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Effect of filter cake and bagasse ash application on selected chemical properties of acidic Nitisol

Abstract. The rising cost of lime, traditionally used to address soil acidity and its detrimental effects on soil fertility, has prompted the exploration of organic by-products as more affordable alternatives for mitigating soil acidity, particularly for low-income farmers. Therefore, the objective of this study was to investigate effects of filter cake (FC) and bagasse ash (BA) application on soil acidity under greenhouse condition. The experiment was laid out in a completely randomised design with four replications. The FC and BA were investigated separately each with six levels (0, 20, 40, 60, 80, and 100) t/ha^{-1}. The acidic soil was collected from Imdibir area at a depth of 0-20 cm, air dried, ground and passed through 4 mm sieve. Each pot was received 4 kg of soil with respective treatment material after they were well homogenised. The laboratory analysis revealed that the soil had an initial pH of 5.1, while filter cake and bagasse ash had pH values of 8.0 and 10.2, respectively. Application of FC increased soil pH from 5.1 to 7.3, along with improvements in organic matter, nitrogen, phosphorus, sulphur, potassium, calcium, magnesium, and cation exchange capacity. Similarly, BA application raised pH from 5.1 to 7.4 and enhanced organic matter, nitrogen, phosphorus, sulphur, potassium, calcium, magnesium, and cation exchange capacity. The maximum effects for both FC and BA occurred at the highest application rate (100 t/ha^{-1}), while iron and manganese content increased with BA application but decreased as rates increased, and copper and zinc levels were positively affected by both FC and BA applications. Overall, both FC and BA applications significantly improved soil pH and nutrient content. The findings of this study can provide practical and cost-effective solutions for improving soil fertility and crop production

Keywords: Imdibir; leaching; fixation; basic cations; acid forming cations; exchangeable acidity

INTRODUCTION

Soil acidity is a significant factor limiting agricultural productivity in highland regions of Ethiopia. Excessively acidic soil hinders the availability of essential macro and micronutrients such as nitrogen, phosphorus, potassium, and iron, leading to reduced crop yields and lower quality agricultural produce. Farmers often have limited resources and may not afford expensive

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lime to address this issue. Therefore, the search for more affordable and environmentally friendly methods of soil acidity correction, including the use of organic materials, becomes an urgent task to support sustainable agricultural development in Ethiopia's highland regions.

M.T. Ejersa (2021) noted that in Ethiopia, 43% of arable lands have been affected by soil acidity. The western, southern, northwestern and central highlands of the country are the areas where soil acidity becoming a serious threat to crop production. Imdibir, the site from where the experimental soil was collected, is located in central highlands that affected with soil acidity. The leaching of basic cations (Ca, Mg, and K) and replacing by acid forming cations (Al^{3+} and H^+) due to heavy rainfall, excessive application of H^+ releasing inorganic fertilisers and removal of basic cations during harvesting of the crops are the main causes of soil acidity in the study area. R. Hume *et al.* (2022) noted that the excessive application of urea (NH_2-CO-NH_2) and ammonium (NH_4^+) containing fertilisers contributes protons (H^+ ions) supply during the nitrification of NH_4^+ to nitrate (NO_3^-). The release of H^+ into the soil solution reduces the pH of the soil. P.M. Kopittke *et al.* (2019) concluded that a small decrease in soil pH decreases the availability of soil nutrients (P, K, Ca, and Mg), affects the soil structure, functioning of microbial communities, nitrogen fixation by soil microbes, and sustainability of crop production. The level of available phosphorus in acidic soils is also low. The reason for low availability of phosphorus in acidic soil is owing to fixation of dissolved phosphorus by aluminium and iron. This condition can be minimised by organic amendments (Mutammimah *et al.*, 2020). In Ethiopia, liming has been practicing improving soil pH and nutrient availability in acid affected soil. However, the high price of agricultural lime has been challenging the low income (poor) farmers. For that reason, the researchers and farmers are shifting their idea to organic amendment of acidic soils. According to D. Alabi *et al.* (2022), N. Xu *et al.* (2022), organic fertiliser is cheap, affordable and reduces the cost of using inorganic fertiliser. Furthermore, the addition of agricultural by-products to mineral soils has the potential to improve crop production. That is why this study was focused on filter cake (FC) and bagasse ash (BA) application for soil acidity amendment. A. Soltangheisi *et al.* (2019**)** determined that both FC and BA are sugar industry by-products. FC is a waste by-product from the process of sugar clarification, composed of a mixture of ground sediment and crushed sludge. FC increases soil fertility by providing nitrogen and phosphorous for crops or soil cover. Due to its chemical nature, FC can increase the organic matter content of the soil. Bagasse ash (BA) is also a sugar industry by-product obtained from combustion of bagasse that is used for steam/energy generation. These industrial by-products improve soil properties and crop yields. Replacing chemical fertilisation with these organic by-products not only minimises the surplus usage of chemical fertilisers, Replacing chemical fertilisation with these organic by-products not only minimises the surplus usage of chemical fertilisers, but also a cost-effective and an eco-friendly approach (Raza *et al.*, 2021). These sugar industry by-products (FC and BA) contain micronutrients and macronutrients (Ca, Mg, P, and K) (Hale *et al.*, 2020). Soil application of FC can provide nutrients and enhance physical quality. FC provides nutrients suitable for plant development, and the levels of available P. A. Gonfa *et al.* (2018) and F. Silva *et al.* (2019) noted that FC keeps available P at agronomically adequate levels by improving soil pH. BA application is also recognised as a potential fertiliser as it contains P and K. Nevertheless, it is often disposed of as waste in landfills. However, many reports have been presented by different researchers as both FC and BA have capacity of amending soil chemical properties. However, there was no exhaustive investigation report of FC and BA on acidic Nitisol. Therefore, the purpose of this study was to investigate the effect of FC and BA application on chemical properties amendment of acidic Nitisol.

MATERIALS AND METHODS

Description of the study site. The pot experiment was conducted in 2021 at Debre Zeit Agricultural Research Centre (DZARC) under controlled environment condition. The experimental soil was acidic Nitisol and collected from Imdibir area. Imdibir is located in Cheha District, Gurage Zone, which is 188 km from the capital city, Addis Ababa. Imdibir is geographically located to south of the capital city, between $8^0 7'$-8.117^0N and $37^0 56'$-37.933^0E. The altitude of Imdibir ranges between 2,130-2,164 m.a.s.l. The average annual rainfall in the Imdibiru area is 1,268 mm, based on the ten years monthly data (2001-2010) of the area. The average maximum and minimum temperature for the last ten years (2001-2010) were 24.64°C and 10.29°C, respectively (Fig. 1).

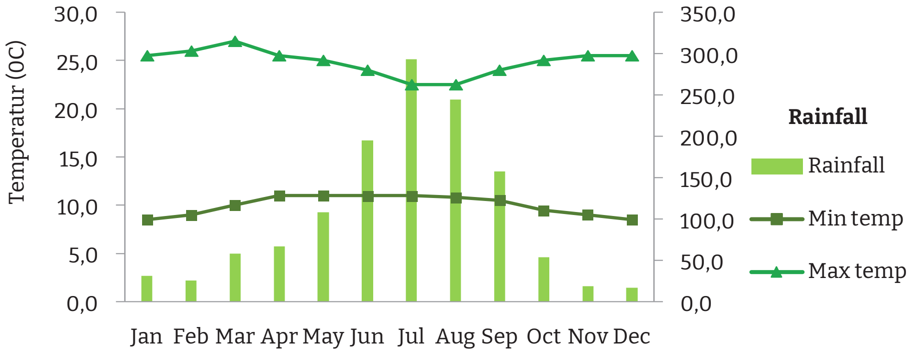

Figure 1. Average ten years monthly precipitation and temperatures of Imdibir area (2001-2010)
Source: District Agricultural Office (n.d.)

Collection of experimental soil. The representative experimental soil was collected for pot experiment from 20 farms. Acid affected soil was selected purposely from the study area to investigate effects of filter cake (FC) and bagasse ash (BA) application in amending soil acidity. The soil was taken at the depth 0-20 cm from each field using sampling system. Ten (10) kg of soil was taken per field. To prepare for pot experiment, all soils that collected separately were composited, well mixed, air dried, ground with mortar and pestle and passed through 4 mm size. One kg of soil sample was taken from homogenised experimental soil, reground, passed through 0.5 and 2 mm sieve and used for laboratory analysis.

Treatment materials. Filter cake (FC) and bagasse ash (BA) were collected from government sugar estate factory. The FC and BA were selected for two reasons: 1) they were locally available in many sugar factories; 2) they were expected to have a high nutrient content and the potential to change soil acidity.

Experimental design and treatment set-up. The pot experiment was conducted at Debre Zeit Agricultural Research Centre (DZARC) under greenhouse condition. The experimental design was completely randomised design (CRD). Filter cake (FC) was air dried, grounded, and weighed according to the treatment levels. The bagasse ash (BA) was also weighed according to the treatment levels. The levels (rates) of filter cake and bagasse ash were 0, 20, 40, 60, 80, and 100 t/ha^{-1}. Each treatment was replicated quartile (four times). The rates of FC were based on that of E.M. Ossom *et al.* (2010) and of BA on that of T. Ferreira *et al.* (2012). Each pot was labelled (tagged) with treatment rate and material that it received. Four (4) kg of experimental soil and known amount of treatment material were well homogenised and transferred to the pot that had been tagged. Each pot was received equal amount of water before sowing and left without receiving seed for one day. In the next day, each pot was received 10 seeds of durum wheat. Each pot was receiving 100 ml of water within three days interval. The seedlings were thinned to seven after they reached 7 cm to minimise the competition for nutrients. Ultimately, the wheat that received BA application has matured earlier than that received FC application. The time variation in maturity may be conditioned by time to taken for FC to be mineralised and being available to the plant.

Analysis of chemical properties of selected soil and treatment materials. The chemical properties of the soil and treatment materials were analysed using standard analytical laboratory procedures. The pH of the soil and treatment materials was analysed potentiometrically with 1:2.5 soil to water ratio. Electrical conductivity (EC) was measured using digital conductometer and the supernatant used for pH reading. Exchangeable acidity (H^{+}+A^{3+}) was determined by percolating the soil with 1M KCl solution. The acidity brought into soil solution from various sources was measured by titration in the presence of standardised 0.02M HCl and 0.02M NaOH using phenolphthalein indicator.

Organic carbon (OC) was determined by Walkley-Black wet oxidation method and the obtained results were converted to organic matter (OM) using the conversion factor 1.724. Total nitrogen (TN) was determined by Kjeldahl macro digestion method using sulphuric acid and mixed catalysts to convert organic nitrogenous to ammonium sulphate. Soil phosphorus (P) was analysed spectrophotometrically using Bray-II method for soil before planting and Olsen method for soil that affected with treatment materials based on their pH. Sulphur (S) was determined turbidimetrically using barium chloride to precipitate SO_4^{2-}-S in the form of barium sulphate ($BaSO_4$). The turbidity was measured using spectrophotometer. Exchangeable bases were determined by ammonium acetate method which adjusted to pH 7.0. The reading was performed using atomic absorption spectrophotometer (AAS), AA series model. Cation exchangeable capacity (CEC) was determined, using 10% sodium chloride as extractant solution after the residue of ammonium salt have been washed with 97% ethanol alcohol. The distillation was conducted using Kjeldahl distillation unit and the quantification was made by titration method. Soil micronutrients were determined using diethylenetriaminepentaacetic acid (DTPA) as extracting solution and reading was conducted using atomic absorption spectroscopy (AAS), AA series model. Correlations among the treatment rates and different variables were computed using Pearson's correlation analysis.

Statistical analysis and data interpretation. All data generated from the soil affected by FC and BA application were subjected to statistical analysis using (SAS virsion 9.0). Significant difference among treatments means was assessed using the least significant difference (LSD) test at 0.05 probability level.

Analytical results of soil and treatment materials before planting. The experimental soil and treatment materials were analysed before sowing and the results are presented below (Table 1).

Table 1. Chemical properties of soil, filter cake and bagasse ash

Chemical parameter	Soil before sowing	Filter cake (FC)	Bagasse ash (BA)
pH-H_2O	5.1	8.0	10.2
EC (dS/m)	0.01	1.70	3.90
OM (%)	3.38	36.20	3.60
N (%)	0.16	1.77	0.17
Avail P (%)	0.0010	1.62	0.85
Avail S (%)	0.0035	1.67	1.29
Exch Na (cmol(+)/kg)	0.25	4.02	1.82
Exch K (cmol(+)/kg)	1.89	4.04	1.41
Exch Ca (cmol(+)/kg)	5.04	65.00	13.18
Exch Mg (cmol(+)/kg)	2.80	26.00	5.84
Exch.Al+H (Meq/100gsoil)	0.54	-	-
Fe (mg/kg)	44.0	3.00	3.00
Mn (mg/kg)	154	39.00	19.00
Cu (mg/kg)	0.56	1.24	0.40
Zn (mg/kg)	2.40	31.00	10.50

Source: developed by the author

The EC of the soil before sowing was low. The reason for low EC may be due to leaching of cations and anions by heavy rain of the study area. The organic matter (OM) content of the soil before sowing was moderate according to G. Getachew & T. Mamo (2019). However, the nitrogen content of the soil before sowing was found being low (Landon, 1991). The reason may be due to leaching of nitrogen that changed into inorganic N form. The available P content of the soil was determined using Bray-II method as the soil was strongly acidic before sowing and the results was found being medium and the value was found being 0.001% (10 mg/kg^{-1}).

The available sulphur was determined by turbidimetry and the result was found being 0.0035% (35.2 mg/kg^{-1}) for soil before sowing. The exchangeable Na, K, Ca, and Mg content of the soil before sowing were found low, very high, very high, and medium, respectively (FAO, 2006) (Table 1). The exchangeable acidity was found being 0.54 meq/100 g soil. The micronutrients were also analysed for experimental soil before planting (Table 1). According to B. Jones (2003), the soil Fe, Mn, Cu, and Zn content are rated as high, very high, low, and high, respectively. The high micronutrients content of this soil shows that the soil was strongly acidic. This may be due to high leaching of basic cations with heavy rainfall.

The experimental materials (filter cake (FC) and bagasse ash (BA)) were analysed to determine their nutrient content. The data revealed that the pH of FC and BA were 8.0 and 10.2, respectively. The FC contained 36.2% OM, 1.77% N, 1.62% P, and 1.67% sulphur. The BA contained 0.85 % P and 1.29% SO_4^{-2}-S before sowing.

The content of Na, K, Ca, and Mg in FC were 4.02, 4.04, 65, and 26 cmol(+) kg^{-1}, respectively (Table 1). Soil CEC, sum of bases (S) and base saturation ratio (V) were significantly improved with increasing rates of filter cake. This coincided with the finding of the Fe, Mn, Cu, and Zn content of the FC of 3, 39, 1.24, and 31 cmol(+) kg^{-1}, respectively. BA contained 3.6% OM, 0.17% N, 0.85% P, and 1.29% sulphur. The exchangeable base of BA were 1.84, 1.41, 13.81, and 5.84 cmol(+) kg^{-1} for Na, K, Ca, and Mg, respectively while the Fe, Mn, Cu, and Zn contents were 3, 19, 0.40, and 10.5 mg/kg, respectively. The results show that FC contained relatively more nutrients compared to BA.

RESULTS AND DISCUSSION

Chemical properties of soil as affected by filter cake (FC) and bagasse ash (BA) application

The soil was also analysed after affected with FC and BA rates application to assess the impact of FC and BA on soil chemical properties. The ANOVA showed that the pH of the soil was significantly affected (P<0.0001) by FC and BA rates application. The pH was increased with increasing rates of FC and BA application (Table 2, 3).

Table 2. Analytical results of the soil as affected by FC application

FC (kg ha^{-1})	pH-H_2O (1.:2.5)	EC (dS/m)	OM (%)	N (%)	Ava.P (mg/kg)	Ava.S (mg/kg)
0	5.1^{e}	0.01^{e}	3.5^{f}	0.14^{e}	10.0^{f}	35.2^{f}
20	6.2^{d}	0.25^{d}	3.8^{e}	0.18^{d}	42.0^{e}	76.5^{e}
40	6.5^{c}	0.30^{c}	4.2^{d}	0.20^{c}	97.5^{d}	119.4^{d}
60	6.9^{b}	0.54^{b}	4.8^{c}	0.21^{b}	139.8^{c}	156.5^{c}
80	7.0^{b}	0.54^{b}	5.1^{b}	0.22^{b}	185.8^{b}	266.5^{b}
100	7.3^{a}	0.63^{a}	5.4^{a}	0.26^{a}	224.5^{a}	389.4^{a}
LSD (5%)	0.20	0.03	0.11	0.01	5.71	0.156
CV (%)	2.14	4.13	1.64	3.75	3.28	0.059

Note: values with the same letters within a column are not significantly different at $\alpha = 0.05$
Source: developed by the author

Table 3. Analytical results of soil as affected by BA application

Ba (kg ha^{-1})	pH-H_2O (1.:2.5)	EC (dS/m)	OM (%)	N (%)	Ava.P (mg/kg)	Ava.S (mg/kg)
0	5.1^{d}	0.01^{e}	3.5^{c}	0.14^{c}	10.0^{f}	35.2^{e}
20	6.8^{c}	0.21^{e}	3.6^{b}	0.15^{b}	14.4^{e}	55.8^{d}
40	6.9^{cb}	0.24^{d}	3.8^{a}	0.16^{b}	19.9^{d}	65.3^{c}
60	7.0^{b}	0.30^{c}	3.8^{a}	0.17^{b}	40.2^{c}	76.6^{b}
80	7.1^{b}	0.34^{b}	3.8^{a}	0.17^{b}	55.0^{b}	77.3^{b}

Table 3, Continued

Ba (kg ha^{-1})	pH-H_2O (1.:2.5)	EC (dS/m)	OM (%)	N (%)	Ava.P (mg/kg)	Ava.S (mg/kg)
100	7.4[a]	0.38[a]	3.8[a]	0.18[a]	57.7[a]	104.9[a]
LSD (5%)	0.19	0.02	0.06	0.01	1.61	3.40
CV (%)	1.81	3.21	2.46	4.56	3.96	3.42

Note: values with the same letters within a column are not significantly different at $\alpha = 0.05$
Source: developed by the author

In general, except for control, the soil pH fell in the range of slightly acidic to slightly alkaline for FC application and neutral to slightly alkaline for BA application (Table 2, 3). The reason for soil pH increment may be due to the presence of basic cations (Ca and Mg) in the form of carbonates within the FC and BA. The finding was in line with that reported by T. Matsi & V.Z. Keramidas (1999) that changes in pH values strongly dependent on ash application rates. The finding also corroborates with A. Demeyer *et al.* (2001) that the increase of pH in acidic soil is conditioned by high alkalinity of BA. Application of FC and BA also highly significantly affected ($P<0.001$) soil EC, OM, N, Ava.P and Ava.S (Table 2, 3). The maximum and the minimum value were recorded at 100 t/ha^{-1} and control treatment both for FC and BA application (Table 2, 3). The EC of the soil was low before FC and BA application. However, the EC of the soil found being increased after the soil affected with FC and BA application. The reason may be due to the availability of free cations and anions in the treatment materials. The soil treated with FC showed the dominance over the same soil treated with BA application in EC. The reason might be due to high Ca and Mg content in the FC. S. Ghulam *et al.* (2010) also reported that FC has capacity to increase the EC of the soil. In general, both FC and BA applications significantly increased the EC of the experimental soil over the control treatment.

The OM content of the soil was highly significantly ($P<0.0001$) increased over control with increasing rates of FC and BA applications (Table 2, 3) and the lowest and the highest values were recorded at control and 100 t/ha^{-1} for both treatment variants. However, FC application increased the soil OM content more than BA applications. Naturally, FC is rich in organic matter content when compared with BA. This may be due to removal of OM from BA during ashing process. Similarly, the N content of the soil was highly significantly ($P<0.0001$) affected with FC and BA application (Table 2, 3). The maximum and minimum values were recorded at 100 t/ha^{-1} and control treatment for both materials. The same to OM, the maximum soil N content, was recorded by the soil that affected with FC application when compared with soil that affected with BA application. This may be due to high N content in FC when compared with that of BA. According to J.R. Landon (1991) the maximum value of N content for soil that affected with FC application was in the range of moderate and in the range of low for soil affected with BA application. The reason is that during burning and /or ashing of bagasse, N escapes in the form of gas. However, both treatment materials increased the soil N content progressively. When comparing the two by-products, the FC application increased soil N content over BA application with respective to their rates. S. Ghulam *et al.* (2010) also reported that application of FC increased the soil N content progressively as the rates of application increased.

The soil available P and S content were highly significantly affected ($P<0.0001$) with FC and BA application. The increment was gone progressively and /or according to their rates for both nutrients. Accordingly, the maximum and minimum results were recorded at 100 t/ha^{-1} and at control for both treatment materials (Table 2, 3). According to B. Jones (2003) the maximum values of P that recorded with soil that affected with FC and BA application are categorised in the rate/range of very high and the minimum value that recorded at control in the range of low. J.M. Khan (2011) reported that both treatment materials (FC and BA) application increased the P content of the soil. The findings also coincide with that of E. Ferreira *et al.* (2012) that application of BA increased soil P content. The reason for soil available P increment may be due to incorporation of P through FC and BA application, and due to soil pH increment. The improvement of soil pH improves the release of P from fixed form to available form. Application of FC and BA was also improved the sulphur content of the experimental soil (Table 2, 3). However, according to D.A. Horneck et *al*. (2011), the experimental soil was high in available S content before it was receiving the treatment materials.

The basic cations of the soil were also subjected to laboratory analysis using neutral ammonium acetate (PH=7.0) as extracting solution.

The ANOVA showed that both FC and BA application highly significantly affected (P<0.0001) the basic cations, CEC and BS of the experimental soil (Table 4, 5).

Table 4. Analytical results of soil exchangeable basic cations as affected by FC application

FC (t/ha^{-1})	Na cmol$^{(+)}$/kg	K cmol$^{(+)}$/kg	Ca cmol$^{(+)}$/kg	Mg cmol$^{(+)}$/kg	CEC cmol$^{(+)}$/kg	BS (%)
0	0.22^{e}	1.40^{d}	4.9^{f}	3.5^{f}	22.8^{f}	43.8^{e}
20	0.46^{d}	2.28^{c}	14.1^{e}	4.8^{e}	30.8^{e}	71.0^{d}
40	0.46^{d}	2.28^{c}	16.6^{d}	5.9^{d}	31.8^{d}	79.6^{c}
60	0.67^{c}	2.88^{b}	18.4^{c}	6.3^{c}	32.8^{c}	86.0^{b}
80	0.93^{b}	2.93^{a}	21.9^{b}	7.8^{b}	34.8^{b}	96.6^{a}
100	1.11^{a}	2.93^{a}	22.9^{a}	8.9^{a}	36.5^{a}	98.0^{a}
Mean	0.64	2.45	16.45	6.03	31.54	79.12
LSD (5%)	0.07	0.14	0.54	0.05	0.74	8.77
CV (%)	7.15	1.14	2.19	0.59	1.56	7.59

Note: values with the same letters within a column are not significantly different at $\alpha=5\%$
Source: developed by the author

Table 5. Analytical results of soil as affected by BA application

BA(t/ha)	Na cmol$^{(+)}$/kg	K cmol$^{(+)}$/kg	Ca cmol$^{(+)}$/kg	Mg cmol$^{(+)}$/kg	CEC cmol$^{(+)}$/kg	BS (%)
0	0.22^{e}	1.4^{f}	4.9^{f}	3.5^{f}	22.8e	43.8^{f}
20	1.1^{d}	2.2^{e}	8.4^{e}	5.6^{e}	28.1^{d}	61.4^{e}
40	1.2^{d}	2.6^{d}	9.6^{d}	6.5^{d}	28.1^{d}	70.9^{d}
60	1.5^{c}	3.5^{c}	9.8^{c}	8.8^{c}	29.1^{c}	78.9^{c}
80	2.1^{b}	3.9^{b}	12.2^{b}	9.1^{b}	31.1^{b}	87.8^{b}
100	2.3^{a}	4.2^{a}	13.1^{a}	9.5^{a}	32.0^{a}	91.4^{a}
Mean	1.52	3.30	9.51	7.54	28.92	72.50
LSD (5%)	0.05	0.13	1.13	0.15	0.62	2.55
CV (%)	2.20	2.57	0.88	1.33	1.41	2.33

Note: values with the same letters are not significantly different at $\alpha=5\%$
Source: developed by the author

The highest values were recorded at maximum rates of FC and BA application and the minimum at control for all basic cations, CEC and base saturation (Table 4, 5). The maximum K results were recorded at maximum rate of FC and BA application with values of 2.93 and 4.20 cmol(+)/kg, respectively. The application of both treatment materials progressively increased the K content in experimental soil. S. Ghulam *et al.* (2010) also reported that filter cake application progressively increased the soil K content. The minimum soil K content was recorded at control with value 1.40 cmol (+)/kg. According to FAO (2006) both maximum and minimum value of K are categorised under very high rate. The same to K the highest Ca content was recorded at the highest rate of FC and BA application with values 22.9 and 13.5 cmol(+)/kg, respectively. Accordingly, the maximum Ca value obtained from the soil that received the maximum application of FC is in the range of very high values, and the maximum value obtained from the soil that received the maximum application of BA is in the range of high values. The maximum Mg content of the soil that affected with FC and BA application was recorded at maximum rate of FC and BA application with values 8.9 and 9.5 cmol(+)/kg, respectively

(Table 4, 5). These values are rated as high and very high for FC and BA application, respectively. The results revealed that BA application was more affected the soil Mg content when compared to FC application. In general, application of FC was increased soil Ca content over the soil that received BA application and BA increased K and Mg content over the soil that received FC rates application. The reason for high Ca content in the soil that affected with FC application may be due to the existence of substantial amounts of $CaCO_3$ in the FC. $CaCO_3$ used to increase soil pH and soil calcium content. However, both treatment materials had increased exchangeable basic cations of the experimental soil. J.M. Khan (2011) and E. Ferreira *et al.* (2012) also reported that both FC and BA application rates increased the basic cations content of the soil. The reason may be conditioned by incorporation of cations through FC and BA application and increment of soil pH which has contribution for nutrient release and availability. This indicates that nutrients are released and available at their optimum pH ranges. S.E. Hale *et al.* (2020) also reported that application of ash at the rates 3 to 5 t/ha^{-1} decreased soil acidity, increased base saturation and the total amount of nutrients.

The CEC of the experimental soil was highly significantly ($P<0.0001$) affected with FC and BA application. The CEC of the soil was increased progressively with increasing rates of FC and BA application (Table 4, 5). The minimum CEC was recorded at control and the maximum at maximum rate (100 t/ha^{-1}) of FC and BA application, and the values were 22.8, 36.5, and 32.0 cmol(+)/kg^{-1}, respectively (Table 4, 5). In general, all treatments that received FC and BA application had recorded the CEC values that fell in the range of high rate. The CEC value that recorded at control treatment was found fell in the range of medium. The reason for increment of soil CEC by FC over that of BA was due to high OM and Ca content of FC. M.S. Mokolobate & R.J. Haynes (2002) reported that application of FC has improved the CEC of the soil. BA also increased the CEC of the soil because of its high cations contents and pH.

Base saturation (BS (%)) of the experimental soil was significantly ($P<0.0001$) affected with FC and BA application. The lowest value was recorded at control and the highest at the maximum rates (100 t/ha^{-1}) of FC and BA application (Table 4, 5) and the results were 43.8, 98.0, and 91.4 cmol(+)/kg. According to P. Hazelton & B. Murphy (2007) the maximum values recorded at 100 t/ha^{-1} of FC and BA application are rated as very high and the minimum as moderate. The finding corresponds to that of S. Ghulam *et al.* (2010) that FC application rates improved the chemical properties of the experimental acidic Nitisol. The finding are also in agreement with that of E. Ferreira *et al.* (2012) that BA applications improved soil base saturation as it contained good amount of basic cations. Hence, FC and BA application can be potentially improve soil fertility by increasing basic cations, of the soil. As a whole, the organic inputs had shown their potential of neutralising acidic Nitisol, improved basic cations and base saturation. This is a great advantage for farmers who cannot afford the inorganic compounds used as lime material.

Exchangeable acidity and micronutrients are other soil chemical parameters that were subjected to laboratory analysis during this study. The results are presented in the (Table 6, 7). The ANOVA showed that soil exchangeable acidity ($H^{+}+Al^{3+}$) highly significantly ($P<0.0001$) affected with FC and BA application. The maximum value was recorded at control and the minimum at 100 t/ha^{-1} FC and BA application (Table 6, 7).

Table 6. Analytical results of soil acidity and micronutrients as affected by FC application

FC rates (t/ha^{-1})	Ex. Acidity meq/100 g soil	Fe mg/kg	Mn mg/kg	Cu mg/kg	Zn mg/kg
0	0.54^{a}	16.1^{f}	66.1^{f}	0.54^{e}	7.8^{f}
20	0.42^{b}	22.3^{e}	89.0^{e}	1.9^{d}	11.9^{e}
40	0.30^{c}	24.6^{d}	102.8^{d}	2.1^{c}	16.5^{d}
60	0.19^{d}	26.5^{c}	116.0^{c}	2.2^{b}	18.1^{c}
80	0.14^{e}	29.1^{b}	140.8^{b}	2.5^{a}	22.0^{b}

Table 6, Continued

FC rates (t/ha^{-1})	Ex. Acidity meq/100 g soil	Fe mg/kg	Mn mg/kg	Cu mg/kg	Zn mg/kg
100	0.06^{f}	31.3^{a}	149.6^{a}	2.5^{a}	24.4^{a}
Mean	0.27	24.9	115.11	2.14	16.80
LSD (5%)	0.01	0.80	2.37	0.06	0.39
CV(%)	2.60	2.29	1.35	1.96	1.52

Note: values with the same letters within a column are not significantly different
Source: developed by the author

Table 7. Analytical results of soil sample as affected by BA application

BA rates (t/ha^{-1})	Ex. Acidity meq/100g soil	Fe mg/kg	Mn mg/kg	Cu mg/kg	Zn mg/kg
0	0.54^{a}	16.1^{d}	66.1^{d}	0.54^{f}	7.8^{d}
20	0.42^{b}	25.2^{a}	75.2^{a}	1.60^{a}	16.2^{c}
40	0.28^{c}	20.4^{b}	72.0^{b}	1.50^{b}	16.5^{c}
60	0.20^{d}	16.7^{c}	60.5^{d}	1.40^{c}	17.5^{b}
80	0.12^{e}	10.4^{e}	54.0^{e}	1.30^{d}	18.1^{a}
100	0.04^{f}	4.4^{f}	43.8^{f}	1.20^{e}	18.5^{a}
Mean	0.27	15.52	62.67	1.41	15.77
LSD (5%)	0.01	0.61	0.80	0.01	0.49
CV (%)	2.72	2.60	0.87	0.55	2.06

Note: values with the same letters within a column are not significantly different
Source: developed by the author

The results were 0.54, 0.06, and 0.04 cmol(+) /kg^{-1} for control, and 100 t/ha^{-1} of FC and BA application, respectively (Table 6, 7). B.M. Dee *et al.* (2002) reported that both FC and BA application significantly reduced the concentration of exchangeable acidity of the soil. The reason may be due to soil pH and basic cations improvement with FC and BA application. The presence of Ca in the FC and BA can precipitate Al in the form of $Al(OH)_3$ and decrease its availability and/or solubility in the soil solution.

Filter cake (FC) and BA application affected the soil micronutrients differently and partly differently. Application of FC affected soil micronutrients highly significantly ($P<0.0001$) and positively (Table 6). The results gradually increased based on the increasing rates of FC applications. The lowest values of micronutrients were recorded at control and the highest – at maximum rate (100 t/ha^{-1}) of FC application. The values for were 16.1, 66.1, 0.54, and 7.8 mg/kg^{-1} for minimum results and 31.1, 149.6, 2.6, and 24.4 mg/kg^{-1}for maximum Fe, Mn, Cu and Zn content, respectively. According to B. Jones (2003), Fe and Zn fell in the range of high and Mn in the range of high to very high categories for FC applications. On the other hand, all results of Cu fell in the range of low for soil affected with FC applications even if the results were going increasing based on the rates of FC applications (Table 6). K. Kaur *et al.* (2004), S. Ghulam *et al.* (2010) also reported that FC application increased the micronutrients content of the soil.

The BA application affected soil micronutrients partly negatively and partly positively. Fe and Mn were affected negatively and Cu and Zn positively with FC applications. Both Fe and Mn were increased at 20 t/ha^{-1} BA applications and then declined. The reason may be that the solubility Fe and Mn decrease as soil pH increase. The lowest and the highest results were recorded at 100 and 20 t/ha^{-1} BA application, and the values were (4.4, 43.8 and, 25.2 75.2 mg/kg^{-1}) for Fe and Mn, respectively (Table 7). The highest Fe value (25.2 mg kg^{-1}) for soil affected with BA application was found in the range of high and the lowest (4.4 mg/kg^{-1}) in the range of medium. For Mn, the lowest value (43.8 mg kg^{-1}) was in the range of high, and the highest (75.2 mg/kg^{-1}) in the range of very high. Both the lowest (0.54 mg/kg^{-1}) and the highest (1.20 mg/kg^{-1}) content of Cu were found in the range of low Cu categories. The Zn content of the soil increased progressively with increasing rates of BA applications. The lowest value (7.8 mg/kg^{-1}) was recorded at control treatment and the highest (18.5 mg/kg^{-1}) – at 100 t/ha^{-1} of BA applications (Table 7). The lowest and the highest values of Zn were found in the range of high and very high, respectively (Table 7). In general, BA application reduced Fe and Mn content of the soil. E. Ferreira *et al.* (2012) also reported that BA application reduced the soil micronutrients. The reason may be due to increase in soil pH as BA rate application increase. As soil pH increase the availability (solubility) of micronutrients decrease. However, Cu availability increase at optimum (neutral) soil pH.

Comparison of soil chemical properties that affected with FC and BA application. The analytical results of FC and BA indicated that the nutrients continent of FC was somewhat higher than that of BA. The analysis was also conducted on soil affected with FC and BA application to observe the nutrients contribution of FC and BA for the soil. As observed from (Fig. 2) above, BA applications more affected soil pH compared with the soil affected with FC applications. On the other hand, FC applications more affected soil OM (%), and N (%) compared with BA rates application. The responses were directly related with properties of treatment materials with BA was high in pH when compared with FC, and FC was high in OM and N content. The reason for high OM and N content in FC may be due to its existence in natural status (without losing OM and N). However, BA was an organic material that subjected to fire (ashing) for the purpose of steam generation. In general, ashing could affects OM, N, and S content of organic substances. FC applications also dominated over BA applications in improving soil phosphorus (P) content (Fig. 3). The reason was that FC was rich in P content compared with BA.

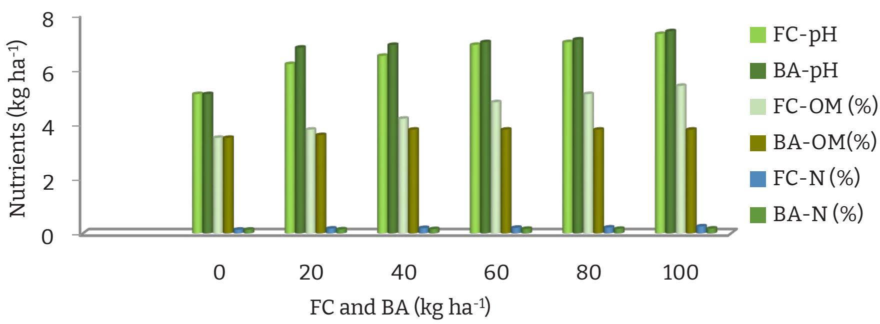

Figure 2. Graph of soil chemical parameters as affected with FC and BA application
Note: FC-pH – FC-affected soil pH
Source: developed by the author

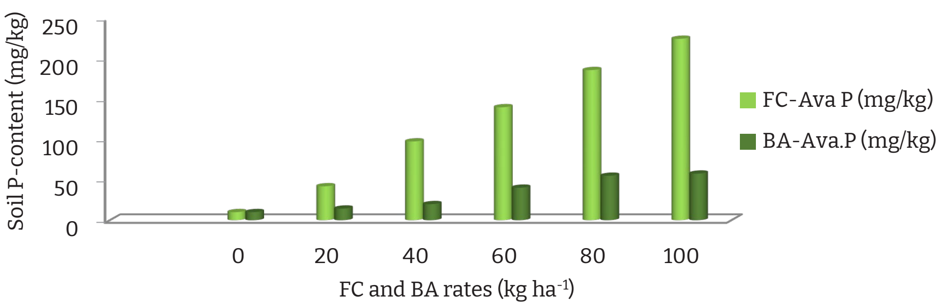

Figure 3. Graph of soil P as affected with FC and BA application
Source: developed by the author

The Figure 4 showed that FC application rates progressively increased the Ca content of the soil by dominating over soil Ca content that affected by BA rate applications. The soil response was correct that FC was high in Ca content compared to BA. However, BA improved soil Mg content more than FC even if FC was high in Mg content (Fig. 4). The lower contribution of Mg in FC compared to BA may be conditioned by nutrient imbalance, as FC had an excess of Ca.

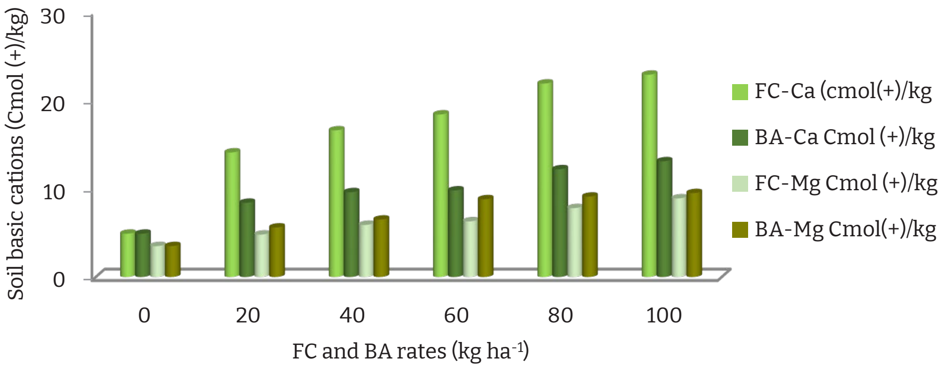

Figure 4. Soil basic cations as affected with FC and BA rates application

Source: developed by the author

The FC application dominated over BA application in improving soil cations exchangeable capacity (CEC) (Fig. 5). The reason was that FC was rich in CEC source substances (OM and $CaCO_3$). However, both treatment materials (FC and BA) increased the soil CEC progressively. In general, FC and BA applications were found to affect the soil nutrients content according to the quantity of the nutrients they contained.

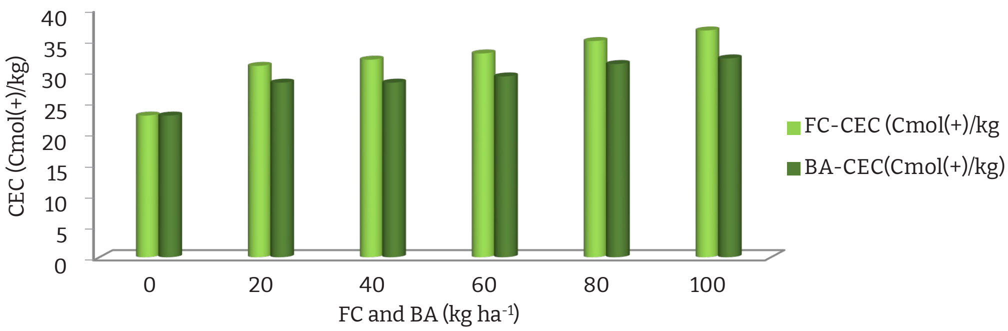

Figure 5. Soil CEC as affected by FC and BA application rates

Source: developed by the author

Correlation analysis. The correlation analysis was conducted among the nutrients and rates of FC and BA, and among different nutrients values obtained from soil affected with FC and BA application. The correlation analysis showed that all nutrients positively and highly significantly ($P<0.0001$) correlated with FC application rates. The OM, Ava.P, Ca, and MG positively correlated with pH with correlation coefficient (r) = 0.86, 0.76, 0.80, and 0.88, respectively (Table 8). OM correlated with Ava.P, Ca, and Mg with r = 0.69, 0.76, and 0.77, respectively. In the same way, Ava.P of the soil positively and highly significantly correlated with Ca and Mg with correlation coefficient r = 0.98 and 0.96 for FC application. Mg correlated with Ca with r = 0.96.

Table 8. Correlation of soil nutrients as affected with FC application

Var.	Rates	pH	OM(%)	Ava.P	Ca	Mg
Rates	1					
pH	0.81****	1				
OM(%)	0.74****	0.86****	1			
Ava.P	0.98****	0.76****	0.69****	1		
Ca	0.98****	0.80****	0.76****	0.98****	1	
Mg	0.98****	0.88****	0.77****	0.96****	0.96*****	1

Source: developed by the author

Table 9. Correlation of soil nutrients as affected with BA application

Var.	Rates	pH	%OM	Ava.P	Ca	Mg
Rates	1					
pH	0.95****	1				
OM (%)	0.99****	0.96****	1			
Ava.P	0.99****	0.95****	0.99****	1		
Ca	0.94****	0.96****	0.93****	0.90****	1	
Mg	0.98****	0.95****	0.90****	0.98****	0.97****	1

Source: developed by the author

The same as FC, the nutrients positively and significantly correlated ($P<0.0001$) with the rates of BA application. OM, Ava.P, Ca, and Mg highly significantly correlated with pH of the soil obtained from the soil affected with BA application and the correlation coefficients (r) were = 0.96, 0.95, 0.96, and 0.95, respectively (Table 9). This indicates that BA application increased soil pH and the availability of P, Ca, and Mg. Available P (Ava.P), Ca, and Mg were correlated with OM with r = 0.99, 0.93, and 0.90, respectively. The Ava.P content of the soil affected with BA positively correlated with Ca and Mg with correlation coefficient (r) = 0.98 and 0.96, respectively. Magnesium (Mg) positively correlated with calcium (Ca) with r = 0.97.

CONCLUSIONS

Soil acidity is becoming a critical problem in Ethiopian high rainfall areas. To solve this problem, researchers and farmers practice liming even on a large scale. However, the cost of lime is rising, and farmers are unable to afford the cost. Hence, organic amendments were considered as an option to manage soil acidity. The application of organic fertilisers increases soil pH, available P, available Ca, organic matter, CEC, and total N. Organic amendments improve soil phosphorus availability by forming Al-complex ($Al(OH)_3$) with organic anions. The complex of Al with organic anions improves soil P availability by making P freely available in the soil. Hence, to amend chemical properties of acidic Nitisol, FC and BA were considered as organic amendment materials. FC and BA had pH of 8.2 and 10.2, respectively and they affected the pH of the soil accordingly. Both sugar industry by-products are also rich in basic cations, CEC, and base saturation. FC was richer in Ca, OM, P, and N content compared to BA. The results showed that the pH of acidic Nitisol was improved with FC and BA application. Both, FC and BA application improved the soil fertility parameters (OM, N, Ava.P, CEC), basic cations (K, Ca, Mg), base saturation, micronutrients, and decreased soil exchangeable acidity ($Al^{+}+H^{+}$). FC has increased soil OM, N, and Ca content of the soil when compared to BA application. The reason is that FC is more organic in nature when compared to BA. The reason is that, bagasse ash is a by-product obtained after bagasse subjected to the boilers of sugar factory for steam for steam/energy generation. Therefore, its OM, N, and S content are negatively affected during combustion. As a result, BA relatively less affected soil OM, N, and S compared to FC application. Nevertheless, BA has well affected acidic Nitisol when compared to the control. BA application also increased soil pH and Mg content over FC application. The reason is that BA was comparatively high in pH compared to FC. In general, the results showed that FC and BA application are promising in amending soil acidity. However, a far-reaching field experiment is required to make a better recommendation.

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CONFLICT OF INTEREST

None.

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Вплив застосування фільтраційного кеку та золи жому на окремі хімічні властивості кислого нітізолу

Анотація. Зростання вартості вапна, яке традиційно використовується для боротьби з кислотністю ґрунту та її негативним впливом на родючість ґрунту, спонукало до вивчення органічних побічних продуктів як більш доступної альтернативи для зменшення кислотності ґрунту, особливо для фермерів з низькими доходами. Тому метою цього дослідження було вивчити вплив застосування фільтраційного кеку (ФК) та золи жому (ЗЖ) на кислотність ґрунту в тепличних умовах. Експеримент був закладений у повністю рандомізованому досліді з чотирма повтореннями. Окремо досліджували ФК та ЗЖ з шістьма рівнями (0, 20, 40, 60, 80 та 100) т/га$^{-1}$. Кислий ґрунт був відібраний з Імдибірського району з глибини 0-20 см, висушений на повітрі, подрібнений і пропущений через сито з розміром отворів 4 мм. У кожен горщик було внесено по 4 кг ґрунту з відповідним оброблювальним матеріалом після того, як вони були добре гомогенізовані. Лабораторний аналіз показав, що початковий pH ґрунту становив 5,1, тоді як фільтраційний осад та зола жому мали значення pH 8,0 та 10,2, відповідно. Застосування ФК підвищило pH ґрунту з 5,1 до 7,3, а також покращило вміст органічної речовини, азоту, фосфору, сірки, калію, кальцію, магнію та ємність катіонного обміну. Аналогічно, застосування ЗЖ підвищило pH з 5,1 до 7,4 і збільшило вміст органічної речовини, азоту, фосфору, сірки, калію, кальцію, магнію та ємність катіонного обміну. Максимальний ефект як для ФК, так і для ЗЖ спостерігався при найвищій нормі внесення (100 т/га$^{-1}$), тоді як вміст заліза і марганцю збільшувався при внесенні ЗЖ, але зменшувався зі збільшенням норми, а вміст міді і цинку позитивно впливав як при застосуванні ФК, так і ЗЖ. Загалом, застосування як ФК, так і ЗЖ значно покращило pH ґрунту та вміст поживних речовин. Результати цього дослідження можуть забезпечити практичні та економічно ефективні рішення для покращення родючості ґрунту та виробництва сільськогосподарських культур

Ключові слова: Імдибір; вилуговування; фіксація; основні катіони; кислотоутворюючі катіони; обмінна кислотність