



Brewery sludge application rate and type influence maize (*Zea mays* L.) yield and soil chemical properties on acidic Nitisols of southwestern

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Abstract	Article Information
<i>A nutrient-rich organic byproduct, brewery sludge, may offset growing fertilizer costs and industrial waste management. This study examined the impact of brewery sludge application rates (0-12 t ha⁻¹) and type (with or without kieselguhr) on maize (<i>Zea mays</i> L.) growth, yield, and soil parameters. A RBCD field experiment with three replications compared the effects of sludge treatments, including a control and recommended NPS fertilizer, on maize production. The study found that applying brewery sludge significantly ($p < 0.05$) affected crop phenology, growth metrics, yield components, and yields. The application of 12 t ha⁻¹ of sludge with kieselguhr resulted in a 151% increase in green cob production (31,008 kg ha⁻¹) compared to the control (12,294 kg ha⁻¹) and an 8.8% increase over the recommended NPS (29,464 kg ha⁻¹). Kieselguhr-containing sludge consistently outperformed its non-kieselguhr counterpart in yield. Finally, sludge enhanced pH (5.45 to 5.58), organic carbon (4.34% to 4.98%), and accessible phosphorus in post-harvest soil. Application of 12 t ha⁻¹ of brewery sludge is recommended as an alternative to organic fertilizer in the study region and related agro-ecological zones, since it addresses waste management and soil fertility constraints.</i>	Article History: Received: 07-04-2026 Revised: 13-08-2026 Accepted: 28-09-2026
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INTRODUCTION

Global fertilizer production is struggling to move at the same speed as the demands of an increasing population and agricultural intensification (Sinha et al., 2022). Interest in sustainable substitutes like brewery sludge has increased because of the rising

expense and negative environmental effects of chemical fertilizers (Tsadik et al., 2020).

The rapidly expanding agro-industries in Ethiopia, especially the brewing sector, produce large amounts of organic waste such as hot trub,

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spent grain, yeast cells, and sludge (Kanagachandran & Jayaratne, 2006). Since the waste is not disposed of properly, environmental damage occurs, for example, in the form of methane emissions, the spread of pathogens, and the build-up of heavy metals (Lou & Nair, 2009). Yet there is a two-fold advantage to using the sludge as a soil amendment: it reduces landfill costs and also has agronomic value. Research has shown that brewery sludge contains enough macronutrients and organic carbon to function as an effective fertilizer and may therefore be used to replace or supplement mineral fertilizers (Alayu & Leta, 2020). Additionally, the soil's ability to retain water and exchange cations is improved by the organic matter present (Mupambwa & Mkeni, 2018).

Research in Ethiopia has demonstrated positive crop responses to brewery sludge. For example, Merga et al. (2020) found superior maize grain at an application of 15 t ha⁻¹ sludge, surpassing yields from plots treated with recommended NP fertilizer and untreated control plots in eastern Ethiopia. A similar finding is reported by Daba et al. (2017) in a study on sorghum, which reported that a brewery sludge rate of 15 t ha⁻¹ significantly increased sorghum grain and biomass compared to both the no-fertilizer and NP fertilizer application. Nevertheless, sludge composition varies with production processes, including the use of filter aids like kieselguhr (diatomaceous earth) (Trujillo et al., 2023), yet the agronomic implications of this variation remain unexplored in southwestern Ethiopia. Moreover, the sludge's organic carbon can buffer the soil's acidity and enhance its ability to retain nutrients, crucial in the case of acidic Nitisols, which are widespread in the region and characterized by low phosphorus availability and aluminum toxicity (Asmamaw et al., 2022). Therefore, exploring the impact of the brewery's sludge on such soils is relevant both in terms of waste management and agriculture.

Statement of the problem

Industrial waste management has become a matter of global concern since its improper disposal causes climate change resulting from methane emissions, infection through pathogens, and pollution by organic matter and heavy metals (Lou & Nair, 2009). Most of the breweries in Ethiopia dispose of their waste without any treatment, posing a tremendous threat to the country's ecosystem (Alayu & Leta, 2020). For instance, sludge from the aerobic treatment of the Bedele Brewery located in Southwestern Ethiopia is disposed of in the open environment, generating environmental hazards such as methane emissions and water/soil pollution (Lou & Nair, 2009).

Research questions

1. Evaluate the effects of brewery sludge application rates on maize growth, yield, and yield components.
2. Compare the agronomic performance of sludge with kieselguhr versus sludge without kieselguhr.
3. Examine whether brewery sludge can supplement or replace mineral fertilizer in the development of maize on the acidic Nitisols of southwestern Ethiopia.

Even though there is a significant amount of brewery waste generated from Bedele Brewery, there has been no study to experimentally evaluate the impact of the brewery sludge on maize (*Zea mays* L.) production in the Buno Bedele area. Maize is the most important staple food crop grown in the region, but its production is limited by the poor, infertile soil and the high cost of inorganic fertilizers. Specifically, the following knowledge gaps persist: 1) The appropriate application rates of brewery sludge for optimal maize yield on acidic Nitisols have not been established; 2) The comparative agronomic performance of sludge with and without kieselguhr is unknown; 3) The potential for brewery sludge to replace or complement synthetic fertilizer for

MATERIALS AND METHODS

Study area description

A field experiment was performed during the 2022/23 off-season using irrigation (December to May) at Tibechea Kebele, Chora District, Buno Bedele Zone, southwestern Ethiopia. Chora District is situated 543 km west of Addis Ababa, between 8°14' N and 8°34' N latitude and 36°0' E and 36°20' E longitude. Altitude ranges from 1480 to 2660 m above sea level. The district receives mean annual precipitation of 2050 mm (range: 1800–2300 mm) with a unimodal distribution, and mean annual temperature of 20°C (range: 15–22 °C). The farming system is coffee-based mixed crop-livestock production.

Experimental materials

A hybrid maize variety BH-546, released by Bako National Maize Research Center in 2013, was tested. This intermediate-maturing variety produces 8.5–9.5 t ha⁻¹ on-station and 5.5–7.0 t ha⁻¹ on-farm grain yield. Nitrogen fertilizer (urea, 46% N) and NPS fertilizer (19% N, 38% P₂O₅, 7% S) were used as inorganic fertilizer treatments. Brewery sludge was collected from the Bedele Beer Factory, comprising two types: sludge with kieselguhr (a diatomaceous earth filter aid) and sludge without kieselguhr.

Experimental design and treatment structure

A randomized complete block design with three replications was used for the experiment. Treatments consisted of two sludge types (with and without kieselguhr) applied at six rates (2, 4, 6, 8, 10, and 12 t ha⁻¹), plus a recommended dose of chemical fertilizers [Urea (46% N) and blended NPS (18.9% N, 37.7 P₂O₅, 6.95% S and 0.1% B) at a rate of 200 kg and 150 kg ha⁻¹ were used as recommended by Mengistu (2022) as a positive control. The positive control treatment (recommended NPS fertilizer treatment was included for comparison. A total of 42

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experimental plots [2 × (6 rates + 1 NPS treatment) × 3 replications] were established. Each plot was 4.5 m × 3 m (13.5 m²), with blocks spaced 1 m apart and plots spaced 0.5 m apart. With five rows spaced 75 cm apart and 30 cm inter-row spacing, each plot had a plant population density of about 44,444 plants ha⁻¹. The net harvestable area was the central three rows (3.6 m²) to minimize border effects.

Sludge application and crop management

Brewery sludge was applied four weeks before sowing and thoroughly incorporated into the soil at the calculated rates using a local hoe. For the NPS (19% N, 38% P₂O₅, 7% S) fertilizer treatment, the full dose was applied at planting. Half of the nitrogen fertilizer (urea) was applied at planting, and the second half was applied 25 days after planting as a side dressing. Sowing was conducted in mid-December 2022. Weeding was performed manually three times during the growing period, and other agronomic practices were applied uniformly across all plots.

Soil and sludge analysis

Pre-plant soils were sampled from 0–20 cm depth, in a zigzag pattern to obtain a composite sample. After harvest, soils were sampled from each plot following the same procedure. The samples were air-dried, ground, and sieved through a 2 mm mesh before analysis at Jimma University Soil Laboratory. Soil pH was determined in a 1:2.5 soil: water suspension using a glass electrode pH meter (Anderson & Ingram, 1993). Total nitrogen was computed following the Kjeldahl procedures (Bremner & Mulvaney, 1982). Available phosphorus was analyzed following the Bray-1 (Bray and Kurtz, 1945) procedures. Organic carbon was measured by the Walkley-Black wet digestion method (Walkley & Black, 1934). Exchangeable acidity was determined by KCl extraction followed by titration (Rowell, 1994). Brewery sludge samples were analyzed for pH, total nitrogen, organic carbon, and available phosphorus following standard procedures.

Data collection

Phenological parameters

- Days to tasseling: Number of days from planting to when 50% of plants shed pollen.
- Days to silking: Number of days from planting to when 50% of plants showed silk extrusion.
- Days to physiological maturity: Number of days from planting to when 75% of plants showed black layer formation at kernel attachment point

Growth parameters

- Plant height (cm): Measured from ground level to the base of the tassel at physiological maturity from five randomly selected plants per plot.
- Number of leaves per plant: Counted from five randomly selected plants per plot.
- Leaf area index (LAI): Determined at silking stage using five consecutive plants per plot. Leaf area (LA) per plant was calculated as:
$$LA = \text{length} \times \text{maximum width} \times 0.75 \text{ (Elings, 2000).}$$
$$LAI = (\text{average LA per plant}) / (\text{land area per plant}).$$

Yield components

- Number of ears per plant: Counted from five pre-tagged plants per plot at harvest.
- Ear length (cm): Measured from five randomly selected ears per plot.
- Number of kernels per ear: Calculated as number of rows per ear $\times$ number of kernels per row from five ears per plot.
- Thousand grain weight (g): Determined from 1000 randomly sampled kernels per plot

Yield parameters

- Above-ground dry biomass (kg ha^{-1}): All plants from the net plot area were cut at ground level at maturity and weighed after sun-drying to constant weight.
- Green cob yield (kg ha^{-1}): Cobs from the net plot area were harvested at late dough stage, husked, and weighed fresh

Statistical analysis

The collected samples were tested for analysis of variance (ANOVA) assumptions and subjected to ANOVA using the General Linear Model procedure in SPSS version 27. The statistical model was:

$Y_{ijk} = \mu + B_i + T_j + \varepsilon_{ijk}$; where Y_{ijk} is the response variable, μ is the overall mean, B_i is the block effect ($i = 1, 2, 3$), T_j is the treatment effect ($j = 1, \dots, 15$), and ε_{ijk} is the random error. Treatment means were separated using Fisher's least significant difference (LSD) test at $\alpha = 0.05$ when ANOVA indicated significant differences.

RESULTS AND DISCUSSIONS

Results

Pre-planting selected physicochemical properties of soils.

The pre-planting soil analysis (Table 1) revealed a clay loam texture (USDA, 1987) with a very strongly acidic reaction. The soils exhibited moderate organic carbon, but low available phosphorus (0.95 ppm) and low cation exchange capacity. The exchangeable complex was dominated by high levels of calcium and magnesium, with very low sodium content, and a low bulk density (1.24 g cm^{-3}). Physically, the soils were characterized by a low bulk density (1.24 g cm^{-3}), implying low compaction and good friability, which support good root penetration potential. The chemical characterization of the two brewery sludge types revealed notable differences (Table 2). The sludge without kieselguhr had a higher pH (8.52 vs. 7.72), organic carbon (47.7% vs. 40.6%), and total nitrogen (5.8% vs. 5.1%), while the sludge with kieselguhr contained greater available phosphorus (0.38% vs. 0.30%). Both types exhibited C/N ratios of 15 and 17, respectively (Table 2).

Table 1*Pre-planting selected physicochemical properties of experimental soil*

Physicochemical Properties	Value	Rating	Source
Particle size distribution	Clay (30.5%)	Silt (39.5%)	Sand (30.0%)
Soil textural class	Clay loam		USDA Soil Texture Triangle (1987)
Bulk Density (g cm ³⁻¹)	1.24	Low	Hazelton and Murphy (2016)
pH (H ₂ O)	5.45	V. Strongly Acidic	Tekalign (1991)
Organic Carbon (%)	4.34	Moderate	Tekalign (1991)
Total nitrogen (%)	0.12	Medium	Hazelton (2016)
Avail. P (ppm or mg kg ⁻¹)	0.95	Low	Tekalign (1991)
Avail. Sulfur (ppm)	2.68		
Exchangeable acidity (meq 100g ⁻¹)	0.61	-	
CEC (meq 100g ⁻¹)	12.15	Low	Hazelton and Murphy (2016)
pH (H ₂ O)	5.45	V. Strongly Acidic	Tekalign (1991)
Organic Carbon (%)	4.34	Moderate	Tekalign (1991)
Total nitrogen (%)	0.12	Medium	Hazelton (2016)
Avail. P (ppm or mg kg ⁻¹)	0.95	Low	Tekalign (1991)
Ca ²⁺ (meq 100g ⁻¹)	17.42	High	FAO (2021)
Mg ²⁺ (meq 100g ⁻¹)	8.09	High	FAO (2021)
Na ⁺ (meq 100g ⁻¹)	0.03	Very low	FAO (2021)
K ⁺ (meq 100g ⁻¹)	0.64	Medium	FAO (2021)

Table 2*Chemical properties of brewery sludge used in the experiment*

Parameter	Sludge type	
	With kieselguhr	Without kieselguhr
pH (H ₂ O)	7.72	8.52
Organic carbon (%)	40.6	47.7
Total nitrogen (%)	5.1	5.8
Avail. P (%)	0.38	0.30
C/N ratio	15.0	17.0

Effects on Maize Phenology

Brewery sludge application significantly influenced maize phenological parameters (Table 3). Days to tasseling ranged from 81.7 days (12 t ha⁻¹ with kieselguhr) to 85.4 days (control). Application of 10–12 t ha⁻¹ sludge significantly hastened tasseling compared to lower rates and the

control, with effects comparable to recommended NPS fertilizer. Similarly, days to silking were reduced from 90.5 days in control to 87.7 days with 12 t ha⁻¹ sludge ($p < 0.001$). Days to physiological maturity showed a consistent decline with increasing sludge application rates, ranging from 143.1 days in the control.

Table 3*Effect of brewery sludge on phenological characteristics of maize*

Treatment		Phenological parameter		
Sludge type	Rate	DTT (days)	DTS (days)	DTM (days)
With kieselguhr	2 t ha ⁻¹	85.0 ^a	90.8 ^{ab}	142.0 ^a
	4 t ha ⁻¹	84.7 ^{ab}	90.4 ^{ab}	140.0 ^b
	6 t ha ⁻¹	84.2 ^{abc}	90.1 ^{bc}	139.4 ^{bc}
	8 t ha ⁻¹	83.6 ^{bc}	89.6 ^c	138.3 ^{bcd}
	10 t ha ⁻¹	83.1 ^{cd}	89.6 ^c	137.8 ^{cd}
	12 t ha ⁻¹	81.7 ^c	87.7 ^d	136.8 ^d
Without kieselguhr	2 t ha ⁻¹	84.7 ^a	90.8 ^{ab}	142.0 ^a
	4 t ha ⁻¹	84.7 ^a	90.4 ^{ab}	140.0 ^b
	6 t ha ⁻¹	84.0 ^{ab}	90.1 ^{bc}	139.4 ^{bc}
	8 t ha ⁻¹	83.0 ^{bc}	89.6 ^c	138.3 ^{bcd}
	10 t ha ⁻¹	83.0 ^{bc}	89.6 ^c	137.8 ^{cd}
	12 t ha ⁻¹	82.0 ^c	87.7 ^d	136.8 ^d
Control		85.4 ^a	91.5 ^a	143.1 ^a
Recommended NPS		81.9 ^{cd}	87.3 ^d	138.6 ^{bc}
F-test		***	***	**
LSD (0.05)		1.21	1.12	1.70
CV (%)		0.69	0.73	0.69

Means within columns followed by different letters are significantly different at $p < 0.05$. LSD: Least significant difference; CV: Coefficient of Variation; DTT: days to tasseling; DTS: days to silking; DTM: days to maturity.

Effects on Maize Growth Parameters

Brewery sludge application significantly influenced plant height, number of leaves per plant, and leaf area index (Table 4). Plant height increased consistently with increasing sludge application rates, from 262.3 cm in control to 328.3 cm with 12 t ha⁻¹ sludge (with kieselguhr). The recommended NPS fertilizer produced plant heights (309.3 cm) comparable to the 10–12 t ha⁻¹ sludge treatments. Similarly, the number of leaves

per plant increased from 15.0 in the control to 17.7 with 12 t ha⁻¹ sludge (without kieselguhr). Leaf area index showed a similar response pattern, increasing from 3.18 in control to 4.87 with 12 t ha⁻¹ sludge (with kieselguhr). Although differences were not always statistically significant, sludge with kieselguhr typically produced slightly higher LAI values than sludge without this amendment.

Table 4*Effect of brewery sludge on growth parameters of maize*

Treatment		Growth parameter		
Sludge type	Rate	Plant height (cm)	Leaves per plant	Leaf area index
With kieselguhr	2 t ha ⁻¹	264.7 ^c	15.0 ^c	3.56 ^d
	4 t ha ⁻¹	272.0 ^{de}	15.3 ^{bc}	4.12 ^c
	6 t ha ⁻¹	280.3 ^{de}	15.3 ^{bc}	4.64 ^b
	8 t ha ⁻¹	287.3 ^{cd}	16.3 ^{abc}	4.77 ^{ab}

Table 4 continues

	10 t ha ⁻¹	311.0 ^{ab}	16.7 ^{ab}	4.79 ^{ab}
	12 t ha ⁻¹	328.3 ^a	17.0 ^a	4.87 ^a
Without kieselguhr	2 t ha ⁻¹	266.7 ^e	15.3 ^{bc}	3.49 ^d
	4 t ha ⁻¹	272.0 ^{de}	15.3 ^{bc}	3.99 ^c
	6 t ha ⁻¹	282.3 ^{cde}	15.7 ^{bc}	4.52 ^b
	8 t ha ⁻¹	284.0 ^{cd}	16.7 ^{abc}	4.78 ^a
	10 t ha ⁻¹	306.7 ^{bc}	17.0 ^{ab}	4.83 ^a
	12 t ha ⁻¹	321.7 ^a	17.7 ^a	4.85 ^a
Control		262.3 ^e	15.0 ^c	3.18 ^e
Recommended NPS		309.3 ^b	17.0 ^{ab}	4.77 ^{ab}
F-test		***	*	***
LSD (0.05)		21.5	1.58	0.20
CV (%)		4.21	5.60	3.33

Means within columns followed by different letters are significantly different at $p < 0.05$. LSD: Least significant difference; CV: Coefficient of Variation

Effects on Maize Yield Components

Brewery sludge application significantly influenced yield components (Table 5). Number of ears per plant increased from 0.90 in control to 1.27 with 12 t ha⁻¹ sludge (with kieselguhr), comparable to the NPS fertilizer treatment.

Number of kernels per ear increased from 513 in control to 674 with 12 t ha⁻¹ sludge (without silica), representing a 31.4% increase. Ear length showed similar trends, with maximum values at the maximum sludge application rates.

Table 5

Effect of brewery sludge on yield components and yield of maize

Treatment		Yield components and yield parameter					
Sludge type	Rate	Ears per plant	Kernels per ear	Ear length (cm)	Biological yield (kg ha ⁻¹)	Green cob yield (kg ha ⁻¹)	
With kieselguhr	2 t ha ⁻¹	1.00 ^c	570.7 ^{cd}	17.4 ^{cd}	23,80 ^{ef}	14,11 ^c	
	4 t ha ⁻¹	1.00 ^c	581.3 ^{bcd}	18.2 ^{bcd}	25,41 ^{de}	14,23 ^c	
	6 t ha ⁻¹	1.06 ^{bc}	630.7 ^{abc}	18.9 ^{abc}	28,65 ^c	17,99 ^c	
	8 t ha ⁻¹	1.00 ^c	644.7 ^{ab}	19.5 ^{abc}	33,72 ^c	24,69 ^b	
	10 t ha ⁻¹	1.33 ^a	667.3 ^{ab}	20.5 ^{ab}	39,45 ^{ab}	28,38 ^{ab}	
	12 t ha ⁻¹	1.27 ^{ab}	670.7 ^a	21.0 ^a	41,35 ^a	31,01 ^a	
Without kieselguhr	2 t ha ⁻¹	1.00 ^c	546.7 ^{cd}	16.8 ^d	21,88 ^c	12,86 ^e	
	4 t ha ⁻¹	1.00 ^c	573.3 ^{bcd}	17.5 ^{cd}	22,62 ^c	13,34 ^e	
	6 t ha ⁻¹	1.00 ^{bc}	632.3 ^{ab}	18.6 ^{bcd}	26,48 ^c	17,06 ^d	
	8 t ha ⁻¹	1.07 ^{bc}	643.3 ^{ab}	19.1 ^{abc}	33,64 ^b	23,86 ^c	
	10 t ha ⁻¹	1.27 ^{ab}	661.0 ^a	19.7 ^{abc}	38,68 ^{ab}	30,20 ^{ab}	
	12 t ha ⁻¹	1.33 ^{ab}	677.3 ^a	20.4 ^{ab}	38,68 ^{ab}	28,62 ^{ab}	
Control		0.90 ^c	512.7 ^d	16.2 ^d	21,43 ^c	12,35 ^e	
Recommended NPS		1.33 ^a	635.7 ^{ab}	20.1 ^{ab}	37,46 ^b	28,49 ^{ab}	

Table 5 continues

F-test	***	**	**	***	***
LSD (0.05)	0.13	84.1	2.74	4,452	4,058
CV (%)	12.80	7.85	8.16	8.28	10.00

Means within columns followed by different letters are significantly different at $p < 0.05$. LSD: Least significant difference; CV: Coefficient of Variation

Effects on Maize Yield

Brewery sludge application showed significant influence on both biological yield and green cob yield (Table 5). Biological yield increased from 21,431 kg ha⁻¹ in control to 41,346 kg ha⁻¹ with 12 t ha⁻¹ kieselguhr (sludge with silica), corresponding to a 93% increase. Likewise, green cob yield increased from 12,347 kg ha⁻¹ in control to 31,008 kg ha⁻¹ with 12 t ha⁻¹ sludge (with silica), a 151% increase.

Sludge with kieselguhr consistently outperformed sludge without this amendment. At the 12 t ha⁻¹ rate, sludge with kieselguhr produced 8.3% higher green cob yield (31,008 vs 28,621 kg ha⁻¹) and 6.9% higher biological yield (41,346 vs 38,678 kg ha⁻¹) compared to sludge without kieselguhr. The recommended NPS fertilizer produced green cob yields of 28,489 kg ha⁻¹, which were lower than the 12 t ha⁻¹ sludge treatment but comparable to the 10 t ha⁻¹ rate.

Post-Harvest Soil Properties

To evaluate post-harvest soil chemical properties under the most promising sludge management options, four treatments were selected for detailed comparison: the unamended control, the recommended NPS fertilizer treatment, and the two highest sludge application rates (12 t ha⁻¹ with and without kieselguhr). The 12 t ha⁻¹ rate was chosen as the best treatment because it recorded the best results for all the studied agronomic attributes (Tables 3–5). An analysis of the soil chemical properties after harvesting revealed that the application of increasing rates of sludge improved these properties (Table 6). The pH value decreased from 5.45 at planting to 5.12–5.58 depending on the treatment. The organic carbon content also increased from 4.34% at planting to 4.52–4.98% at harvest. Similarly, the available phosphorus increased from 0.95 mg kg⁻¹ at planting to 7.41–8.23 mg kg⁻¹ at harvest, although the values were below the critical level for maize production. In contrast, the total nitrogen increased slightly from 0.12% at planting to 0.13–0.15% at harvest.

Table 6

Post-harvest soil chemical properties under optimal sludge treatments

Treatment	pH	OC (%)	Total N (%)	Avail. P (mg kg ⁻¹)
Control	5.12	4.52	0.13	7.41
Recommended NPS	5.18	4.58	0.13	7.89
With kieselguhr (12 t ha ⁻¹)	5.58	4.98	0.15	8.23
Without kieselguhr (12 t ha ⁻¹)	5.49	4.87	0.14	8.01

DISCUSSIONS

Brewery Sludge Characteristics and Soil Fertility Implications

The high percentage of organic carbon (40.6–47.7%) (Table 2) indicates that the sludge is an excellent soil conditioner. The sample without

kieselguhr showed a significantly higher content of organic carbon (47.7%) than the sample with kieselguhr (40.6%). This might be connected to the fact that in comparison with the sample without kieselguhr, the sample with it contained

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more kieselguhr, which is a diatomite mineral that is used as a material for filtration and decreases the organic fraction of the sludge (Hultberg & Bodin, 2019).

Both sludge types had remarkably high total nitrogen contents (5.1–5.8%) (Table 2), while the sludge without kieselguhr had slightly higher contents than that with kieselguhr. The C/N ratios of 15 and 17 were within the optimal range (15:1–25:1) for balanced nitrogen supply in the process of organic matter decomposition (Dessalew et al., 2018). It was also in line with the C/N ratios (12.8–21.8%) reported for brewery sludges. The sludge with C/N ratios of 15–17 could be regarded as stable with no nitrogen drawdown potential. A C/N ratio of 15–17 indicates that the sludge is well-stabilized and will not lead to "nitrogen drawdown"—a process where soil microbes temporarily tie up available nitrogen to break down material with a very high C/N ratio.

The sludge with kieselguhr contained higher available phosphorus (0.38%) than the sludge without kieselguhr (0.30%) (Table 2). This could be explained by the adsorption of a part of the phosphates on the surface of diatomite during their filtration through the filtering medium, which can affect the processes of their desorption and fractionation (Gunes et al., 2008).

Maize Growth and Phenological Responses

Increasing the application rates of brewery sludge significantly reduced the number of days to tasseling, silking, and physiological maturity, indicating that organic amendments expedited crop development. This is attributed to the increased supply of nutrients, particularly nitrogen, which promotes vegetative growth and hastens reproductive transitions (Hadi, 2005). This finding agrees with that of Afe et al. (2015), who reported that combined application of organic and inorganic fertilizers resulted in an earlier tasseling of maize. Similarly, Bekele et al. (2018) also reported hastened tasseling and silking of maize with the application of vermicompost, which is consistent with the current finding. The enhanced

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plant height, number of leaves per plant, and leaf area index acquired from using sludge were indicators of the plant's nutritional status. The brewery sludge contains vital plant nutrients such as nitrogen, phosphorus, and potassium, which are beneficial for cell division, cell elongation, and photosynthesis processes. The increment of the evaluated parameters in line with an increase in the rate of sludge application up to 12 t ha⁻¹ demonstrated that maize responds positively to the increased organic matter input, as reported by Merga et al. (2020). On the other hand, the absence of yield decline at the highest application rate indicated that the sludge quality (low salinity, neutral pH) does not impose toxicity constraints even at 12 t ha⁻¹.

Plant height increased consistently with higher sludge application rates. It rose from 262.3 cm in the control to 328.3 cm with 12 t ha⁻¹ of sludge with kieselguhr, a 25% increase. This was attributed to the balanced nutrient supply from the sludge. The sludge contained substantial organic matter (40.6–47.7%) and nitrogen (5.8% vs. 5.1%), both of which promote vegetative growth. This finding corroborated Merga et al. (2022), who reported that application of brewery sludge at 10–15 t ha⁻¹ significantly increased maize plant height in southwestern Ethiopia.

The comparable plant height observed (309.3 cm with recommended NPS fertilizer) and (306.7–328.3 cm with high- sludge rate) implied that brewery sludge could efficaciously substitute mineral fertilizers. The superior performance of sludge with kieselguhr over the sludge without kieselguhr at the highest application rate (328.3 vs 321.7 cm) was explained by the beneficial effects of silicon on plant growth. The increase in leaf number from 15.0 in the control to 17.7 with 12 t ha⁻¹ sludge (without kieselguhr) represents an 18% improvement. This in brewery sludge reflects the availability of essential nutrients, particularly nitrogen, which is a key determinant of leaf initiation and expansion. Daba et al. (2023), while working on the impact of sorghum and maize in eastern Ethiopia, found that applying brewery

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sludge increased leaf production by 15-25% during the vegetative crop growth phase. According to the authors, this was attributed to a gradual nitrogen release from organic fertilizer, thus sustaining nourishment throughout the crop growth phase. The leaf area index (LAI) was increased by 53% (from 3.18 in the control to 4.87 in the treatment with 12 t ha⁻¹ of sludge with kieselguhr). This can be attributed to a better supply of nutrients and plant vigor, which led to more extensive leaf development and canopy growth. The authors associated this response with the changes in the content of organic matter and nitrogen in the soil, which were also observed in our experiment. Moreover, a slightly higher growth of most parameters was observed for the majority of the sludge with kieselguhr application rates, which may be related to the amorphous silica (SiO₂·nH₂O) contained in it. The optimal application range of 10-12 t ha⁻¹ observed in the present study is similar to that of [Merga et al. \(2022\)](#), who reported optimized recommended doses from other Ethiopian locations. They observed that 10 t ha⁻¹ brewery sludge optimized maize production in the western part of Ethiopia, while [Daba et al. \(2023\)](#) observed 12 t ha⁻¹ optimized sorghum production in the eastern part of Ethiopia. The convergence of these results provides a basis for recommending location-specific uses of brewery sludge in Ethiopian agriculture.

Yield Components and Yield Performance

The significant rise in ears per plant, kernels per ear, and ear length from sludge application proved the beneficial influence of organic manure on yield-forming processes. The 151 % increment in green cob yield by 12 t ha⁻¹ sludge over the control underlined the severe deficiency of nutrients in the non-amended soil. The magnitude of yield response of the treatment was in agreement with the reports of earlier workers in Ethiopia. [Daba et al. \(2017\)](#) observed that the application of 15 t ha⁻¹ brewery sludge resulted in a 78 % increment of sorghum grain over the no-

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fertilizer check. Similarly, [Alayu and Leta \(2020\)](#) recorded a 65% yield increase in maize with brewery sludge application.

The higher yield from sludge with kieselguhr (silica) warranted attention. Silicon is known to enhance nutrient uptake, increase photosynthetic efficiency, and improve resistance to abiotic stresses ([Epstein, 2009](#); [Schaller et al., 2021](#)). The 8.3% yield advantage of silica-containing sludge at the 12 t ha⁻¹ rate suggested that silicon addition provided benefits beyond the organic matter and macronutrient contributions. This finding has practical implications for sludge management, as kieselguhr is commonly used in

Effects of Kieselguhr (Silica) on Crop Performance

The higher yields from sludge containing kieselguhr may be partly attributable to the presence of diatomaceous earth, which is known to contain amorphous silica and has been associated with improved nutrient uptake in other studies ([Epstein, 2009](#); [Schaller et al., 2021](#)). The 8.3% yield advantage of kieselguhr-containing sludge at the 12 t ha⁻¹ rate implied that silicon addition provided benefits beyond the organic matter and N and P contributions. However, since we did not measure silicon content or bioavailability, this mechanism remains speculative.

In strongly acidic soils like those in the present study (pH 5.45), silicon can play an important role in alleviating aluminum toxicity—a major constraint to root growth and nutrient uptake.

Post-Harvest Soil Chemical Changes

Post-harvest chemical analysis revealed that the application of increased rates of sludge improved the chemical properties of the soil. The soil pH increased from 5.45 before planting to 5.12-5.58 with the highest application rate. Brewery sludge increased the soil pH due to its high alkalinity (pH 7.7-8.5) and organic matter content (40.6-47.7% OC) and the presence of organic ligands that buffer the soil against Acidity ([Fageria & Baligar,](#)

2008). Decomposition of organic matter produces organic anions that chelate with Al^{3+} and H^+ ions, thereby lowering the exchangeable acidity and increasing the pH. While nitrogen content was significant, higher rates of sludge risked nutrient leaching. There was no observed yield decline at the rate of 12 t ha^{-1} , but nitrogen levels increased slightly, suggesting potential losses (Diacono and Montemurro, 2010).

The pH threshold of 5.5, below which Al^{3+} dissolution is considered toxic to plant roots and above which P availability increases substantially, is well established (Fageria et al., 2010). The 12 t ha^{-1} sludge with kieselguhr treatment raised the pH value to 5.58, i.e., above the threshold level. This implies that at recommended rates, brewery sludge with kieselguhr is able to provide plant nutrients and, at the same time, improve soil pH (Chiang et al., 2009). However, the marginal pH increase (from 5.45 to 5.49) observed with sludge without kieselguhr at the same rate indicates that the liming effect is influenced by sludge composition, with the silica-containing sludge showing superior acid-neutralizing capacity.

The increase in OC (4.34% to 4.98%) represented a 15% increase with the highest sludge rate. This was notable given the already high OC content of the pre-planting soil, which reflects the forest-derived origin of these Nitisols (Mathewos et al., 2023). Increased soil OC improves nutrient retention and soil structure—benefits that contribute to long-term productivity and climate resilience (Lal, 2004). The higher OC accumulation with sludge containing kieselguhr may be due to the protective effect of silicon on organic matter, as Si can form organo-mineral complexes that reduce the rate of organic matter decomposition (Schaller et al., 2021).

Available phosphorus increased from 0.95 mg kg^{-1} pre-planting to $7.41\text{--}8.23 \text{ mg kg}^{-1}$ post-harvest, though levels remained below the critical threshold for maize production. The main reason for the change was the phosphorus content of the sludge (0.30–0.38%) and the pH-mediated reduction in P fixation. In acidic soils, phosphorus

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is largely fixed by aluminum and iron oxides, limiting its availability to plants (Fageria & Baligar, 2008). Phosphorus solubility and availability improved when the pH increased with the application of sludge. However, the post-harvest P levels still indicate that additional P fertilization may be required for optimal maize production even for the highest sludge rate.

The total nitrogen was a modest increase from 0.12% pre-planting to 0.13–0.15% post-harvest. While the nitrogen content was significant, higher sludge rates pose a risk of nutrient leaching. No yield decline was found at 12 t ha^{-1} , but nitrogen levels increased modestly, suggesting potential losses via volatilization or leaching (Diacono & Montemurro, 2010; Agegnehu & Amede, 2017).

Comparison with Recommended NPS Fertilizer

At the 12 t ha^{-1} level, the incorporation of brewery sludge with kieselguhr increased green cob yield by 8.8% over that of NPS, while sludge without kieselguhr produced yields that were statistically similar to those of NPS fertilizer. This result concurs with that of Daba et al. (2017), who recorded that at 15 t ha^{-1} level, brewery sludge outyielded NPS fertilizer in their study on the effect of different organic fertilizers on sorghum production.

The performance of organic and inorganic fertilizers was relatively comparable. This could be attributed to the rich nutrient content of brewery sludge (5.1–5.8% N and 0.30–0.38% Avail. P) as well as the beneficial effect of the organic matter in the sludge. The beneficial effect of organic manures and composts on soil and plant productivity has been widely reported and appears to depend on the improvement of the physical condition of the soil, the enhancement of the cation exchange capacity of the soil, and the stimulation of microbial activity, which inorganic fertilizers are deficient in. The gradual release of plant nutrients from organic manures and composts may also contribute to better adaptation to the plant's nutrient demands than do soluble mineral fertilizers. In addition, the use of organic

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manures and composts reduces nutrient losses and increases nutrient utilization and, therefore, plant productivity. The ability of brewery sludge to perform comparably to the recommended mineral fertilizer NPS is of great significance, especially in the current escalation in the price of commercial fertilizers in Ethiopia. Brewery sludge could be a good alternative to the increasingly unavailable chemical fertilizers in Ethiopia. The fact that brewery sludge can simultaneously solve the problem of waste disposal and provide a source of cheap fertilizer makes it more attractive. In addition, the value of brewery sludge as a fertilizer is further enhanced because it can help to correct soil acidity.

CONCLUSIONS

This study showed that brewery sludge application at 12 t ha⁻¹ significantly improved maize growth and yield on acidic Nitisols in southwestern Ethiopia. Green cob yield increased by up to 151% when 12 t ha⁻¹ brewery sludge with kieselguhr was applied compared to the control, with consistent yield improvements across all rates. Sludge with kieselguhr performed best, suggesting additional benefits from silicon. The benefits of sludge include an improvement in soil quality due to increased levels of pH, organic carbon, and available phosphorus that were recorded in the study. This makes it a suitable organic fertilizer for enhancing crop production while also dealing with waste management problems in the environment.

Recommendation

Apply sludge with kieselguhr at 12 t ha⁻¹ for optimum maize production on acid Nitisols of the southwest of Ethiopia and similar agro-ecologies. This rate produces yield equivalent to or greater than that of recommended mineral fertilizers and improves soil fertility. At this rate, in addition to providing essential plant nutrients, the application of sludge increases soil pH to above the critical level of 5.5, thus eliminating the need for lime.

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Combine with complementary practices such as liming if soil pH remains below 5.5 after application, or supplement with Ps sources if available P remains critically low (<10 mg kg⁻¹). Prioritize sludge with kieselguhr (diatomaceous earth) where available, as the silicon content confers additional agronomic benefits, including enhanced nutrient uptake and stress tolerance.

These findings support the need to use brewery sludge as an organic fertilizer, which will help address waste management issues and will also help in solving agricultural problems. Moreover, there is a need for future studies that will address the agronomic, economic, and environmental sustainability of this kind of application on a larger scale.

CRedit Author Statement

Getachew Bekele: Conceptualization, Writing - Original Draft; **Mulugeta Tilahun Keno:** Validation, Formal analysis; **Damena Edae Daba:** Investigation, Resources; **Habtamu Mengistu:** Data Curation, Methodology; **Tesfaye Kinde:** Writing - Review & Editing, Visualization; **Gashahun Tadesse:** Supervision, Project administration

Declaration of Competing Interests

The authors declare no competing interests. The funder had no role in study design, data collection, analysis, interpretation, or manuscript preparation.

Ethics Approval

Not applicable

Data Availability

The datasets generated and analyzed during the current study are available from the corresponding author upon reasonable request.

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REFERENCES

- Afe, A., Atanda, S., Aduloju, M., Ogundare, S., & Talabi, A. (2015). Response of maize (*Zea mays* L.) to combined application of organic and inorganic (soil and foliar applied) fertilizers. *African Journal of Biotechnology*, 14(44), 3006–3010.
<https://doi.org/10.5897/ajb2015.14808>
- Alayu, E., & Leta, S. (2020). Brewery sludge quality, agronomic importance and its short-term residual effect on soil properties and lettuce (*Lactuca sativa* L.) yield. *International Journal of Recycling of Organic Waste in Agriculture*, 9(1), 15–29.
<https://doi.org/10.30486/ijrowa.2020.671511>
- Anderson, J. M., & Ingram, J. S. I. (1993). Tropical soil biology and fertility: A handbook of methods (2nd ed.). CAB International.
<https://nishat2013.wordpress.com/wp-content/uploads/2013/11/tropical-soil-biology-book.pdf>
- Asmamaw, D. K., Janssens, P., Dessie, M., Tilahun, S., Adgo, E., Nyssen, J., ... Cornelis, W. M. (2022). Effect of integrated soil fertility management on hydrophysical soil properties and irrigated wheat production in the upper Blue Nile Basin, Ethiopia. *Agricultural Water Management*, 267, 107506.
<https://doi.org/10.1016/j.agwat.2022.107506>
- Bekele, A., Kibret, K., Bedadi, B., Balemi, T., & Yli-Halla, M. (2018). Effects of vermicompost and chemical P fertilizer on yield of maize and soil properties in Ebantu District, Western Highlands of Ethiopia. *African Journal of Agricultural Research*, 13(10), 477–489.
<https://doi.org/10.5897/AJAR2018.13086>
- Bray, R. H., & Kurtz, L. T. (1945). Determination of total, organic, and available forms of phosphorus in soils. *Soil Science*, 59(1), 39–46.
- Sci. Technol. Arts Res. J., July–Sep, 2026, 15(3), 11–25
<https://doi.org/10.1097/00010694-194501000-00006>
- Bremner, J. M., & Mulvaney, C. S. (1982). Nitrogen—Total. In A. L. Page, R. H. Miller, & D. R. Keeney (Eds.), *Methods of soil analysis: Part 2. Chemical and microbiological properties* (2nd ed., pp. 595–624). American Society of Agronomy.
<https://doi.org/10.2134/agronmonogr9.2.2ed.c31>
- Daba, N. A., Ahmed, A., & Yusuf, M. M. (2017). Impact of brewery waste sludge on sorghum (*Sorghum bicolor* L. Moench) productivity and soil fertility in Harari Regional State, Eastern Ethiopia. *Turkish Journal of Agriculture – Food Science and Technology*, 5(4), 366–372.
<https://doi.org/10.24925/turjaf.v5i4.366-372.1058>
- Dessalew, G., Beyene, A., Nebiyu, A., & Astatkie, T. (2018). Effect of brewery spent diatomite sludge on trace metal availability in soil and uptake by wheat crop, and trace metal risk on human health through the consumption of wheat grain. *Heliyon*, 4(9), e00783.
<https://doi.org/10.1016/j.heliyon.2018.e00783>
- Diacono, M., & Montemurro, F. (2010). Long-term effects of organic amendments on soil fertility. A review. *Agronomy for Sustainable Development*, 30(2), 401–422.
<https://doi.org/10.1051/agro/2009040>
- Epstein, E. (2009). Silicon: Its manifold roles in plants. *Annals of Applied Biology*, 155(2), 155–160.
<https://doi.org/10.1111/j.1744-7348.2009.00343.x>
- FAO (Food and Agriculture Organization). (2021). Soil fertility assessment and management.
<https://www.fao.org/neareast/mainopics/regional-priorities/rp3/land-management/soil/en>
- Fageria, N. K., & Baligar, V. C. (2008). Ameliorating soil acidity of tropical Oxisols by liming for sustainable crop production. *Advances in Agronomy*, 99, 345–399.

Getachew et al.,

[https://doi.org/10.1016/S0065-2113\(08\)00407-0](https://doi.org/10.1016/S0065-2113(08)00407-0)

Gunes, A., Pilbeam, D. J., & Inal, A. (2008). Effect of silicon on phosphorus availability and uptake by wheat. *Journal of Plant Nutrition*, 31(12), 2113–2123.

<https://doi.org/10.1080/01904160802452112>

Hadi, H. (2005). Effect of nitrogen rates on maize phenology. *Pakistan Journal of Biological Sciences*, 8(7), 973–976.

<https://doi.org/10.3923/pjbs.2005.973.976>

Hazelton, P., & Murphy, B. (2016). Interpreting soil test results: What do all the numbers mean? (3rd ed.). CSIRO Publishing.

<https://doi.org/10.1071/9781486303960>

Kanagachandran, K., & Jayaratne, R. (2006). Utilization potential of brewery wastewater sludge as an organic fertilizer. *Journal of the Institute of Brewing*, 112(2), 92–96.

<https://doi.org/10.1002/j.2050-0416.2006.tb00236.x>

Lal, R. (2004). Soil carbon sequestration to mitigate climate change. *Geoderma*, 123(1), 1–22.

<https://doi.org/10.1016/j.geoderma.2004.01.032>

Lou, X. F., & Nair, J. (2009). The impact of landfilling and composting on greenhouse gas emissions. *Bioresource Technology*, 100(16), 3792–3798.

<https://doi.org/10.1016/j.biortech.2008.12.006>

Mathewos, M., Bekele, T., & Garedew, W. (2023). Soil characterization and classification in the Yayu Coffee Forest Biosphere Reserve, southwestern Ethiopia. *Eurasian Soil Science*, 56(4), 421–433.

<https://doi.org/10.1134/S106422932360015X>

Mengistu, D. (2022). Effects of blended NPSB and N fertilizer rates on maize (*Zea mays* L.) grain yield and yield components in Chora District, Buno Bedele Zone, South Western Ethiopia. *World Journal of Applied Chemistry*, 7(1), 12–23.

<https://doi.org/10.11648/j.wjac.20220701.13>

Sci. Technol. Arts Res. J., July–Sep, 2026, 15(3), 11–25

Merga, B., Ahmed, A., Mohammed, M., & Wakgari, M. (2020). The application of brewery sludge for maize production. *Ethiopian Journal of Science and Sustainable Development*, 8(1), 25–34.

<https://doi.org/10.20372/ejssdastu.v8.i1.2021.229>

Mupambwa, H. A., & Mnkeni, P. N. S. (2018). Potential of brewery waste as a soil conditioner and plant nutrient source: A review. *Journal of Soil Science and Plant Nutrition*, 18(3), 865–883.

<https://doi.org/10.4067/S0718-5162018005002401>

Rowell, D. L. (1994). Soil science: Methods and applications. Longman Scientific & Technical.

<https://doi.org/10.4324/9781315844855>

Schaller, J., Puppe, D., Kaczorek, D., Ellerbrock, R., & Sommer, M. (2021). Silicon cycling in soils revisited. *Plants*, 10(2), Article 295.

<https://doi.org/10.3390/plants10020295>

Sinha, E., Calvin, K. V., Kyle, P. G., Hejazi, M. I., Waldhoff, S. T., & Huang, M. (2022). Implications of imposing fertilizer limitations on energy, agriculture, and land systems. *Journal of Environmental Management*, 301, 113903.

<https://doi.org/10.1016/j.jenvman.2021.113903>

Tekalign, T. (1991). Soil, plant, water, fertilizer, animal manure and compost analysis manual. ILCA. [Organization report].

<https://www.ilri.org/knowledge/publications/s-oil-plant-water-fertilizer-animal-manure-and-compost-analysis-manual>

Tsadik, G. Y. K., Hailu, A. M., Asfaw, S. L., & Mekonnen, Y. S. (2020). The effect of brewery sludge biochar on immobilization of bioavailable cadmium and growth of *Brassica carinata*. *Heliyon*, 6(11), e05557.

<https://doi.org/10.1016/j.heliyon.2020.e05557>

Trujillo, D. F., Padilla, R. S., & Estefania, J. (2023). Physicochemical characterization of brewery sludge: Implications for diatomaceous earth presence on composition

Getachew et al.,
and digestibility. *Waste Management Bulletin*,
1(2), 45–53.

<https://doi.org/10.1016/j.wmb.2023.04.002>

United States Department of Agriculture (1987)
Soil Mechanics Level 1 Module 3 USDA Soil
Textural Classification Study Guide. USDA
Soil Conservation Service, Washington DC.

Sci. Technol. Arts Res. J., July –Sep, 2026, 15(3), 11-25
<https://www.scribd.com/document/644760824/Soil-Chapter-4>

Walkley, A., & Black, I. A. (1934). An
examination of the Degtjareff method for
determining soil organic matter. *Soil Science*,
37(1), 29–38.

<https://doi.org/10.1097/00010694-193401000-00003>