Socio-economic impacts of possible brewery waste recycling in agriculture

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Abstract: Adoption of agricultural technology may solve problem of farmers in agriculture, but its environmental, social and economic impacts should be evaluated in advance of field and laboratory experiments in context of food crops. The use of brewery sludge (BS) technology is one of the means by which soil fertility, crop production and productivity can be improved to meet the growing food demands of people in the world. However, the use of BS or brewery by-product as alternative means of organic fertilizer source in agriculture was ignored by farmers in Ethiopia for decades. This study was elucidated the environmental, social and economic impacts of brewery waste recycling in agricultural crop production. Additionally, the obtained information was forwarded to Ethiopian government to include this environmentally friend technology in agricultural policy of country. Primary data were collected from respondents drawn from smallholder farmers who used BS on their farm lands, and in supplement of this study field experiments also carried out on research station and farm site to evaluate crops productivity. Descriptive statistics and other experimental methods were used evaluate the obtained data. The use brewery waste recycling technology in agriculture has an impact of environmentally friend, better crops productivity, socially acceptable and economic importance.

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PUBLIC INTEREST STATEMENT

The use of brewery sludge (BS) technology is one of the means by which soil fertility, crop production and productivity can be improved to meet the growing food demands of people in the world. This study was evaluated the environmental, social and economic impacts of brewery waste solid sludge on food crops.

The application of chemical fertilizers to the soil was a practice that most commonly used in agriculture. However, the use of inorganic fertilizer can cause environmental pollution and increase the cost of crop production. To reduce such expenditure and to improve the soil fertility of land, BS application (which is considered an organic fertilizer) is an alternative source of plant nutrients. Thus, considering Ethiopia’s industrial expansions that can cause negative impact on terrestrial ecosystem and human health, this study was important that may provide information on scientific way of BS technology use in agriculture.
1. Introduction
In Ethiopia, agricultural soils were used extensively in crop production on low soil organic matter that had less essential plant nutrients (Food and Agriculture Organization [FAO], 2015; Hurni et al., 2010). The application of chemical fertilizers to the soil was a practice that most commonly used in agriculture. However, the use of inorganic fertilizer can cause environmental pollution and increase the cost of crop production. To reduce such expenditure and to improve the soil fertility of land, brewery sludge (BS) application (which is considered an organic fertilizer) is an alternative source of plant nutrients.

The increase of population, expansion of industries and technologies were main reasons of increased of human demand and reduced natural resource supply (Jassim, 2017). In Ethiopia, agricultural soils were highly degraded and become unproductive, because they have been used intensively for crop production for extended period of time and run out of soil organic matter and essential plant nutrients. Addition of chemical fertilizers is most commonly used, which increased the cost of crops. To reduce such expenditure and to sustain soil productivity, BS application (which is considered an organic fertilizer) can be used as an alternative source of plant nutrients.

The scientific use of brewery waste sludge in crop production was almost negligible in majority of developing countries, because less efforts taken by researchers to cope-up the perceptions of farmers on understanding of the economic values of brewery waste sludge in agriculture (Sadh, Duhan, & Duhan, 2018). Industrial waste solid sludge can be used in agricultural practices, because of the presence of high organic content which further help to obtain high crop productivity and also it can be easily available (Sharanappa, Wani, & Pallavi, 2011).

BS can substitute commercial fertilizers if it is applied in right amounts to the soil and used at appropriate time by farmers. The use of brewery waste can provide opportunity to farmers to supply their lands with organic fertilizer at low costs. Therefore, recycling of sludge for agricultural purpose seems to be an appealing solution for sustainable management of soil.

On the other hand different scholars stated that, brewery waste sludge has very important biological organic fertilizer/soil conditioner for sustainable agriculture. It can improve organic matter status of the soil. Additionally, it can add macro and micronutrients to the soil. Improvement in organic matter content in soil can improve the soil physical conditions, rejuvenating soil health and stimulating biological activity. Generally, positive impacts of application of BS have been reported on cereals, vegetable and horticultural plants, pastures and forestry in many researches (Dessalew et al., 2017).

Although the Harar City cannot be considered among the growing brewery cities in Ethiopia, the Harar beer factory has been expanding in its production capacity. The current daily sludge production of the brewing industry has increased significantly along with the expansion and increase of beer production. It was therefore inevitable to focus on the development of appropriate brewery waste management strategy and management plan that enables to reutilize the brewery solid waste for other purposes in an environmentally friendly manner. The reutilization of such waste product can be linked with minimized losses of resources and production opportunities and with increased productivity and profitability along with environmental benefits. This study was assessed the socio economic impacts of brewery waste recycling technology in agriculture including crops productivity evaluations.
2. Methods and materials

2.1. Description of the study sites

The total land area of the Harari region is estimated of 34.2 km\(^2\) (34,320 ha) out of which the rural area accounts about 323.7 km\(^2\) (94.3%) and the remaining 19.5 km\(^2\) (1950 ha) accounts for the urban area. The Harari Regional State consists of six urban and three rural districts. The rural districts were Sofi, Direteyara and Erer-Woldiya (Figure 1). Farmer’s field in Sofi district was used for maize and sorghum experiment while Haramaya University Raaree Research farm was used for potato and haricot bean experiments. The districts chosen were important for agriculture; they were diversified in terms of agricultural pattern, farmers’ characteristics and BS application.

2.2. Methods of data collection and procedures

In data collection through survey we used opted anonymous, semi-structured personal interviews with farmers. The method we approached was superior to others (face-to-face, focus group discussion and phone interviews) in data collection process as semi-structured interview gives farmers an opportunity to explain, increases response rate of finished questionnaires. The questionnaire consists of 18 questions categorized into four parts: (i) personal data of farmers (e.g. age and family size); (ii) farmers’ knowledge level about BS use (e.g. time of BS application, crop types cultivated by BS use, land management inputs, trends of sampled farmers crop yield, overall trends of sampled farmers crop productivity and application of BS for soil fertility); (iii) crop yield obtained (maize, sorghum and khat); and (iv) estimated households incomes from aforementioned crops. The questionnaire has been prepared in non-scientific language for clarification of the questions to the farmers. The set of questions was developed upon consultations with a good numbers of researchers and experts so that it can hold scientific ethics and can be appeared easier to farmers. A pilot study was conducted with eight farmers before full study to prove its quality.

For the diversification of these agricultural areas, the credibility and reliability of the data can be considered higher. We conducted 236 interviews with farmers in 2012/2013 and opportunistic sampling was chosen (Table 3). Out of the total users of BS 12 households were interviewed to obtain the real users ideas. Moreover, from the regional and district level experts about five comments were collected from the development agent (DA’s) experts and finally a panel discussion was conducted with about 15–20 smallholder farmers and agricultural experts to clarify and cross check their ideas.

In addition to the above methods, field and laboratory experiments were conducted to prove or disprove the smallholders and agricultural experts’ ideas. As sampling techniques the users’ kebele was purposively selected due to existence of applied farms. Then the total population of the kebele...
was stratified in to two strata, users and non-users, and then finally the sample from the users' stratum was selected randomly by simple random sampling methods.

2.3. Data process and analysis
Data collected from interviews were analysed by SPSS (SPSS Inc. Released 2007. SPSS for Windows, Version 16.0. Chicago, SPSS Inc.) for statistical analysis. Descriptive statistics has been carried out by tabular statistics that showed the basic socio-economic and demographic features of farmers using descriptive tools: mean percentile, standard deviation and variance. To obtain the impacts among the variables, the general linear model (GLM) was applied. Applying Uni-variate analysis of variance of GLM, we find out Type III Sum of Square, DF, F and P value for examining the impacts and interaction between dependent and independent variables. Two dependent variables such as excessive and small amount of BS application were applied. The dependent variable small amount of BS application has been used as a cross-analysis tool for confirming the significance level.

3. Results and discussions
The average age of the sample household heads was 40 years where the minimum was 20 years and the maximum was 70 years. The survey result showed that all the sampled farmers were headed by male as well; the average family size of the sample household was 8.75 persons where the minimum was 4 while the maximum of 25 (Table 1). About 58.33%, 16.33% and 16.33% of the sampled household applied BS to their land before sowing, during sowing and after sowing, respectively (Table 2). For these questions all of the sampled households answered yes. Farmers with positive attitude recommend that it should be applied during dry season before sowing. This was because; it facilitates the growth of weed that competes with other crops for nutrients.

Table 1. Summary descriptive results of continuous variables

| Variable     | Mean | SD   | Min  | Max  |
|--------------|------|------|------|------|
| Age          | 40   | 14.18| 20   | 70   |
| Family size  | 8.15 | 5.43 | 4    | 25   |

Where; BS = Brewery sludge, SD = Standard deviation, Min = Minimum age, and Max = Maximum age. Sources: survey result, 2012/2013.

Table 2. Farmer’s perception on the brewery sludge use for crop production and soil fertility

| Activities                                | Variables | Share (%) |
|-------------------------------------------|-----------|-----------|
| Time of brewery sludge application        | Before sowing | 7 | 58.33 |
|                                           | During sowing | 2 | 16.66 |
|                                           | After sowing | 2 | 16.66 |
| Crop types cultivated by brewery sludge use | Maize and sorghum | 4 | 33.33 |
|                                           | Khat       | 2 | 16.66 |
|                                           | Maize, sorghum and khat | 6 | 50 |
| Land management inputs                    | Brewery sludge | 5 | 41.66 |
|                                           | Fertilizer | 5 | 41.66 |
|                                           | Both | 2 | 16.66 |
| Trends of sampled farmers crop yield      | Increasing | 10 | 83.33 |
|                                           | Decreasing | 2 | 16.66 |
| Overall trends of sampled farmers crop productivity | Increasing | 7 | 83.33 |
|                                           | Decreasing | 2 | 16.66 |
| Application of brewery sludge for soil fertility | Yes | 7 | 83.33 |
|                                           | No | 2 | 16.66 |
There was no measuring rate of application of BS. The sludge in solid form was transported by truck driven container factory and directly transferred to the farm. The farmer applied as much as they get to their farm. Accordingly one farmer can apply up to 25 truck containers ha$^{-1}$ per season. Most of the farmers did not apply every year. This was because of the lack of BS and lack of awareness of farmers in the study areas before survey conducted. According to the survey result about 67% applied 1 year before, about 25% used 2 years before, while about 8% used before 3 years as fertilizers for food crops production.

Farmers of the study area cultivated crops and rear livestock's as the components of agricultural production. Among the crops they produce crops such as maize, sorghum, khat, haricot bean, ground nut, bean and etc. However, most of the time they applied the BS for maize, sorghum and khat. Accordingly, about 33.33%, 16.33% and 16.33% of the sampled household applied BS to their maize and sorghum, khat and maize, sorghum and khat crops in intercropped agricultural system, respectively.

About 41.66%, 41.66% and 16.66% of the sampled household used sludge, fertilizer and both sludge and fertilizer as land management inputs respectively. In addition to this, in the case of maize and sorghum management activities needed was only weeding or removing unwanted weeds from the crops. However, in the case of khat opening the remaining sludge from the root of the khat after it observe the water and weeding were major management activities undertaken to maximize its advantage.

Farmers of the study area used fertilizers, manure and compost to improve the soil fertility. However, those farmers used this sludge showed that after application of BS, the soil did not require other inputs for about 2 years. So the sludge has more fertilizing power than other inputs for a time being. The long impact on soil fertility was recommended after the laboratory result. About 83.33% and 16.66% of the sampled household responded that the application of BS shows increasing and decreasing trends in their crop productivity, respectively.

About 83% of the users (farmers) were observed the increasing trend on their crop yield in maize, sorghum and khat due to the fact that the sludge served as resistance against striga and increase soil fertility. Moreover, it was also used to increase soil moisture, especially for khat crop and khat produced yield throughout the year without application of water. Accordingly to farmer experience, the average maize yield increased from 2.0 to 3.0 t ha$^{-1}$, the sorghum yield from 1.4 to 2.2 t ha$^{-1}$, and that of khat increased from 70 to 180 kg ha$^{-1}$ as a result of the BS application to agricultural soils.

### 3.1. Overall trends in crop productivity

About 83% said BS was good for soil fertility enhancement in which this sludge protects the harmful weed (striga) from affecting the crop yield especially that of maize and sorghum and it increased the soil productivity and fertility.
3.2. Brewery sludge impacts on crop yields and income

3.2.1. Economic impacts of BS on maize and sorghum crops

The mean annual sorghum income of sample households was found to be 503.66 USD after they applied BS, while economic return was about 333.84 USD before the application of BS (Table 4). The mean difference analysis revealed that the mean annual sorghum income before and after the application of BS was statistically significant at less than 1% probability level. This shows that BS has positive impact on the sorghum income of smallholder farmers. This result obtained was consistent to the findings of Dapaah, Mohammed, and Awuah (2014).

3.2.2. Impacts of different rates of brewery waste sludge on maize yield

The experimental result indicated that the maize treated with 10 t ha$^{-1}$ of BS rate revealed 5.19 t ha$^{-1}$ of grain yield. This result exceed the maize yield obtained from the recommended rate of mineral fertilizer (2.04 t ha$^{-1}$) by 60.69%, and with that of control 82.22% over maize yield (0.77 t ha$^{-1}$) (Table 5).

3.2.3. Impacts of different rates of sludge application on sorghum yield

The statistical result of the study revealed that as the rate of sludge application to the sorghum field increased from 2.5 to 15 t ha$^{-1}$ the corresponding sorghum yield also significantly increased from 2.04 to 4.08 t ha$^{-1}$ (Table 5). This enables the smallholder farmers obtain significant economic benefits of 126.37 USD and 264.65 USD and 599.59 USD and 737.87 USD more over that of similar farmers who used mineral fertilizers only, and those who did not use any mineral fertilizer to their sorghum production, respectively. This showed that BS has more nourishing potential than that of mineral fertilizer due to its high nitrogen contents and water contents. This indicated that if smallholder farmers adopt the utilization of BS they can secure both economic benefits from increased sorghum grain yield, and opportunity costs of sludge (the market value of mineral fertilizer) in crop production.

### Table 4. Estimated sample households incomes from maize and sorghum crops per hectare in USD

| Sources | Before BS application | After BS application | Mean difference |
|---------|-----------------------|----------------------|-----------------|
|         | Mean | SD | Mean | SD |  |
| Maize   | 471.20 | 152.63 | 686.81 | 206.40 | 215.61 |
| Sorghum | 333.84 | 111.93 | 503.66 | 103.31 | 169.83 |

Where; BS = Brewery sludge, SD = Standard deviation and USD = United States Dollars. Sources: survey result, 2012/2013.

### Table 5. Impacts of different rates of brewery sludge on maize and sorghum yield

| BS rate ha$^{-1}$ | Maize yield (t ha$^{-1}$) | Sorghum yield (t ha$^{-1}$) | Percentage of Nitrogen contents |
|-------------------|--------------------------|-----------------------------|--------------------------------|
|                   | Maize | Sorghum | Maize | Sorghum |
| 2.5               | 3.16  | 2.01    | 1.21  | 1.39    |
| 5.0               | 4.13  | 2.99    | 1.32  | 1.46    |
| 7.5               | 4.31  | 3.08    | 1.33  | 1.55    |
| 10.0              | 4.35  | 3.28    | 1.40  | 1.61    |
| 12.5              | 4.37  | 3.13    | 1.44  | 1.54    |
| 15.0              | 5.19  | 4.08    | 1.33  | 0.61    |
| NP                | 2.04  | 1.77    | 1.29  | 1.36    |
| Control           | 0.77  | 0.86    | 1.55  | 1.45    |

Where; BS = Brewery sludge, NP = Recommended rate of inorganic nitrogen and phosphorus fertilizer, and t ha$^{-1}$ = Total yield per hectare.
Taking into consideration, the yield obtained as a result of BS application, sorghum grower can enhance the crop production significantly increasing rates of BS up to 15 t ha$^{-1}$ that was because of the improvement soil fertility.

3.2.4. Impacts of different rates of brewery waste sludge on potato yield

The experimental result showed that application least rate of BS's (2 t ha$^{-1}$) revealed significant impacts on potato tuber yield of 14.59 t ha$^{-1}$. While this result compared with the potato yield (9.52 t ha$^{-1}$) obtained from the recommended rate of mineral fertilizer exceed by 34.75%. Similarly, the application of 2 t ha$^{-1}$ BS rate in potato soil showed significant tuber yield increase that was exceed the tuber yield (7.59 t ha$^{-1}$) obtained from the control treatment (not fertilized) by 47.98% (Table 6).

Furthermore, the obtained results indicated that as the rate of BS application to the potato farm in the range of 2–10 t ha$^{-1}$ the corresponding tuber yield also increased in the range of 14.59–28.24 t ha$^{-1}$. This revealed that BS has more nutrient providing ability than that of mineral fertilizer due to its high nitrogen and water contents. The use BS can reduce cost of crop production and increase yield when it was applied to the agricultural soil in place of other commercial fertilizers.

The output of this study revealed that potato tuber yield can increase with application of BS up to 10 t ha$^{-1}$, but crop production was declined when the amount BS rate increased to 12 t ha$^{-1}$. These indicated that the optimum rate of BS application should not be more that 10 t ha$^{-1}$ of potato tuber production.

3.2.5. Impacts of different rates of brewery sludge on haricot bean yield

Statistical results revealed that application of BS from the least (2 t ha$^{-1}$) to the highest treatment (12 t ha$^{-1}$) rates were showed significant increase of haricot bean yield proportionally. This proportional increase of BS rates and haricot bean yield indicated the presence another room for new finding if the higher level of BS studied in comparison with this research results.

The highest significant haricot bean yield (5.99 t ha$^{-1}$) was obtained from experimental plots treated with the high rate BS (10 t ha$^{-1}$) while the least crop yield (1.84 t ha$^{-1}$) was recorded from the experimental soil that received zero (control treatment) BS rate.

The haricot bean yield obtained from plots that received 10 t ha$^{-1}$ BS rate revealed exceeding results of 69.28% and 52.92% over the crop yield that harvested from experimental soils treated with 0 t ha$^{-1}$ BS rate and recommended rate NP mineral fertilizer, respectively. This showed that high economic return and crop yield can be obtained from the use 10 t ha$^{-1}$ BS in haricot bean production at the experimental area.

| BS rate (t ha$^{-1}$) | Potato yield (t ha$^{-1}$) | Haricot bean yield (t ha$^{-1}$) | Nitrogen contents In Haricot bean |
|-----------------------|---------------------------|---------------------------------|----------------------------------|
| 2.5                   | 14.59                     | 3.39                            | 2.95                             |
| 5                     | 14.77                     | 4.90                            | 3.22                             |
| 7.5                   | 19.59                     | 4.90                            | 3.13                             |
| 10                    | 20.39                     | 4.94                            | 3.37                             |
| 12.5                  | 28.24                     | 5.96                            | 3.15                             |
| 15                    | 25.02                     | 5.99                            | 3.08                             |
| NP                    | 9.52                      | 2.82                            | 2.82                             |
| Control               | 7.59                      | 1.84                            | 2.91                             |

Where: BS = Brewery sludge, and t ha$^{-1}$ = Total yield per hectare.
3.2.6. Economic implication of experimental results

Statistical analysis of yield data showed that in all crops used (maize, sorghum, haricot bean and potato) in this study from the application of different levels of BS showed significant ($P \leq 0.05$) impacts on yield and yield related parameters. An economic analysis of the results, using partial budget technique (CIMMYT, 1988), was thus used to evaluate economic benefit of the different rates of BS and recommended rate of NP mineral fertilizers. The economic data used in partial budget analysis included market prices of crops, labour cost of BS application, BS transportation cost, and cost of NP fertilizers. Economic yield, adjusted yield (90% of experimental yield for each crop) total variable costs, net benefit, dominance analysis and resulting selection of treatments with positive marginal rate of return were presented in Tables 7–14.

The input and output prices used in the economic analysis were those prevailing on the local market during the period of the experiment. Market prices were ever changing and as such a recalculation of the partial budget using a set of likely future prices, i.e. sensitivity analysis, is necessary to pinpoint treatments which were likely to remain stable and sustain acceptable returns for farmers despite price fluctuations.

3.2.6.1. Economic analysis for maize. 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 resulted 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 (Tables 7 and 8).

3.2.6.2. Economic analysis for sorghum. Partial budget and marginal rate of return analysis for sorghum production revealed that the highest marginal rate of return (535.62%) at application of 2.5 t ha$^{-1}$ BS. The application of 15 t ha$^{-1}$ BS revealed MRR (71.48%) which was less than recommended value (100%). The application of 5 t ha$^{-1}$ BS showed the net benefit of 544.83 USD and MRR (461.48%) that can be applied by smallholder farmers to maximize their economic benefit from BS use (Tables 9 and 10).

3.2.6.3. Economic analysis for potato. Partial budget and marginal rate of return analysis for production of potato with application of BS revealed that the highest MRR (4083.85%) was obtained from the application of 10 t ha$^{-1}$ BS to the agricultural soil. However, the application of 2, 6, 8 and 10 t ha$^{-1}$ BS rates also showed the acceptable MRR (%) for smallholder framers. Maximum net benefit and the highest MRR percentage were recorded from the application of 10 t ha$^{-1}$ BS rate to the experimental farm. Smallholder farmers can apply 10 t ha$^{-1}$ BS rate to the agricultural soil in order to maximize the economic return from potato production (Tables 11 and 12).

3.2.6.4. Economic analysis for haricot bean. Partial budget and marginal rate of return analysis for production of haricot bean from the application of BS’s revealed that the highest MRR (1,057.15%) was obtained at application of 4 t ha$^{-1}$ BS rate. However, the application of 2, 4 and 10 t ha$^{-1}$ BS rates showed acceptable MRR percentage that can be acceptable for smallholder farmers. The application of 4 t ha$^{-1}$ BS rate reveal the net benefit of 958.20 USD that can be used by smallholder farmers to enhance the economic benefit from this crop production (Tables 13 and 14).

The awareness status of farmers and information gaps were main factors to adopt a given technology in agriculture. Lack of know-how, less availability, opportunity at time of crop sowing or/and planting towards BS use as a source of fertilizers were main determinants for use or not use of BS in agricultural farms. Less educated and the low-income farmers use high amount of BS for agricultural production at the study area. The regional and district level agricultural expert of Harari Regional state of Deker district have also information on the BS used as an input by farmers in the area. However, they have different idea regarding its impact on the soil fertility.
Table 7. Partial budget analysis for different rates of brewery sludge and NP fertilizers in maize production

| BS rate (t ha⁻¹) | Average yield (t ha⁻¹) | Adjusted yield (t ha⁻¹) | GFB (0.18 USD kg⁻¹) | Costs of BS application | Cost of NP | BS TP cost | Total cost that vary | Net benefit | Domain |
|------------------|------------------------|-------------------------|---------------------|------------------------|------------|------------|---------------------|-------------|--------|
| 0                | 0.77                   | 0.73                    | 1.134.34            | 0.00                   | 0.00       | 0.00       | 134.34              | 0.00        | ND     |
| 2.5              | 3.16                   | 2.84                    | 5.520.86            | 7.79                   | 0.00       | 28.14      | 35.93               | 484.93      | ND     |
| NP               | 2.04                   | 1.94                    | 3.54.49             | 6.87                   | 0.00       | 70.05      | 284.44              | 3D          |        |
| 5                | 4.13                   | 3.72                    | 6.681.49            | 15.58                  | 0.00       | 56.28      | 71.85               | 609.64      | ND     |
| 7.5              | 4.31                   | 3.88                    | 7.1.036             | 23.36                  | 0.00       | 84.42      | 107.78              | 602.57      | D      |
| 10               | 4.35                   | 3.92                    | 7.1.764             | 31.15                  | 0.00       | 112.56     | 143.71              | 573.93      | D      |
| 12.5             | 4.37                   | 3.93                    | 7.2.016             | 38.94                  | 0.00       | 140.70     | 179.64              | 540.52      | D      |
| 15               | 5.19                   | 4.67                    | 8.561.14            | 46.73                  | 0.00       | 168.84     | 215.57              | 640.57      | ND     |

Where; MRR = Marginal rate of return, GFB = gross field benefit, TP = transportation, ND = Non-Dominated, D = Dominated, BS = Brewery sludge, USD = United States Dollars, and average exchange rate in 2012/2013 of one dollar was 21.84 ETB (Ethiopian Birr).
Farmers responded that the importance of brewery waste sludge depends on the rate of application, time of application, soil type and chemical contents of the sludge itself. Therefore, research should be carried out on the above factors and recommend the optimum rate of application, the best time it should be applied and for which crops it should applied for the future.

In the application of BS for soil fertility, most of regional and district level agricultural experts recommend the smallholder farmers to apply the BS; to increase the soil productivity, crop yield, increase soil moisture and reduce the impacts of striga on crop yield especially that of maize and sorghum. Farmers responded that it was good if chemical content of brewery waste sludge also known and the time of application was determined. As it was discussed in the focus group discussion, BS helped smallholder farmers against the infections of striga which was the most dangerous weed that affecting cereal crops in many parts of Africa including Ethiopia. The degree of striga infestation was most severe in eastern Africa where invasion by the parasite is expanding at an alarming rate, often resulting in total loss of crops in any given crop season. The infestation is more prevalent in drier tracts than in irrigated conditions (Teka, 2014). Striga possess a serious threat to successful cultivation of sorghum in areas of insufficient and ill distributed rainfall. Since, it establishes directly over the vascular system of the host plant, it drains out water and nutrients from host resulting in yield losses from 15 to 75% depending on the extent of infestation (Teka, 2014).

Annual sorghum losses attributed to striga in Ethiopia was 25% (African Agricultural Technology Foundation [AATF], 2011). Some of the expert did not recommend the farmers to apply the BS because the sludge may increase the productivity of crop at a time. However, it may have a long term impact on the soil fertility and environment as well. About 83% of the farmers had positive attitude toward the use of BS can increase crop productivity by improving soil fertility and protecting the impacts of harmful weed (striga) on crop yields especial cereal crops such as maize and sorghum. However, about 16.66% responded that the sludge does not increase crop productivity, even it dry out khat crop.

According to the survey result; the maize yield was increased from 2.0 to 30 t ha\(^{-1}\) whereas the sorghum yield increased from 1.4 to 2.2 t ha\(^{-1}\) because of the use of brewery waste sludge. In addition to improvements in maize and sorghum yield, this sludge also increased the khat yield in more than 50% than what they produced before the application of this sludge. From economic point of view this BS enables smallholder farmers obtain significant economic benefits of 228.94 USD, 1,831.50 USD and 755.49 USD more income from maize, sorghum and khat crops respectively than non-users. As indicated in Bellamy, Chong, and Cline (1995) and Dapaah et al. (2014), the experimental result showed that sludge has the impact of increasing growths and yields of various crops. However, because the sludge usually contains a lot of heavy metals, thus ensuring that the use of sewage sludge applied to soils also needs to be tightly controlled. Some studies in the United States indicated that if applied at high volume 20 t ha\(^{-1}\) would be harmful to plants (US-Environmental Protection Agency, 1979).

| BS rate (t ha\(^{-1}\)) | Average yield (t ha\(^{-1}\)) | Adjusted yield (kg ha\(^{-1}\)) | GFB (0.18 USD kg\(^{-1}\)) | Total cost that vary | Net benefit | MRR (%) |
|-------------------------|-------------------------------|-------------------------------|-----------------------------|---------------------|------------|---------|
| 0.0                     | 0.77                          | 0.73                          | 134.34                      | 0.00                | 134.34     |        |
| 2.5                     | 3.16                          | 2.84                          | 520.86                      | 35.93               | 484.93     | 975.84 |
| 5                       | 4.13                          | 3.72                          | 681.49                      | 71.85               | 609.64     | 347.1  |
| 15                      | 5.19                          | 4.67                          | 856.14                      | 215.57              | 640.57     | 21.52  |

Where; MRR = Marginal rate of return, GFB = gross field benefit, USD = United States Dollars, and average exchange rate in 2012/2013 of one dollar was 21.84 ETB (Ethiopian Birr).
Table 9. Partial budget analysis for brewery sludge and NP fertilizers for sorghum production

| BS rate (t ha⁻¹) | Average yield (t ha⁻¹) | Adjusted yield (t ha⁻¹) | GFB (0.23 USD kg⁻¹) | Costs of BS application | Cost NP | BS TP cost | Total cost that vary | Net benefit | Domain |
|------------------|------------------------|-------------------------|---------------------|-------------------------|---------|-------------|---------------------|-------------|--------|
| 0.0              | 0.86                   | 0.82                    | 0.00                | 0.00                    | 0.00    | 0.00        | 0.00                | 186.61      | ND     |
| 2.5              | 2.01                   | 1.81                    | 414.97              | 7.79                    | 0.00    | 28.14       | 35.93               | 379.04      | ND     |
| NP               | 1.77                   | 1.68                    | 384.52              | 6.89                    | 63.19   | 0.00        | 70.05               | 314.47      | D      |
| 5                | 2.99                   | 2.69                    | 616.69              | 15.58                   | 0.00    | 56.28       | 71.85               | 544.83      | ND     |
| 7.5              | 3.08                   | 2.77                    | 634.20              | 23.36                   | 0.00    | 84.42       | 107.78              | 526.42      | D      |
| 10               | 3.28                   | 2.95                    | 676.24              | 31.15                   | 0.00    | 112.56      | 143.71              | 532.52      | D      |
| 12.5             | 3.13                   | 2.82                    | 644.71              | 38.94                   | 0.00    | 140.70      | 179.64              | 465.07      | D      |
| 15               | 4.08                   | 3.67                    | 840.87              | 46.72894                | 0.00    | 168.84      | 215.57              | 625.30      | ND     |

Where; MRR = Marginal rate of return, GFB = gross field benefit, TP = transportation, ND = Non-Dominated, D = Dominated, BS = Brewery sludge, USD = United States Dollars, and average exchange rate in 2012/2013 of one dollar was 21.84 ETB (Ethiopian Birr).
The experimental fields revealed that as the rate of sludge application to the maize, sorghum, potato and haricot bean increases, the corresponding yields of maize, sorghum and potato and haricot bean crops were also increased. Therefore, BS has more fertilizing power than that of mineral fertilizer due to its nitrogen contents and high water contents. It is better for smallholder farmer to adopt the utilization of this brewery to secure both economic benefits of increased yield and opportunity costs of using sludge (the market value of mineral fertilizer) in their crop production (Tables 5 and 6).

Maximum possible application of BS rate of 15 t ha\(^{-1}\) of maize and sorghum fields enable smallholder farmers obtain economic benefits up to 791.90 USD, 991.76 USD and 599.59 USD, 737.87 USD incomes more over that of those farmers with recommended rate of mineral fertilizer and control farmers’ fields respectively. Whereas, the maximum application of BS of 10 t ha\(^{-1}\) of potato and haricot bean fields enable smallholder farmers to obtain economic benefits up to 5,214.29 USD, 5,673.08 USD and 1086.72 USD, 1,328.53 USD more income than those farmers applied recommended rate of mineral fertilizer and with no any fertilizer to crop fields, respectively.

In addition to improvements in soil fertility and crops yield, application of BS serves smallholder farmers against the infections of striga which was the most dangerous weeds affecting cereal crops in many parts of Africa including Ethiopia. The degree of striga infestation was most severe in eastern Africa where invasion by the parasite is expanding at an alarming rate, often resulting in total loss of crops in any given crop season. The infestation was more prevalent in drier tracts than in irrigated conditions (Teka, 2014). So due to its high water content BS reduce the impacts of striga on crop yields.

The mean annual maize yield of sample household was found to be 3.0 t ha\(^{-1}\) with a minimum of 1.8 and a maximum 4.0 in t ha\(^{-1}\). The maize yield of the households before the application of BS was estimated to be 2.0 t ha\(^{-1}\) with a minimum of 1.2 and a maximum 3.2 t ha\(^{-1}\). The reason for this could be that the striga weed was problem of crop production for most of the farmers in the study area and the application of BS serves as a resistance against this harmful weed in addition to increase the soil fertility.

The t-test analysis revealed that the mean difference of maize yield before and after the application of BS was statistically significant at less than 1% probability level. This shows that BS has positive impact on the maize yield of smallholder farmers.

The mean annual sorghum yield was 2.2 t ha\(^{-1}\) with a minimum of 1.4 t ha\(^{-1}\) and maximum of 2.7 t ha\(^{-1}\) on farm research. The sorghum yield of the household before the application of BS was estimated to be 1.4 t ha\(^{-1}\) with a minimum of 8 and a maximum 2.5 in t ha\(^{-1}\). The t test analysis revealed that the mean difference of sorghum yield before and after the application of BS was statistically significant at less than 1 % probability level. This shows that BS has positive impact on

\[
\begin{array}{|c|c|c|c|c|c|c|}
\hline
\text{BS rate (t ha}^{-1}\text{)} & \text{Average yield (t ha}^{-1}\text{)} & \text{Adjusted yield (kg ha}^{-1}\text{)} & \text{GFB (0.23 USD kg}^{-1}\text{)} & \text{Total cost that vary} & \text{Net benefit} & \text{MRR (\%)} \\
\hline
0.0 & 0.86 & 0.82 & 186.61 & 0.00 & 186.61 & - \\
2.5 & 2.01 & 1.81 & 414.97 & 35.93 & 379.04 & 535.62 \\
5 & 2.99 & 2.69 & 616.69 & 71.85 & 544.83 & 461.46 \\
15 & 4.08 & 3.67 & 840.87 & 215.57 & 625.30 & 71.48 \\
\hline
\end{array}
\]

Where; MRR = marginal rate of return, GFB = gross field benefit, BS = Brewery sludge, USD = United States Dollars, and Average exchange rate in 2012/2013 of one dollar was 21.84 ETB (Ethiopian Birr).
| BS rate (t ha$^{-1}$) | Adjusted yield (t ha$^{-1}$) | Cost of Sludge application | Cost of NP Sludge TP cost | Total cost that vary | Net benefit | Domain |
|-----------------------|-----------------------------|----------------------------|--------------------------|----------------------|------------|--------|
| 0                     | 7.59                        | 1,155.68                   | 0.00                     | 0.00                 | 0.00       | ND     |
| 2                     | 14.59                       | 2,104.62                   | 4.58                     | 27.09                | 2,077.52   | ND     |
| 4                     | 14.77                       | 2,130.29                   | 9.16                     | 54.18                | 2,076.11   | ND     |
| 6                     | 14.77                       | 2,130.29                   | 9.16                     | 54.18                | 2,076.11   | ND     |
| 8                     | 14.77                       | 2,130.29                   | 9.16                     | 54.18                | 2,076.11   | ND     |
| 10                    | 28.24                       | 4,073.65                   | 27.47                    | 162.55               | 3,411.09   | ND     |
| 12                    | 25.02                       | 3,607.93                   | 27.47                    | 162.55               | 3,411.09   | ND     |

Where; MRR = Marginal rate of return, GFB = gross field benefit, ND = Non-Dominated, D = Dominated, BS = Brewery sludge, USD = United States Dollars, and average exchange rate in 2012/2013 of one dollar was 21.84 ETB (Ethiopian Birr).
the sorghum yield of smallholder. This result was consistent with the findings of Bellamy et al. (1995) and Dapaah et al. (2014).

From economic point of view this BS enables smallholder farmers obtained grain yield of 8 tons more than those farmers who did not use the BS at the study area. This indicates that as a result of this BS the income of small holder farmer's increase by 228.94 USD than non-users in terms of maize market value (the estimated market price of maize was 228.94 USD t ha$^{-1}$). The use of BS allowed smallholder farmers to obtain 8 t ha$^{-1}$ more than those farmers who did not use the BS in the area or this indicated that as a result of this BS increase the income of small holder farmers also increased by 183.15 USD than non-users in terms of sorghum market value (the estimated market price of sorghum was 228.94 USD t ha$^{-1}$).

The focal group discussion indicated that the mean difference of khat yield of sample household was found to be 180 kg with a minimum of 30 and a maximum 400 kg year$^{-1}$ after the application of brewery waste sludge. The khat yield of the households before the application of BS was estimated to be 70 kg with a minimum of 18 and a maximum 98 in kg year$^{-1}$. The reason was that application of the BS increased soil moisture (irrigate khat) rather than increasing the soil fertility which in turn allowed smallholder farmers save the irrigation and labour costs that might incur.

The t test analysis revealed that the mean difference of khat yield before and after the application of BS was statistically significant at less than 1% probability level. This shows that BS has positive impact on the khat yield of smallholder farmers.

From economic point of view this BS enables smallholder farmers obtain 11.0 t more than those farmers who did not use the BS in the area or this indicate that as a result of this BS the income of small holder farmers increase by 755.49 USD than non-users in terms of khat market value (the estimated market price of khat was 6.87 USD kg$^{-1}$). Similarly, the mean annual maize income of sample household was found to be 686.81 USD after they applied this BS while it was about 471.20 USD before the application of BS. The mean difference analysis revealed that the mean annual maize income before and after the application of BS was statistically significant at less than 1% probability level. This showed that BS has positive impact on the maize income of smallholder farmers. Moreover, the application of BS in crop production helps smallholder farmers of the study area, to have more crop yield, farm income that they might use further socio economic activities like improve housing, educate children, accumulated assets and become food secure and life better living standards in the long run.

The result of field experiment elucidated that as the rate of brewery waste sludge application to the maize field increased from 2.5 to 15 t ha$^{-1}$ the corresponding maize yield also increased from 3.15 t ha$^{-1}$ to 5.19 t ha$^{-1}$. This shows that BS has more fertilizing power than that of mineral fertilizer due to its nitrogen contents and high water contents. It is better for smallholder farmer to

| BS rate (t ha$^{-1}$) | Average yield (t ha$^{-1}$) | Adjusted yield (t ha$^{-1}$) | GFB (0.16 USD kg$^{-1}$) | Total cost that vary | Net benefit | MRR (%) |
|------------------------|-----------------------------|-----------------------------|-------------------------|---------------------|-------------|---------|
| 0.0                    | 7.59                        | 7.21                        | 1,155.68                | 0.00                | 1,155.68    | -       |
| 2                      | 14.59                       | 13.13                       | 2,104.62                | 27.09               | 2,077.52    | 3,402.57 |
| 6                      | 19.59                       | 17.63                       | 2,825.77                | 81.27               | 2,744.50    | 1,231.02 |
| 8                      | 20.39                       | 18.35                       | 2,940.14                | 108.36              | 2,831.78    | 322.18  |
| 10                     | 28.24                       | 25.42                       | 4,073.65                | 135.45              | 3,938.20    | 4,083.85 |

Where; MRR = Marginal rate of return, GFB = gross field benefit, BS = Brewery sludge, USD = United States Dollars, and average exchange rate in 2012/2013 of one dollar was 21.84 ETB (Ethiopian Birr).
Table 13. Partial budget analysis for brewery sludge and NP fertilizers in haricot bean production

| BS rate (t ha\(^{-1}\)) | Average yield (t ha\(^{-1}\)) | Adjusted yield (t ha\(^{-1}\)) | Gross field return (0.23 USD kg\(^{-1}\)) | Costs of Sludge application | Cost of NP | BS TP cost | Total cost that vary | Net benefit | Domain |
|-------------------------|-------------------------------|---------------------------------|------------------------------------------|-----------------------------|------------|------------|-----------------------|------------|--------|
| 0                       | 1.84                          | 1.75                            | 400.66                                   | 0.00                        | 0.00       | 0.00       | 400.66                | 0.00       | ND     |
| 2                       | 3.39                          | 3.05                            | 698.88                                   | 4.58                        | 0.00       | 22.51      | 27.09                 | 671.79     | ND     |
| 4                       | 4.91                          | 4.42                            | 1,012.38                                 | 9.16                        | 0.00       | 45.02      | 54.18                 | 958.20     | ND     |
| NP                      | 2.82                          | 2.67                            | 612.35                                   | 6.87                        | 0.00       | 0.00       | 70.05                 | 542.29     | D      |
| 6                       | 4.90                          | 4.41                            | 1,008.69                                 | 13.74                       | 0.00       | 67.54      | 81.27                 | 927.42     | D      |
| 8                       | 4.94                          | 4.44                            | 1,016.99                                 | 18.32                       | 0.00       | 90.05      | 108.36                | 908.63     | D      |
| 10                      | 5.96                          | 5.36                            | 1,227.38                                 | 22.89                       | 0.00       | 112.56     | 135.45                | 1,091.93   | ND     |
| 12                      | 5.99                          | 5.39                            | 1,233.59                                 | 27.47                       | 0.00       | 135.07     | 162.55                | 1,071.04   | D      |

Where; MRR = Marginal rate of return, TP = transportation, ND = Non-Dominated, D = Dominated, BS = Brewery sludge, USD = United States Dollars, and average exchange rate in 2012/2013 of one dollar was 21.84 ETB (Ethiopian Birr).
adopt the utilization of this brewery to secure both economic benefits of increased yield and opportunity costs of sludge (the market value of mineral fertilizer) in their crop production.

In context to crop yield obtained, as the application of sludge increases from 2.5 t to 8 t ha$^{-1}$, the respective yield also increase, but not that much in increasing rates. However as the rate of sludge application increase from 10 t ha$^{-1}$ to 15 t ha$^{-1}$, the resulting yield increases by significant figure.

4. Conclusions
With regards to the bio-solid BS was no doubt that it significantly increases crop yields per unit area apparently through improving soil fertility and/or nutrient levels. This was highlighted from the responses of the farmers during the questionnaire survey, the reflections of user and-non-user farmers’ as well as from the indication of agricultural development agents and district level experts during the focus group discussion. The respondent farmers indicated that on the average the yield increments in maize, sorghum and khat crops due to the application of the bio-solid BS (BS) at rates not supported by research were 50, 57 and 157%, respectively. The farmers and other participants of the farmers’ field research day were also very much excited on the responses of sorghum, maize, potato and haricot beans to the different rates of application of the bio-solid BS on farmers’ fields at the Deker area on Luvisols and on the research station fields of the Haramaya University on Fluvisols.

The use bio-solid BS or by-product of brewing industry may enhance the soil fertility that can be reflected in significantly improvement of yield levels of crops. However, undertaking detailed further field and laboratory research on the potentials and impacts of the by-product was imperative. Among others, the optimum rates and appropriate time as well as handling or methods of its application for different crops and different/major soil types need to be established through field studies repeated over years. Furthermore, its impact on soil fertility and on crop yields when used in integration with other organic and inorganic fertilizers was investigated. The need for investigating the chemical composition and monitoring and control its probable negative impacts on soil fertility in particular and on the environment at large when used continuously for many years on the same land was important. Land application of BS can be an option for safe and economic methods for waste disposal. On the other hand, it can affect the soil fertility, food safety and natural ecosystem in general.

Economically, the BS allowed smallholder farmers to obtain significant economic benefits of 228.94 USD, 1,834.86 USD and 755.49 USD more income from maize, sorghum and khat crops respectively than non-users. From this study, the maximum possible application of BS of up to 15 t ha$^{-1}$ of maize and sorghum fields enable smallholder farmers obtain economic benefits up to 791.90 USD, 991.76 USD and 599.59 USD, 737.87 USD, incomes more over that of those farmers with recommended rate of mineral fertilizer and control farmers’ fields respectively. The potato and haricot bean test crops treated with10 t ha$^{-1}$ rate of BS resulted in economic benefits of up to 5,214.29 USD, 5,673.08 USD and 1,086.72 USD, 1,328.53 USD, more income than treated with recommended rate of mineral fertilizer and no fertilizer respectively.

| BS rate (t ha$^{-1}$) | Average yield (t ha$^{-1}$) | Adjusted yield (t ha$^{-1}$) | GFB (0.23 USD kg$^{-1}$) | Total cost that vary | Net benefit | MRR (%) |
|------------------------|-----------------------------|------------------------------|--------------------------|---------------------|-------------|---------|
| 0.0                    | 1.84                        | 1.75                         | 400.66                   | 0.00                | 400.66      | -       |
| 2                      | 3.39                        | 3.05                         | 698.88                   | 27.09               | 671.79      | 1,000.74 |
| 4                      | 4.91                        | 4.42                         | 1,012.38                 | 54.18               | 958.20      | 1,057.15 |
| 10                     | 5.96                        | 5.36                         | 1,227.38                 | 135.45              | 1,091.93    | 164.55   |

Where; MRR = marginal rate of return, GFB = gross field benefit, BS = Brewery sludge, USD = United States Dollars, and average exchange rate in 2012/2013 of one dollar was 21.84 ETB (Ethiopian Birr).
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