yield attribute value (0.28 kg plot$^{-1}$).

### 3.2.2. Grain Yield and Thousand Kernels Weight

The effects of brewery sludge (BS) under the rainfed condition on grain yield and thousand kernels weight of maize was measured and revealed statistically significant difference when compared with NP mineral fertilizers recommended for crop production. Results of the experiment showed that the average maize grain yield for the application of different levels of sludge from 2.5 to 15 t ha$^{-1}$ increased maize grain yield by 309% to 572% and 55% to 154% over the NP fertilizer and control treatments, respectively (Table 3). The statistical analysis of the results revealed the superiority of brewery sludge on maize grain yield at all rates (Table 3). The highest grain yield (5.19 t ha$^{-1}$) was obtained from plots that received a 15 t ha$^{-1}$ brewery sludge rate. The least maize grain yield (0.77 t ha$^{-1}$) was recorded from plots that received zero brewery sludge rate (control treatment). The results for the sludge application indicated the existence of an opportunity for increasing maize grain yield through the application of brewery sludge beyond 15 t ha$^{-1}$. Similarly, the result obtained from brewery sludge analysis indicated that the application of 0.96 t ha$^{-1}$ BS exceeds the plots that received NPS fertilizer and control treatment by 12.59% and 26.8% of maize grain yield, respectively at the northern part of Ethiopia (Alayu and Leta, 2020). This is because of the richness of sludge with organic matter, total nitrogen and total phosphorus content, optimal pH, and salinity level including other secondary nutrients ($Ca^{2+}$, $Mg^{2+}$, $Na^{+}$, and $K^{+}$) than that of NPS and control treatments. The higher availability of essential nutrient elements from the applied sludge at the proper application might have contributed to this difference. The low yield in NP fertilized and control plots might have been due to reduced leaf area development resulting in lesser radiation interception and, consequently, low efficiency in the conversion of solar radiation.

Application of sludge from 2.5 to 15 t ha$^{-1}$ levels showed 1000 kernels weight increment from 12.6% to 20% and 33.6 to 42.5% over the recommended rate of NP mineral fertilizer and control treatment, respectively (Table 3). The mean separation for the treatments revealed that no significant thousand-kernel weight difference was observed between 2.5 to 15 t ha$^{-1}$ sludge applications. This indicated that the application of sludge beyond 2.5 t ha$^{-1}$ did not significantly increase the thousand-kernel weight of maize. The highest significant value of thousand kernels weight (32.18 g) was noted from crop soil that received BS 10 t ha$^{-1}$ rate while the least result (22.58 g) was recorded in zero BS rate (control treatment).

### 3.2.3. Nitrogen Concentration in Grain and Straw of Maize

The concentration of N in corn grain was significantly ($P \leq 0.05$) influenced by brewery sludge rates, while the concentration of N in the straw of maize revealed non-significant ($P \geq 0.05$) influences. The highest (1.44%) N concentration in corn grain was recorded from the application of brewery sludge at 12.5 t ha$^{-1}$ rate, followed by 10 and 7.5 t ha$^{-1}$ which revealed similar results with the application of brewery sludge at 15 t ha$^{-1}$ rate. This was significantly higher than the application of brewery sludge at 2.5 t ha$^{-1}$ rate, recommended rate of NP mineral fertilizer, and control treatments. Further, the result of this study depicted non-significant differences among other brewery sludge rates (5; 7.5; 10; 12.5 and 15 t ha$^{-1}$) (Table 4).

**Table 4**: Nitrogen concentration percentage (%) in grain and straw of maize.

| Treatments | Mean concentration of nitrogen in % grain | Mean concentration of nitrogen in % straw |
|---|---|---|
| 2.5 | 1.21 | 0.56 |
| 5 | 1.32 | 0.60 |
| 7.5 | 1.33 | 1.38 |
| 10 | 1.40 | 0.54 |
| 12.5 | 1.44 | 0.63 |
| 15 | 1.33 | 0.56 |
| NP-fertilizer | 1.29 | 0.56 |
| Control | 1.15 | 0.58 |
| LSD (0.05) | 0.18 | 0.91 |
| CV (%) | 7.71 | 77 |

LSD (5%) = Least significant difference at p = 0.05, CV (%) = Coefficient of variation, BS= Brewery sludge, and NP= recommended nitrogen and phosphorus rate.

### 3.2.4. Total N uptake by maize grain and straw

Analysis of variance showed significant differences ($P < 0.05$) among brewery sludge treatments for grain N uptake, straw N uptake, and total N uptake of maize. Increasing brewery sludge rates up to 15 t ha$^{-1}$ also raised corn grain N uptake (68.82 kg ha$^{-1}$) and the lowest N uptake (8.86 kg ha$^{-1}$) value was recorded from the control treatment (Table 5). Application of 12.5 and 15 t ha$^{-1}$ brewery sludge resulted in 609 and 676% more grain N uptake than the control treatment, respectively.

The applications of NP mineral fertilizer to crop soil revealed significantly the least corn grain N uptake than all other brewery sludge rates used in this study (Table 5). The nutrient content of brewery sludge is better than NP mineral fertilizer. Hence, the sludge can substitute other mineral fertilizers and used for soil fertility improvement and higher grain yield production. Similarly, maize straw N uptake exhibited an increasing trend with increased brewery sludge rate up to 12.5 t ha$^{-1}$, a further increase in brewery sludge rates revealed a decreasing trend. Mean straw N uptake from the control treatment to the highest brewery sludge rate (15 t ha$^{-1}$) ranged between 46.67 to 116.67 kg ha$^{-1}$ (Table 5). The applications of NP mineral fertilizer recommended rate to cropped soil had significant effects on maize straw N uptake. The highest (179.45 kg ha$^{-1}$) and the lowest (55.53 kg ha$^{-1}$) total N uptake values were obtained from the application of 12.5 t ha$^{-1}$ brewery sludge rate and the control treatments, respectively. There was a trend of linear increment of total N uptake as brewery sludge rate increased from the control treatment to the 12.5 t ha$^{-1}$ rate. The highest brewery sludge rate (15 t ha$^{-1}$) resulted in 223% more total N uptake than the control treatment. About 179.45 kg ha$^{-1}$ total nitrogen uptake was obtained in the application of 12.5 t ha$^{-1}$ BS rate; from the use of the recommended NP mineral fertilizer rate, this was fallen to 72.91 kg ha$^{-1}$.

From the evidence of economic analysis report under the same project with this study, partial budget and marginal rate of return analysis for maize production revealed the highest marginal rate of return (44.68%) from the application of 2.5 t ha$^{-1}$ BS rate. However, the MRR (21. 52%) from the application of 15 t ha$^{-1}$ BS that was lower than the minimum MRR recommendation (100%) (CIMMYT, 1988). The application of 5 t ha$^{-1}$ BS that revealed the net benefit of 609.64 USD and marginal rate of return of 15.89 USD can be used by smallholder farmers that produce maize (Bulti Merga et al., 2020).

**Table 5**: Nitrogen uptake (kg ha$^{-1}$) of maize grain and straw.

| Treatments | Mean Nitrogen uptake by grain (kg ha$^{-1}$) | Mean Nitrogen uptake by straw (kg ha$^{-1}$) | Total N uptake (kg ha$^{-1}$) |
|---|---|---|---|
| 2.5 | 38.33 | 46.67 | 85.00 |
| 5 | 54.41 | 46.67 | 101.08 |
| 7.5 | 57.49 | 46.67 | 104.16 |
| 10 | 60.95 | 48.22 | 109.17 |
| 12.5 | 62.78 | 116.67 | 179.45 |
| 15 | 68.82 | 52.89 | 121.71 |
| NP fertilizer | 26.24 | 46.67 | 72.91 |
| Control | 8.86 | 46.67 | 55.53 |
| LSD (0.05) | 19.54 | 75.10 | 80.24 |
| CV (5 %) | 6.74 | 22.00 | 13.02 |

LSD (5%) = Least significant difference at p = 0.05, CV (%) = Coefficient of variation, BS= Brewery sludge, and NP= recommended nitrogen and phosphorus rate.

## 4. Conclusion

Managing industrial waste is one of the ways to protect our environment from harmful pollutants. As such, manufacturers and companies might be held responsible for the waste they generate. The result of the comparison of the different rates of brewery sludge to recommended NP fertilizer and control (zero application) was found to be promising in reducing environmental pollution because of the negative effects of brewery sludge disposal. The result indicated that between 2.5 to 15 t ha$^{-1}$ brewery sludge rates, maize grain yield increased by 309 to 572% when it was compared with NP mineral fertilizer treatment but this result was fallen to 55 to 154% with control treatment. There was a proportional increase in brewery sludge rate and corn grain yield from least to the highest value. Furthermore, the study revealed that the highest concentration of cobalt (36 mg kg$^{-1}$) was recorded from the soil that received 10 t ha$^{-1}$ brewery sludge treatment. However, this result was statistically non-significant with other treatments that were above tolerable values. The application of 12.5 t ha$^{-1}$ brewery sludge rate to crop soil revealed the highest total N uptake value (179.45 kg ha$^{-1}$), but this value was fallen to the least (55.53 kg ha$^{-1}$) in soils treated with zero brewery sludge. The physicochemical analysis of brewery sludge that was collected from the brewing industry showed 3.5% organic carbon, 1.33% total N, and 39.75 mg kg$^{-1}$ available phosphorus. These components supplemented crop soils to increase their ability in the sustainable release of essential nutrients for maize plants. Maize grain yield was high with the soil crop that was treated with brewery sludge. This indicated that brewery sludge has the potential of releasing nutrients slowly when applied to agricultural soil that can increase the ability of soil for the sustainable provision of nutrients to plants. The slow release of nutrients prevents leaching of excess plant-available nutrients and possible contamination of ground and surface water.

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