Effects of Brewery waste sludge on potato (*Solanum tuberosum* L.) productivity and soil fertility

Muktar Mohammed¹, Bulti Merga²* and Abdulatif Ahmed²

**Abstract:** This field experiment was conducted during the 2013/2014 main cropping season at Haramaya University Raaree Research farm. The objective of the experiment was to elucidate the effect of brewery waste sludge on the growth, yield and yield-related traits of the crop. The treatments consisted of seven levels Brewery sludge (0.0, 2.0, 4.0, 6.0, 8.0, 10.0 and 12.0 t ha⁻¹) and recommended rate of NP mineral fertilizer of N (92 kg N ha⁻¹) and P (92 kg P₂O₅ ha⁻¹). The experiment was laid out as a Randomized Complete Block Design (RCBD) with four replications. The results of the experiment revealed that the application brewery sludge (BS) influenced total dry weight, unmarketable tuber yield, percentage of small-sized tubers, and percentage of medium-sized tubers. The main effects of seed tuber planting depth significantly influenced shoot fresh weight, total dry weight, average tuber number produced per hill, unmarketable tuber yield, total tuber yield, marketable tuber yield, mean tuber weight, and percentage of small-sized tubers produced. Increasing the application level of BS generally enhanced the aforementioned parameters. However, for most parameters, the highest values were obtained already at the brewery sludge rate of 10 t ha⁻¹. In conclusion, the

**ABOUT THE AUTHORS**

Bulti Merga is lecturer and researcher in School of Plant Sciences, Haramaya University, Ethiopia. His profession is Horticulture and Agronomy, and Coordinator for Highland Pulse Crops Research Improvement Programme at same institution. His key research area is on potato, carrot, legume crops and other vegetable crops research improvement, and waste re-cycling to use as crop essential nutrient input for sustainable agricultural production.

Muktar Mohammed currently works at Oda Bultum University, Ethiopia. He is doing research in natural resources management, environmental protection, soil science, agroforestry, rehabilitation of degraded land, vegetation ecology, climate smart agriculture, and Remote Sensing.

Abdulatif Ahmed is a senior Instructor in the School of Plant Science under Agronomy Programme at Haramaya University of Ethiopia. As an Agronomist his key research area focuses on crop rotation, irrigation and drainage, plant breeding, plant physiology, soil classification, soil fertility, weed control, and insect and pest control.

**PUBLIC INTEREST STATEMENT**

Potatoes are important to food security and they are a cash crop in Ethiopia for the small-scale farmers. They are widely grown in the highland areas and are one of the few fast-growing commodities expanding into non-traditional areas. In the time of rapid growth of industrialization, there is increased production of brewery waste sludge, and due to that its storage and disposal have become a major problem in developing countries like Ethiopia. To reduce the storage and disposal problem to some extent, the brewery sludge (BS) can be better used in the agriculture sector for an increase in potato crop productivity. A number of researchers have reported that brewery waste sludge application improves the physical, chemical and biological properties of soil. Therefore, the aim of this research analysis is to evaluate the effects of brewery waste sludge on potato plant growth and tuber yield, soil fertility and accumulations of heavy metals in soil.
optimum total and marketable tuber yields of 28.24 t ha\(^{-1}\) and 25.03 t ha\(^{-1}\) were obtained in response to brewery sludge rate of 10 t ha\(^{-1}\).

Subjects: Agriculture & Environmental Sciences; Soil Sciences; Environment & Economics

Keywords: potato; heavy metals; soil contaminations

1. Introduction
In Ethiopia, there was a potato production of 932,701 tones on 67,591 hectares with an average yield of 13,799.3 kg ha\(^{-1}\) during 2017 cropping year (FAO, 2019). The potato (Solanum tuberosum L.) is widely cultivated in the eastern Hararghe of Ethiopia. In recent years, the farmers in western and eastern regions are used high amounts of nitrogen (N) fertilizers (sometimes more than 400 kg N ha\(^{-1}\)), and they have been doing frequent irrigation to get a very high yield. The potato is an important cash and food security crop in the eastern highlands of Ethiopia (Merga, Dechassa, & Mohammed, 2019). To protect human health, the concentration of contaminants in food products must be controlled. In many countries, maximum permissible concentrations (MPC) for heavy metals have been set by national health authorities (Tiller, Oliver, McLaughlin, Merry, & Naidu, 1997). Accordingly, heavy metals are of special interest in assessments of soil quality. Some trace metals are necessary for plants. However, in the plants growing in the polluted areas when the elements reach high concentration, they may cause serious damage to human health (Jusufi et al., 2017; Sharma, Bangar, Jain, & Sharma, 2004; Shkurt, Gjoka, Conti, & Kasa, 2017). A great amount of heavy metals and other chemicals, particularly produced by industries, mining, agriculture, combustion of fossil fuels and traffic, are often released to the atmosphere, water and soil. Evidence revealed that the contaminations of zinc, copper and nickel are higher than the other heavy metals such as the cadmium, lead and chrome in potatoes (Leblebici, Aksoy, & Akgul, 2017).

Currently, high attention is given on environmental pollutions and the effects of heavy metal concentration found in soil on human health and crop productions globally. Heavy metals have both merit and demerit on the life of animals and human beings (Colak, Soylak, & Turkoglu, 2005). The research evidence reported that heavy metals like lead (Pb), mercury (Hg), cadmium (Cd) and copper (Cu) are majorly hazard to terrestrial ecosystems if highly accumulated and consumed by organisms (Ellen, van Loon, & Tolsma, 1990). In contrary to this, metals like iron (Fe), copper (Cu), zinc (Zn), and manganese (Mg) are essential metals for humans while consumed in accordance with their scientific recommendations not cause toxicity to the biological systems (Mendil, Tuzen, Yazici, & Soylak, 2005). Even though the concentrations of heavy metals vary from crop variety to the other, the scientific study is required to assess their levels in each species of the plants to be safe from deviation of normal human health (Kabata-Pendias &Pendias, 2001).

Proper management of sludge utilization must consider many aspects including its heavy metal content, crop type and its nutrient requirement, and biological and physic-chemical properties of soils. These aspects are essential to determine the optimum rate, time and method of sludge application.

Vegetable crops grown on Cu-deficient soils are occasionally treated with Cu as an addition to the soil, and Mn may similarly be supplied to cereal and root crops. Large quantities of fertilizers are regularly added to soils in intensive farming systems to provide adequate N, P and K for crop growth. The compounds used to supply these elements contain trace amounts of heavy metals (e.g., Cd and Pb) as impurities, which, after continued fertilizer, the application may significantly increase their content in the soil (Jones & Jarvis, 1981).

Metals, such as Cd and Pb, have no known physiological activity. Application of certain phosphatic fertilizers inadvertently adds Cd and other potentially toxic elements to the soil, including F, Hg and Pb (Wuana & Okieimen, 2011). Long-term and extensive use of land for agriculture with
frequent application of agrochemicals is one of the major causes of trace metal, such as copper, nickel, zinc and cadmium, accumulation in soil.

Widespread distribution of Cd and its high mobility makes it a potential contaminant in a wide range of natural environments. Generally, soil Cd concentrations exceeding 0.5 mg kg$^{-1}$ are considered evidence of soil pollution. Phosphatic fertilizers are one of the most ubiquitous sources of Cd contamination in agricultural soils throughout the world (Zovko & Romic, 2011). Besides anthropogenic sources, trace metals can be also found in the parent material from which the soils developed. Whether the said inputs will become toxic and to what degree mobile depends on a number of factors; specific chemical and physical trace metal characteristics, soil type, land use, geomorphological characteristics within the soil type and exposure to emission sources.

From this point of view, it can be concluded that potato genotypes and agricultural soils also will have a difference in heavy metal concentrations. This information may be useful for designing a project proposal to study the effects of brewery waste sludge that may have many heavy metal elements and plant breeding program is required to improve potato quality management. Little information on the magnitude of variation in heavy metal content of soils and potato genotypes is currently available in the literature, and more data would benefit future nutritional studies.

Some farmers in the region have already started using the brewery sludge of the Harar Beer factory as a fertilizer input for crop production. However, there is no scientific study carried out yet to investigate the effects of brewery waste sludge on potato production and soil fertility. Keeping this in view, the effects of brewery waste sludge on potato growth, tuber yield components, yield and soil fertility were studied.

2. Materials and methods

2.1. Description of the study area

The field experiment was conducted during the 2013/2014 main rain season, at Haramaya University Raaree research field. Haramaya University is located 25 km northwest of Harar town. Haramaya University Raaree research farm is located at 2020 meters above sea level, 9°41′ N latitude and 42°03′ E longitude. The area receives an annual rainfall of 760 mm with bimodal rainfall pattern and an average maximum and minimum temperatures of 23.4°C and 8.25°C, respectively. The area has a bimodal rainfall distribution and is representative of a sub-humid mid-altitude agro-climatic zone. The short rainy season extends from March to April and constitutes about 25% of the annual rainfall whereas the long rainy season extends from June to October and accounts for about 45% of the total rainfall (Belay, Wortman, & Hoogen, 1998). The soil of the experimental site is a well-drained deep alluvial with a sub-soil stratified with loam and sandy loam (Tamire, 1973). The chemical properties of the soil indicated that the soil has an organic carbon content of 1.15%, a total nitrogen content of 0.11%, the available phosphorus content of 18.2 mg kg soil$^{-1}$, the exchangeable potassium content of 0.65 cmol kg soil$^{-1}$ (255 mg exchangeable K kg soil$^{-1}$), pH of 8.0. The physical properties of the soil indicated percent sand, silt, and clay contents of 63, 20, and 17, respectively, which is sandy clay (Burga, Dechassa, & Tsegaw, 2014).

2.2. Experimental materials

2.2.1. Planting material

Improved potato variety, named “Bubu” (CIP-384321.3) was used as a planting material. Bubu was released by Haramaya University in 2011 which is adapted to the altitude of 1650–2330 m above sea level, high yielding and resistant to late blight. Bubu takes to mature in about 95 to 100 days (MARD (Ministry of Agriculture and Rural Development), 2009).
2.2.2. Fertilizer material
Urea (CO\(\text{NH}_2\)) (46% N) and (TSP) Triple-super phosphate (Ca\(\text{H}_2\text{PO}_4\))\(_2\), which constitutes about 46% P\(_2\text{O}_5\), was used as a source of inorganic fertilizer.

2.2.3. Brewery waste sludge
Was collected from Harar Beer factory, Ethiopia.

2.3. Treatments and experimental design
The treatments consisted of seven levels brewery sludge (0.0, 2.0, 4.0, 6.0, 8.0, 10.0 and 12.0 t ha\(^{-1}\)) and recommended rate of NP mineral fertilizer of N (92 kg N ha\(^{-1}\)) and P (92 kg P\(_2\text{O}_5\) ha\(^{-1}\)). The experiment was laid out as a Randomized Complete Block Design (RCBD) in factorial arrangement and replicated four times per treatment. Thus, there were eight treatments, with a total of 32 experimental units (plots). The treatments were assigned to each plot randomly.

2.4. Experimental procedure

2.4.1. Land preparation and planting
2.4.1.1. Land preparation. The land was prepared in accordance with a standard practice of Haramaya University (HURC (Haramaya University Rare Research Centre), 1996). The experimental plot was cultivated to a depth of 25–30 cm using a tractor. In order to create a good seedbed for proper crop growth, the experimental field was cleared and ploughed and disked three times using a tractor.

2.4.1.2. Planting. Medium-sized potato tubers with sprouts measuring about 1.5 to 2.5 cm were planted on prepared ridges at the spacing of 75 cm between rows and 30 cm between plants at the depth of about 10 cm 8 July 2013 at Haramaya University. Plot size was 3.6 m \(\times\) 4.5 m (16.2 m\(^2\)), 6 rows per plot and 12 hills per row. Hence, there were 72 hills per plot. Weeds were managed by regular hoeing.

2.4.2. Fertilizer application and other cultural practices
2.4.2.1. Fertilizer application. All phosphorus were applied at planting time in prepared ridges by banding the granules at the depth of 10 cm below and around the seed tuber. Nitrogen fertilizer was side dressed in three splits: one-third at planting; one-third at active vegetative stage (about 50 days after planting) and the remaining one-third just before the start of flowering or tuber initiation (about 75 days after planting). Nitrogen will be applied as urea (46% N) 7–10 cm away from the plant as three times split applications where 1/3 during emergency, 1/3 during tuber initiation, and the last 1/3 will be at the enlargement of tubers or bulking (Vitosh, Paul, Harwood, & Smucker, 1997).

2.4.2.2. Other cultural practices. Weeding, cultivation and earthing-up and ridging were done at the appropriate time to facilitate root, stolon and tuber growth. Weeds were controlled by hoeing and earthing-up as required to prevent exposure of tubers to direct sunlight and for promoting tuber bulking and for ease of harvesting. Other cultural practices were applied as per the usual practices used by Haramaya University to grow potato plants.

2.4.2.3. Harvesting. To avoid bruising and skinning of tubers during harvesting and post-harvest handling, the haulms were mowed 2 weeks before harvesting to thicken tuber periderm. Mowing of haulms was carried out when the plants reached physiological maturity, i.e., when yellowing or senescence was apparent on the lower leaves. 40 plants were harvested from a net plot area of 3 m \(\times\) 3 m (9 m\(^2\)), leaving aside all plants at the border rows as well as those at both ends of each row to avoid edge effects, to estimate tuber yield and other yield-related parameters.
2.5. Data gathered

The following parameters were recorded from randomly taken samples or on plot basis, using the central four rows.

2.5.1. Growth parameters
2.5.1.1. Survived plant number (at harvest). This refers to the difference between potato tuber plant germinated and survived plant number at harvest and multiplied by 100 then presented in percentage.

2.5.1.2. Plant height (cm). This refers to the height from the base to the apex of the plant. It was measured using a tape meter on 10 randomly selected plants per plot from middle rows at the height from the soil surface to the topmost growth point just before flowering.

2.5.2. Yield and yield components
2.5.2.1. Shoot fresh and dry mass yield (g). The shoot fresh and dry mass was measured from five randomly selected plants for which total fresh biomass yield was measured. The fresh biomass of five randomly selected plants in each plot was obtained by measuring all the aboveground parts (stem, branch, and leaves) and the average was considered for statistical analysis. The measured fresh biomass were sun-dried for 7 days followed by an oven drying at 72°C for 24 h to a constant mass, then after weighted and averaged to record dry shoot mass yield per plant in each plot.

2.5.2.2. Total dry biomass (g). It was recorded as the sum of shoot dry mass yield per plant in each plot from the data recorded for each part as mentioned above.

2.5.2.3. Marketable tuber yield (ton ha$^{-1}$). The number of tubers which were free from blemishes due to diseases, insect pests, physiological disorders, and that weighs greater than or equals to 20 g in weight per plot were determined by counting. This was determined at harvest by calculating the total population per hectare for each (first was determined per plot and then converted to ton ha$^{-1}$).

2.5.2.4. Unmarketable tuber yield (ton ha$^{-1}$). The number of tubers which were free from blemishes due to diseases, insect pests, physiological disorders, and that weighs less than or equals to 20 g in weight per plot were determined by counting. This was determined at harvest by calculating the total population per hectare for each (first was determined per plot and then converted to ton ha$^{-1}$).

2.5.2.5. Total tuber yield (ton ha$^{-1}$). This refers to the entire tubers harvested from the net plots. At harvest, the total tuber yield per plot was recorded by adding up the weights of marketable and unmarketable tubers.

2.5.2.6. Tuber size distribution in weight. This refers to the yield of proportional weight of tubers in size categories. All tubers from five randomly taken plants per plot were categorized into small (<39 g); medium (39–75 g), and large (>75 g) according to Lung’aho et al., 2007. The proportion of the weight of each tuber category was expressed in percentage, and the average of each category was recorded a single plant.

2.6. Analytical procedure for soil, and brewery sludge chemical properties

Soil samples were collected from all experimental plots and selected soil chemical parameters were analyzed in Haramaya University soil chemistry and central laboratories. The pH of the soil suspension in a 1:2.5 (soil: liquid ratio) was measured potentiometrically using a glass-calomel combination electrode (Van Reewijk, 1992). The Walkley and Black (1934) wet digestion method was used to determine soil carbon content Total N was analyzed using the Kjeldahl digestion, distillation and titration method as described by Black, Evans, and Dinauer (1965) by oxidizing the organic matter in concentrated sulfuric acid solution (0.1N H$_2$SO$_4$). Since the pH of the soil in the study area ranges from 8.49 to 8.67, available P of soils and bio-solid was analyzed according to the standard procedure of Olsen (1954). Extractable heavy metals (Fe, Cu, Zn, Mn, Cr, Mo, Co, Pb, Se
and Cd) were extracted by the DTPA extraction method (Lindsay & Norvel, 1978) and all these heavy metals were measured by atomic absorption spectrophotometer.

2.7. Data analysis
Data were subjected to analysis of variance (ANOVA) of RCBD in factorial arrangements for each location using the general linear model of SAS statistical package updated 9.1 versions (SAS (Statistical Analysis System) Institute, 2003). Treatment means that exhibited significant differences were separated using Tukey test at 5% level of significance.

3. Results and discussions

3.1. Selected chemical properties of soil and brewery sludge used
Some chemical properties of brewery sludge used for the experiment and soils of the experimental site are given in Table 1. The soil of the experimental site is characterized by 1.18% organic carbon, 0.08% total nitrogen, 7.51 mg kg\(^{-1}\) available phosphorus. Brewery waste sludge is characterized by 3.5% organic carbon, 1.33% total nitrogen, 39.75 mg kg\(^{-1}\) available phosphorus (Table 1).

3.2. Effect of brewery sludge on heavy metal accumulation in soil

3.2.1. Heavy metal accumulation in the soil before and after BWS application
As evident from the data presented in Table 3, the accumulation of heavy metal ions in the soil due to bio-liquid sludge and recommended rate of NP mineral fertilizer were below the tolerable value for most of the metal ions except for Co and Se metal ions. In general, the highest accumulation of Zn (17 mg kg\(^{-1}\)) at 2 t ha\(^{-1}\), Fe (25.24 mg kg\(^{-1}\)) at application of 10 t ha\(^{-1}\), Cd (1.29 mg kg\(^{-1}\)) at application of recommended NP-fertilizer, Ni (34.67 mg kg\(^{-1}\)) at application of 4 t ha\(^{-1}\) Mn (3.68 mg kg\(^{-1}\)) from control treatment, Co (38.00 mg kg\(^{-1}\)) at application of 6 t ha\(^{-1}\) which is higher than indicated tolerable level of 20 mg kg\(^{-1}\), Cu (6.00 mg kg\(^{-1}\)) at application of 2 t ha\(^{-1}\), Se (13.37 mg kg\(^{-1}\)) at application of 2 t ha\(^{-1}\) and in fact very high for control plots compared to tolerable level of 2 mg kg\(^{-1}\), Mo (1.55 mg kg\(^{-1}\)) at application of 2 t ha\(^{-1}\) and Cr (1.69 mg kg\(^{-1}\)) from the control treatment followed by application of recommended rate of NP mineral fertilizer was recorded in the soil treated with different rates of sludge and recommended rate of NP mineral fertilizer (Table 3).

| Parameters | Before application | Brewery waste sludge (BWS) | Difference in percent |
|------------|--------------------|----------------------------|-----------------------|
| pH         | 8.49               | 8.67                       | 2.08                  |
| Total N, % | 0.08               | 1.33                       | 93.98                 |
| Organic Carbon, % | 1.18 | 3.50 | 66.29 |
| Available P, mg kg\(^{-1}\) | 7.51 | 39.75 | 81.11 |
| Zn (mg kg\(^{-1}\) soil) | 6.00 | 28.50 | 78.95 |
| Fe (mg kg\(^{-1}\) soil) | 24.71 | 20.50 | -17.04 |
| Cd (mg kg\(^{-1}\) soil) | 0.73 | 1.27 | 42.52 |
| Ni (mg kg\(^{-1}\) soil) | 19.33 | 31.33 | 38.30 |
| Mn (mg kg\(^{-1}\) soil) | 3.63 | 0.83 | -77.13 |
| Co (mg kg\(^{-1}\) soil) | 32.00 | 33.00 | 3.03 |
| Cu (mg kg\(^{-1}\) soil) | 3.50 | 20.00 | 82.5 |
| Se (mg kg\(^{-1}\) soil) | 12.87 | 12.56 | 2.41 |
| Mo (mg kg\(^{-1}\) soil) | 1.00 | 0.45 | -55 |
| Cr (mg kg\(^{-1}\) soil) | 1.72 | 0.47 | -72.67 |
| Sludge levels (t ha\(^{-1}\)) | Survival percentage of plant | Plant height (cm) | Total biomass g plant\(^{-1}\) | Small size tuber t ha\(^{-1}\) | Large size tuber t ha\(^{-1}\) | Medium size tuber t ha\(^{-1}\) | Marketable tuber t ha\(^{-1}\) | Unmarketable tuber t ha\(^{-1}\) | Total tuber yield (t ha\(^{-1}\)) | CV (%) |
|-------------------------------|-------------------------------|-------------------|-----------------------------|-----------------------------|-----------------------------|-----------------------------|-------------------------------|-------------------------------|--------------------------------|-------|
| 2                             | 84.38                         | 49.56\(^{a,b}\)   | 432.10\(^{b,c}\)           | 2.24                       | 5.49\(^{a,b}\)             | 4.46\(^{b,c}\)             | 10.64\(^{b,c}\)           | 1.52\(^{a}\)                 | 12.16\(^{b,c}\)              | 4.92  |
| 4                             | 86.81                         | 45.06\(^{a,b}\)   | 555.60\(^{b,c}\)           | 1.42                       | 6.09\(^{a,b}\)             | 4.80\(^{b,c}\)             | 10.74\(^{b,c}\)           | 1.57\(^{f}\)                 | 12.31\(^{b,c}\)              | 5.40  |
| 6                             | 87.15                         | 51.59\(^{a,b}\)   | 617.30\(^{b}\)            | 1.08                       | 9.88\(^{a,b}\)             | 5.37\(^{b,c}\)             | 14.05\(^{b}\)             | 2.28\(^{a}\)                 | 16.33\(^{b}\)               | 6.47  |
| 8                             | 87.84                         | 53.99\(^{a,b}\)   | 401.20\(^{b,c}\)          | 1.33                       | 8.39\(^{a,b}\)             | 7.27\(^{b}\)              | 14.55\(^{a,b}\)          | 2.44\(^{c}\)                 | 16.99\(^{a,b}\)             | 2.05  |
| 10                            | 84.38                         | 54.35\(^{a}\)     | 864.20\(^{b}\)            | 2.16                       | 1.01\(^{a}\)               | 1.13\(^{a}\)              | 21.03\(^{a}\)             | 2.50\(^{c}\)                 | 23.53\(^{a}\)               | 1.61  |
| 12                            | 80.90                         | 53.55\(^{a,b}\)   | 925.90\(^{a}\)            | 1.61                       | 1.12\(^{a}\)               | 8.06\(^{a,b}\)           | 17.72\(^{a}\)             | 3.12\(^{a}\)                 | 20.84\(^{a,b}\)             | 1.88  |
| NP                            | 88.19                         | 46.76\(^{a,b}\)   | 339.50\(^{b,c}\)          | 1.099                      | 4.40\(^{a,b}\)             | 2.46\(^{c}\)              | 6.05\(^{b,c}\)            | 1.88\(^{e}\)                 | 7.93\(^{b,c}\)              | 3.25  |
| 0                             | 84.38                         | 39.19\(^{b}\)     | 246.90\(^{c}\)            | .64                        | 2.44\(^{b}\)               | 3.25\(^{b,c}\)           | 5.38\(^{g}\)              | 8.70\(^{h}\)                 | 14.08\(^{b,c}\)             | 11.34 |
| LSD (0.05)                    | 4.92                          | 8.21              | 259.40\(^{c}\)            | 1.82                       | 4.54\(^{b}\)               | 4.49\(^{c}\)              | 7.78\(^{h}\)              | 2.09\(^{c}\)                 | 7.11\(^{c}\)                | 42.62 |
| CV (%)                        | 5.40                          | 11.34             | 32.19                       | 85.75                      | 42.62                      | 52.00                      | 42.26                       | 57.63                        | 33.91 |

CV = coefficient of variation, LSD = least significant difference, t ha\(^{-1}\) = tons per hectare, and means in columns of the same parameter followed by the same letter(s) are not significantly different at 5% level of significance.
Table 3. Physicochemical characteristics of the soil before and after application of brewery waste sludge (BWS)

| Sludge levels (t ha$^{-1}$) | Zn  | Fe  | Cd  | Ni  | Mn  | Co  | Cu  | Se  | Mo  | Cr  |
|-----------------------------|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|
| Soil boundary Values (EU)   | 100 | -   | 3   | 50  | -   | 20  | 80  | -   | 2.0 | 150 |
| Sludge boundary Values (EU) | 2500| -   | 30  | 300 | -   | -   | 1000| -   | -   | 1000|
| Before application          | 6   | 24.71| 0.73| 19.33|3.63|32  |3.5 |12.87|1  |1.72 |
| Change (%)                  | 64.71| 0.00| 21.51|38.30|−0.55|−18.75|41.67|3.74|35.48|−88.95|
| Change (%)                  | 8.00| 24.71| 1.20| 34.67|3.50|27.00|5.00|12.94|0.64|0.50 |
| Change (%)                  | 25  | 0.00| 39.17|44.25|−3.58|−15.63|30  |0.54|−36|70.93 |
| Change (%)                  | 12.50| 24.45| 0.78| 24.33|3.15|38.00|0.50|12.50|1.18|0.66 |
| Change (%)                  | 52  | −1.05| 6.4  | 20.55|−13.22|15.79|−85.71|−2.87|15.25|−61.63|
| Change (%)                  | 15.00| 24.45| 0.05| 11.67|3.36|27.00|4.00|12.87|1.27|0.72 |
| Change (%)                  | 60  | −1.05| −93.15|−39.63|−7.44|−15.63|12.5|0.00|21.26|−58.14|
| Change (%)                  | 11.00| 25.24| 1.21| 22.67|3.25|18.00|4.00|11.62|0.64|0.38 |
| Change (%)                  | 45.45| 2.10| 39.67|14.73|−10.47|−43.75|12.5|−9.71|36|77.91 |
| Change (%)                  | 6.50| 24.71| 1.27| 6.00 |3.11|17.00|1.50|11.37|0.55|0.81 |
| Change (%)                  | 7.69 | 0.00| 54 |−68.96|−14.33|−46.88|−57.14|−11.66|−45|−52.91 |
| Change (%)                  | 2.50| 24.76| 1.29| 25.33|3.64|24.00|5.50|12.94|0.36|1.34 |
| Change (%)                  | 7.69 | 0.00| 54 |−68.96|−14.33|−46.88|−57.14|−11.66|−45|−52.91 |
| Change (%)                  | 2.50| 24.76| 1.29| 25.33|3.64|24.00|5.50|12.94|0.36|1.34 |
| Change (%)                  | 7.69 | 0.00| 54 |−68.96|−14.33|−46.88|−57.14|−11.66|−45|−52.91 |
| Change (%)                  | 2.50| 24.76| 1.29| 25.33|3.64|24.00|5.50|12.94|0.36|1.34 |
| Change (%)                  | 7.69 | 0.00| 54 |−68.96|−14.33|−46.88|−57.14|−11.66|−45|−52.91 |
| Change (%)                  | 2.50| 24.76| 1.29| 25.33|3.64|24.00|5.50|12.94|0.36|1.34 |
| Change (%)                  | 7.69 | 0.00| 54 |−68.96|−14.33|−46.88|−57.14|−11.66|−45|−52.91 |

EU = European Union standard, 2001; *after application of brewery waste sludge; **without application of brewery waste sludge, and Change (%) = the change in percentage for heavy metal accumulation in the soil before and after application of brewery waste sludge (BWS).
Accumulation of all heavy metals in the soil after the potato was harvested was found to be below internationally tolerable standard for most of the metal ions except for Co and Se (Table 3). In general, heavy metal accumulation was below allowable levels of Zn (100 mg kg$^{-1}$), Ni (50 mg kg$^{-1}$), Cd (3 mg kg$^{-1}$), Cu (80 mg kg$^{-1}$) and Cr (150 mg kg$^{-1}$).

The research result revealed that the contaminations of zinc, copper and the nickel are higher than the other heavy metals such as the cadmium, lead and chrome in potatoes (Leblebici et al., 2017). Metal hyper-accumulators are generally slow-growing with a small biomass and shallow root systems. Plant biomass must be harvested and removed, followed by proper disposal. Plants experience stress due to prevailing high concentrations of metals (Vara Prasad & de Oliveira Freitas, 2003).

The pH values indicate that the experimental soil samples taken before BWS application were slightly alkaline, starting at 8.49 and slightly higher in brewery waste sludge used (8.67) (Table 1). The sources of water, process, and skill of manpower are main factors that can vary the range of pH in brewery waste sludge (Luque, Bracho, & Maier, 1990). The use of brewery waste sludge for crop production can affect the availability and toxicity level of heavy metals in soil.

Among the application of various levels of brewery sludge 12 t ha$^{-1}$ produced negative changes that was below the heavy metals in the soil before application. Mercury, lead, arsenic and cadmium are considered as the most hazardous metals that can be up-taken by plants in high proportion with others and accumulate in potato tissues (Jusufi et al., 2017).

Fe concentrations in the experimental soil before and after the application of brewery sludge are almost similar that was non-significant (P < 0.05) also among BS rates (Table 3). The reason for this result would be the presence of abundant iron elements previously in the experimental soil. The iron content of the soil before BS application was 24.71 mg kg$^{-1}$ while the range of iron revealed 24.45 to 24.71 mg kg$^{-1}$ after application of BS. The application of 6 t ha$^{-1}$ and 8 t ha$^{-1}$ BS rates showed the same least result of soil iron concentration (24.45 mg kg$^{-1}$). Even though iron is an essential element that required in large amount for plant growth and development, the use of BS revealed a non-significant difference with the soil iron concentration present before BS application. From 17 essential nutrients, iron is the necessary element that helps plant for the accomplishment of metabolism, photosynthesis and plant growth, and needed in abundant (Öztürk, Atsan, Polat, & Kara, 2011).

Copper is one of the micronutrients that required by plant growth without deviation from health manner, and its optimum supply can be obtained from artificial or/and organic fertilizers including brewery sludge (Itanna, 2002).

Even though the function of Cu is difficult to be known clearly, it can make a vital function in plant metabolism for the normal function of plant physiology (Kabata-Pendias & Pendias, 2001).

The increase in biomass yield compared to NP fertilizer was about 63.33% higher for 12 t ha$^{-1}$ brewery waste sludge application. This may be explained by the fact that nutrient release from is slower than that of NP fertilizer. This finding was in line with Leblebici et al. (2017) who reported a significant increase in the biomass yield of crops following evaluation of heavy metal accumulation in potatoes.

In this study, it was found that maximum equal level of iron (Fe) value in the soil before application and after application of 2 t ha$^{-1}$, and 12 t ha$^{-1}$ BWS (Table 3). The contents of heavy metals in the potato cultivars revealed various results that ranges: 48.87–72.64 mg kg$^{-1}$ for iron, 3.07–5.43 mg kg$^{-1}$ for copper, 13.80–18.89 mg kg$^{-1}$ for zinc, 6.93–13.06 mg kg$^{-1}$ for manganese, 0.51–0.77 mg kg$^{-1}$ for lead, 2.02–3.55 mg kg$^{-1}$ for nickel and 0.08–0.32 mg kg$^{-1}$ for cadmium.
3.3. Growth parameters

3.3.1. Survival percentage of plant and plant height
The separate analysis of variance computed for two parameters (Survival percentage of plant and plant height) revealed that Brewery waste sludge and NP fertilizers had significant (P < 0.01) influence on plant height at the experimental site. However, both brewery sludge (BS) and NP fertilizer had a non-significant influence on the survived plant parameter (Table 2).

The application of brewery sludge did not affect survived plant number. However, this treatment significantly affected plant height. In general, increasing the application rate of brewery sludge in both directions, below and above 10 t ha⁻¹ decreased plant height. Furthermore, for this parameter, there was a non-significant difference within brewery waste sludge levels and with the recommended NP fertilizer rate applied. However, the control treatment and brewery sludge levels showed a significant difference also with NP fertilizer used (Table 2). The height of plants obtained from the brewery sludge rate of 10 t ha⁻¹ exceeded the height of plants that grew from the BS rate of 2, 4 and 6 t ha⁻¹ by about 8.81%, 17.09%, and 5.08% respectively. The plants grown from brewery waste sludge rate of 10 t ha⁻¹ also exceeded the height of plants grown from the recommended NP fertilizer rate and the control treatment by about 12.49% and 27.89%, respectively (Table 2).

3.4. Yield and yield components of potato
The analysis of variance revealed that the effect of industrial sludge significantly (P < 0.05) influences total biomass yield (Table 2). Increasing the rate of sludge from 0 to 6 t ha⁻¹ brewery sludge and 8 to 12 t ha⁻¹ brewery sludge increased total biomass yield linearly by 150% and 275%, respectively, over control treatment and by 81.82% to 172.72%, respectively, as compared to NP-treated plot (Table 2).

The mean of separation revealed that the brewery sludge treatments resulted significantly (P < 0.05) more total dry biomass as compared to control and NP mineral fertilizer applied (Table 2). In this regard, the highest (925.9 kg ha⁻¹) total biomass was obtained from the application of 12 t ha⁻¹ brewery sludge followed by 10 t ha⁻¹ brewery sludge (864.2 kg ha⁻¹), whereas the lowest (246.9 kg ha⁻¹) total biomass was obtained from the control treatment which was statistically at par with the total biomass obtained from the recommended rate NP mineral fertilizers.

3.4.1. Total tuber yield
Total tuber yield ha⁻¹ was significantly (P < 0.05) influenced by brewery sludge treatments (Table 2). Similar to marketable tuber yield, increasing the sludge application rate from 0 to 10 t ha⁻¹ increased total tuber yield ha⁻¹ of potato plants. However, increasing the rate of sludge from 10 to 12 reduced total tuber yields. Thus, the highest (28,244 kg ha⁻¹) total tuber yield was recorded for the application of 10 t ha⁻¹ brewery sludge which was statistically at par with the tuber yield obtained from the application of 12 t ha⁻¹ brewery sludge, while the lowest (7,591 kg ha⁻¹) was obtained from the control plot (Table 2). There was no significant difference among the total tuber yield recorded in response to the recommended rate of NP mineral fertilizer and brewery sludge application at 2 and 4 t ha⁻¹ and control. With the application of 75 kg N and 92 kg P₂O₅, ha fertilizer on improved potato Bubu variety produced 35.62 ton ha⁻¹ and 1.19 ton ha⁻¹ of marketable and unmarketable tuber yield, respectively, at Haramaya during 2013 (Bilate & Mulualem, 2016). Similarly, another research results at the same research site reported 26.00 ton ha⁻¹ and 0.93 ton ha⁻¹ of marketable and unmarketable potato tuber yield, respectively (Merga et al., 2019).

For potato tuber yield, an approximately three-fold increase was observed following the addition of 10 t ha⁻¹ BS when compared to the NP fertilizer application. Increases in yield compared to
control were fourfold for 10 t ha$^{-1}$ BWS application. Nevertheless, the effect of BS on the yield of potato tuber was far than that of recommended NP fertilizer used, and the control treatment. This is the first evidence that the use of BWS improves yields of potato (28.24 t ha$^{-1}$), a cash crop in many parts of Ethiopia that is eastern, western and central to local food traditions.

### 3.4.2. Marketable tuber yield

Analysis of variance showed that marketable tuber yield ha$^{-1}$ was significantly ($P < 0.01$) affected by the sludge treatments (Table 2). Mean of separation revealed that increasing the rate of industrial sludge from 0 to 10 t ha$^{-1}$, increased the marketable tuber yield by 291% and 255% over control and NP treated plots, respectively. However, beyond 10 t ha$^{-1}$ brewery sludge, further increasing the rate of sludge decreased marketable tuber yield indicating that the application of sludge beyond 10 t ha$^{-1}$ did not significantly increase marketable tuber yield (Table 2). Thus, the highest (21.03 t ha$^{-1}$) marketable tuber yield produced was obtained from applying 10 t ha$^{-1}$ brewery sludge whereas the lowest (5.38 t ha$^{-1}$) marketable tuber yield was recorded from the control plot which was at par with that of NP mineral fertilizer treated plot (Table 2).

### 3.4.3. Unmarketable tuber yield

The brewery sludge applications had significant ($P < 0.05$) influence on unmarketable tuber yield hectare (Table 2). Increased brewery sludge rate from 0 to 12 t ha$^{-1}$ consistently increased the unmarketable tuber yield ha$^{-1}$, which ranged from 0.87 to 3.12 t ha$^{-1}$. The lowest and the highest unmarketable tuber yield ha$^{-1}$ of potato were recorded for the application of 0 and 12 t ha$^{-1}$ brewery sludge, respectively (Table 2). This may be due to the increased sludge application is accelerated the growth of aboveground biomass and promoted re-absorption tubers, leading to reduced tuber size and weight and thereby high unmarketable tuber yields.

### 3.4.4. Potato tuber size categories

#### 3.4.4.1. Large size tuber

The sludge application had a significant ($P < 0.05$) effect on large size tuber of potato ha$^{-1}$. Increased brewery sludge rates from 0 to 6 t ha$^{-1}$ and 8 to 12 t ha$^{-1}$ increased the number of large size tubers which ranged from 2.44 to 11.17 t ha$^{-1}$ (Table 2). In this regard, the highest (11.17 t ha$^{-1}$) and lowest (2.44 t ha$^{-1}$) of large size tuber of potato were recorded from the application of 12 t ha$^{-1}$ brewery sludge and control, respectively.

#### 3.4.4.2. Medium size tuber

Similar to the large size tube, medium size tuber was also significantly ($P < 0.05$) affected by different rates of brewery sludge. The mean of separation indicated that increasing brewery sludge rate from 2 to 10 t ha$^{-1}$ increased the medium size tuber of potato from 37.26% to 248% and 81.40% to 360% as compared to control and NP applied plots, respectively. However, further increasing the rate of sludge beyond 10 t ha$^{-1}$ decreased the medium size tuber indicating that the application of sludge above 10 t ha$^{-1}$ did not significantly increase the medium size tuber (Table 2). The highest (8,062 kg ha$^{-1}$) and the lowest (3,247 kg ha$^{-1}$) medium size tuber of potato were recorded from the application of 12 t ha$^{-1}$ brewery sludge and control, respectively. This could be due to the interaction of the nutrients and re-absorption of stored food from tubers because of the fast growth of aboveground biomass due to brewery sludge application. The results of this investigation clearly indicated that the different levels of brewery sludge used largely affected large and medium potato tuber size distribution. The applications of 46 kg ha$^{-1}$ N and 92 P$_{2}$O$_{5}$ kg ha$^{-1}$ fertilizer during 2015 cropping season revealed 35.32%, 29.60% and 35.08% of small-, medium- and large-sized potato tuber yield, respectively (Merga et al., 2019).

#### 3.4.4.3. Small-size tuber

The result of the analysis indicated that a non-significant ($P > 0.05$), small-size tuber of potato variation was obtained among brewery sludge treatments. Nevertheless, the mean of separation revealed that the lowest (635.8 kg ha$^{-1}$) small size tuber was recorded from the control plot followed by 6 t ha$^{-1}$ brewery sludge application, whereas the highest (2,240.7 kg ha$^{-1}$) small size tuber obtained from 2 t ha$^{-1}$ brewery sludge application (Table 2).
4. Conclusion
The results obtained revealed that there were significant effects of Brewery waste sludge on the growth, tuber yield components, and total tuber yield of potato crop at the experimental site. However, there was no significant effect of brewery sludge application on heavy metal concentrations in the soil after crop harvest, compared to an international standard tolerable level. Total tuber yield was highest at 10 t ha\(^{-1}\) rate of brewery sludge (BS) rate and decreased in both directions, below and above this treatment. Thus, the maximum total tuber yield recorded from 10 t ha\(^{-1}\) BS rate was 28.24 t ha\(^{-1}\) crop yield production. In conclusion, potato responded well to the BS rate of 10 t ha\(^{-1}\) in terms of growth and yield in the study area. Therefore, smallholder farmers in the area could be advised to use a BS rate of 10 t ha\(^{-1}\) to optimize potato tuber yield. However, it is premature to come up with a conclusive recommendation since the experiment was conducted for one season only. Therefore, similar experiments should be carried out especially during the main rainy season by including Brewery waste sludges and recommended NP fertilizer rates to come to a conclusive recommendation.

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Author details
Muktar Mohammed\(^1\)
E-mail: mukhtar.muhammad@gmail.com
Bulti Merga\(^2\)
E-mail: bultimerga@gmail.com

ORCID ID: http://orcid.org/0000-0002-4362-3035
Abdulatif Ahmed\(^3\)
E-mail: ahmadabdulatif5@gmail.com

\(^1\) College of Natural Resources and Environmental Science, Oda Bultum University, P.O. Box 226, Chiro, Ethiopia.
\(^2\) School of Plant Sciences, Haramaya University, P. O. Box 138, Dire Dawa, Ethiopia.

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References
Belay, S. C., Wortman, W., & Hoogen, G. (1998). Haricot bean agro-ecology in Ethiopia: Definition using agro-climatic and crop growth stimulation models. African Crop Science Journal, 6(1), 9–18.
Bilate, B., & Mulualem, T. (2016). Performance evaluation of released and farmers’ potato (Solanum tuberosum L.) varieties in eastern Ethiopia. Sky Journal of Agricultural Research, 5(2), 034–041.
Block, C. A., Evans, D. D., & Dinuauer, R. C. (1965). Methods of soil analysis (Vol. 9, pp. 653–708). Madison, WI: American Society of Agronomy.
Burga, S., Dechassa, N., & Tsegaw, T. (2014). Influence of mineral nitrogen and potassium fertilizers on ware and seed potato production on alluvial soil in Eastern Ethiopia. East African Journal of Sciences, 8(2), 155–164.
Colak, H., Soyak, M., & Turkoglu, O. (2005). Determination of trace metal content of various herbal and fruit teas produced and marketed from Turkey. Trace Elements and Electrolytes, 22(3), 192–195.
doi:10.5416/TEP22192
Ellen, G., van Loon, J. W., & Tolsma, K. (1990). Heavy metals in vegetables grown in the Netherlands and in domestic and imported fruits. Zeitschrift Für Lebensmittel-Untersuchung Und Forschung, 190(1), 34–39. doi:10.1007/BF01188261
FAO (Food and Agriculture Organization). (2019). FAOSTAT statistical database of the United Nation Food and Agriculture Organization (FAO) statistical division. Rome, Italy.
HURC (Haramaya University Rare Research Centre). (1996). Proceedings of the 13th annual Research and extension review meeting (pp. 26–28), Haramaya University, Ethiopia.
Itanna, F. (2002). Metals in leafy vegetables grown in Addis Ababa and toxicological implications. Ethiopian Journal of Health Development, 16(3), 295–302. doi:10.4314/ejhd.v16i3.9797
Jones, L. H. P., & Jarvis, S. C. (1981). The fate of heavy metals. The Chemistry of Soil Processes, 599.
Jusufi, K., Stafilov, T., Vasjari, M., Korca, B., Halili, J., & Berisha, A. (2017). Measuring the presence of heavy metals and their bioavailability in potato crops around Kosovo’s power plants. Fresenius Environmental Bulletin, 26(2), 1682–1686.
Kabata-Pendias, A., & Pendias, H. (2001). Trace elements in soils and plants (3rd ed.). Boca Raton, FL: CRC Press.
Leblebici, Z., Aksoy, A., & Akgul, G. (2017). Accumulation and effects of heavy metals on potatoes (Solanum tuberosum L.). In Dr. H (Ed.), Feb-frenesius environment.mental bulletin (pp. 7083). The Nevşehir, Turkey.
Lindsay, W. L., & Norvel, W. A. (1978). Development of a DTPA as a soil response investigation of Mn 2+ complexion in natural and synthetic organics. Soil Science Society of America Journal, 46, 1137–1143.
Lung’aho, C., Lemago, B., Nyongesa, M., Gildermacher, P., Kinylale, P., Demo, P., & Kabira, J. (2007). Commercial seed potato production in eastern and central Africa (pp. 140). Kenya: Keny Agricultural Institute.
Luque, O., Bracho, O., & Maier, T. W. (1997). Utilization of brewery waste water sludge for soil improvement. USA: Technical quarterly-Master Brewers Association of the Americas.
MARD (Ministry of Agriculture and Rural Development). (2009). Ethiopia.
Mendil, D., Tuzen, M., Yazici, K., & Soyak, M. (2005). Heavy metals in lichens from roadsides and an industrial zone in Trabzon, Turkey. Bulletin of Environmental Contamination and Toxicology, 74(1), 190–194. doi:10.1007/s00128-004-0567-x
Merga, B., Dechassa, N., & Mohammed, W. (2019). Effect of seed tuber planting depth and nitrogen rate on yield and yield related traits of potato (Solanum...
tuberosum L.) at Haramaya and Hirna, Eastern Ethiopia. *East African Agricultural and Forestry Journal*, 83(2), 101–118. doi:10.1080/00128325.2019.1599490

Olsen, S. R. (1954). Estimation of available phosphorus in soils by extraction with sodium bicarbonate. *United States Department of Agriculture*, 939, 1–19.

Öztürk, E., Atsan, E., Polat, T., & Kara, K. (2011). Variation in heavy metal concentrations of potato (Solanum tuberosum L.) cultivars. *Journal of Animal and Plant Sciences*, 21(2), 235–239.

SAS (Statistical Analysis System) Institute. (2003). *SAS Version 9.1 © 2002-2003*. Cary, NC: SAS Institute, Inc.

Sharma, O. P., Bangar, K. S., Jain, R., & Sharma, P. K. (2004). Heavy metals accumulation in soils irrigated by municipal and industrial effluent. *Journal of Environmental Science & Engineering*, 46(1), 65–73.

Shkurta, E., Gjoka, F., Contin, M., & Kasa, E. (2017). Heavy metals in vegetables from soils contaminated by various sources. *Fresenius Environmental Bulletin*, 26(2 A), 1771–1777.

Tamire, H. (1973). Characterization of alemaya soils. *Soil Science Paper*, 1, 45.

Tiller, K. G. P. J. K., Oliver, H., McLaughlin, D. P. J. K. H., Merry, M. J. K. H., & Naidu, R. (1997). Managing cadmium contamination of agricultural land. *Science Reviews. Australia: Adelaide Research & Scholarship, The University of Adelaide.*

Van Reewijk, L. P. (1992). Procedures for soil analysis (3rd ed.). Wageningen, the Netherlands: International Soil Reference Center (ISRIC).

Vora Prasad, M. N., & de Oliveira Freitas, H. M. (2003). Metal hyperaccumulation in plants: Biodiversity prospecting for phytoremediation technology. *Electronic Journal of Biotechnology*, 6(3), 285–321. doi:10.4067/S0717-34582003000300012

Vitosh, M. L., Poul, E. A., Harwood, R. R., & Smucker, D. R. (1997). Nitrogen stewardship practices to reduce nitrate leaching and sustain profitability in an irrigated potato production system (pp. 66). Dewitt, MI: Michigan State University Agricultural Experiment Station and Michigan Potato Industry Commission.

Walkley, A., & Black, I. A. (1934). Method for determining soil organic matter and a proposed modification of the chromic acid titration method. *Soil Science*, 37, 29–38. doi:10.1097/00010694-193401000-00003

Wuana, R. A., & Okieimen, F. E. (2011). Heavy metals in contaminated soils: A review of sources, chemistry, risks and best available strategies for remediation. *Isrn Ecology*, 2011. doi:10.5402/2011/402647

Zovko, M., & Romic, M. (2011). Soil contamination by trace metals: Geochemical behaviour as an element of risk assessment. In *Earth and environmental sciences*. IntechOpen.