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Full Length Article

Effect of Liquid Bioslurry and Chemical Fertilizer Applications on Growth and Yield Response of Potato (*Solanum tuberosum*) and Soil Properties

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Abstract

The study aimed at investigating the influence of adding liquid-bioslurry (Biosl) and chemical fertilizer on the growth of potato and soil nutrient improvement. Factorial combinations, fertilizer treatments, and complete random block design with triplicates were used. The soil analysis before planting indicated slightly acidic (pH 6.5) and deficient in organic carbon, total nitrogen, available phosphorus, available potassium, and exchangeable cations. The soil nutrient analysis of Biosl was high in the major nutrients having neutral pH. After planting, pH, carbon content, amount of nitrogen, phosphorus and potassium were improved by 4.0–5.7, 8.9–25, 2.1–8.3, 5.7–34.2 and 3.1–10.9%, respectively. The combined fertilizer showed the plant height of 82.53±0.17 and 79.62±0.16 cm for Belete and Ayenekule varieties, respectively. Potatoes given with combined fertilizer and Biosl performed better as compared to chemical fertilizer treated and control potato plants. The potato plants treated with combined fertilizer, Biosl, and chemical fertilizer alone showed 40.1, 28.3 and 19.8% increase in marketability over control, respectively. The combined fertilizer and Biosl given potato improved the marketability by 19.8 and 9.8%, respectively. The highest yield for Belete variety (22.77±0.67 t/ha) and local variety (20.90±0.36 t/ha) was recorded from potato plants given with combined fertilizer. The highest weight for big-sized potato (11.27±0.21 t/ha) was obtained from Biosl + NP followed by Biosl (10.33±0.55 t/ha) and chemical fertilizer (9.50±0.10 t/ha) treated soil. The pattern of increase was Biosl + NP > Biosl > NP > Control was recorded for all parameters tested. The combined fertilizer and Biosl alone could be recommended instead of chemical fertilizer for achieving better potato yield.

Keywords: Bioslurry; Fertilizer; Marketing; Potato; Yield

Introduction

Based on its agricultural sector development plan, Ethiopia strives for enhancing the production and productivity of smallholder farmers and decreases the degradation of natural resources. The use of chemical fertilizer is one of the strategies for increasing the productivity, yield and income of farmers (Jeptoo *et al.* 2013). The agricultural system that applies organic fertilizers is eco-friendly, simple to practice, economically affordable and publicly acceptable (FAO 2017). Practically, it is believed that sustainable agriculture consumes fewer external inputs and in practice, sustainable agriculture uses fewer external inputs and uses the existing natural resources effectively (Lee 2005). The application of compost and bioslurry (Biosl) contributes to crop productivity and improvement of soil fertility. Among the yield results obtained with the applications of inorganic fertilizers, organic fertilizers, or their combinations, the yield from organic fertilizers is very high (Khan and Shad 2014).

In Ethiopia, the highland and mid-altitude living sustenance farmers cultivate vegetable crops including tomatoes and potatoes that are declining year to year. Currently, in Ethiopia, the yield of potatoes is reduced due to the exhausted and low soil fertility (Amrit 2006), less application of inorganic fertilizers and either few or no application of organic manures (CSA 2000), and as well as the lack of inputs important for crop management (Hussain *et al.* 2008). In the century-long agricultural history of Ethiopia, soil fertility has degraded due to several factors including low external agricultural inputs, poor agricultural practices, lack of awareness, and lack of appropriate land use management plan.

Potato is one of the most important vegetable crops used as the main staple non-grain diet (Rykaczewska 2013). It ranked third important vegetable crop after rice and wheat in terms of consumption (De Jong *et al.* 2011; Birch *et al.* 2012), with overall cultivation beyond 19.34 million hectares of land in more than 158 different nations,

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producing an estimated 364 million tons annually (FAOSTAT 2014). In addition to being used as food, potatoes can also be utilized to produce ethanol, provide pulp for the paper industry, and possibly even act as a raw material for the chemical industry (FAO 2017). It plays a significant role in national food security and nutrition, poverty alleviation, income generation, and employment in the production, processing, and marketing subsectors. In eastern and central Africa, potato is a key food and cash crop (Lung'aho *et al*. 2007). According to Gildemacher *et al.* (2009), the total area of potatoes grown in Ethiopia increased from 40,000 hectares in 1996 to 160,000 hectares in 2006. The productivity of potatoes has increased from 7 to 11 t ha^{-1} in 10 years. In Ethiopia's mid- and highlands, where the crop covered more than 0.45% of the area under all crops and contributed 2.24% to the nation's total crop production in 2014–15, over 1,288,146 million farmers farmed the crop (CSA 2008). However, potatoes made up 31.05% of all root crop production and 16.88% of all root crop area (CSA 2014).

With the availability of a variety of climate and soil conditions, over 70% of Ethiopia's cultivated agricultural area is suitable for the production of potatoes (FAOSTAT 2008). For instance, extensive frost-free periods in the environment enable production throughout both the rainy and off-seasons. In the county, there are more than 3.5 billion m^3 of water resources that might be used to grow potatoes outside of the rainy season. In general, there are great chances to raise the current low levels of crop quality and output. Pests and diseases, lack of proper agronomic practices, such as balanced and optimal nutrition and water inputs, lack of high-quality seed, etc. are some of the main causes of the poor production and consumption of potatoes. The availability of better agronomic practices is not well supported by research (Burton *et al*. 2008).

In Ethiopia, the yield of potatoes and their production is strongly influenced by a number of additional factors, the main ones in the study area being poor agronomic management practices, such as spacing, planting time, and irrigation, poor soil fertility, a lack of well-adapted improved varieties, a lack of adequate nutrient supply, and poor nutrient supply are the main factors (Dandena *et al*. 2011; Shao *et al.* 2023). Furthermore, these authors reported that in the major potato production area of Ethiopia, some of the factors that limit adequate vegetative and reproductive organ growth for appropriate tuber placements and maturity include high temperatures, infections, improper watering techniques, and fertilization.

Chemical fertilizers are not the best way to get around these problems, especially for vegetables that are consumed fresh and have a decreasing shelf life. Chemical fertilizer use is cost-intensive and poses a risk to human health (Wakene *et al*. 2004). Therefore, it is advised that a focus be placed on discovering alternatives to chemical fertilizers, such as compost and bio-slurry, which are affordable and safe than other sources of nutrients (Pervez *et al*. 2000). The management of plant diseases and soil fertility in fields and greenhouses is supported by the use of these organic sources (Shahbaz 2011).

It is important to mention that a sizable number of biogas buildings were built in Kutaber Woreda for use as domestic fuel. Thus, focusing on inexpensive organic manure that is readily available locally becomes a desirable choice. Using Biosl properly might lessen farmers' reliance on pricey chemical fertilizers. In order to show agricultural specialists and farmers, among others, its impact on enhanced output, its advantages also need to be supported by scientific data (Getachew 2011). Declining soil fertility has become a global issue since it is reducing down due to various factors including nutrient mining, salt buildup, and soil erosion. Nowadays, the large dose application of chemical fertilizer associated with intensification of agriculture is resulting in adverse environmental effects. Several efforts are put into practice for combating these negative consequences of chemical farming (Faheed and Fattah 2008). The application of organic fertilizers has come into prominence as a potential remedy for improving the supply of nutrients.

Currently, in Ethiopia, farmers are commonly applying diammonium phosphate (DAP) and urea as fertilizers for increasing their crop yields. However, the smallholder farmers are unable to afford the full levels of these chemical fertilizers. Moreover, the balanced use of both macro- and micronutrients that play a significant role in increasing the yield are not available from chemical fertilizers. In addition to these, Integrated Soil Fertility Management (ISFM) has become a global focus for enhancing eco-friendly organic farming approach (Amrit 2006). Consequently, farmers look for the introduction of organic fertilizers.

Biogas technology produces dregs and slurry as by-products of which biogas slurry is used as an important fertilizer for improving soil fertility which could serve as plant nutrients (Garg *et al*. 2005). In Ethiopia, upon harvesting farmers retain part of crop as crop residues to be used as livestock feed, sources of energy and cash, and material for construction purpose. Farmers are not applying adequate amounts of chemical fertilizer due to their poor economic background (Girma 2017). Consequently, farmers are forced to use only an optimum amount of chemical fertilizer which does not allow them produce high yield. Thus, farmers need to supplement their chemical fertilizer with organic manure which can improve soil fertility by improving soil microbial biomass and activity.

The human population is increasing at an alarming rate reaching over 8 billion worldwide. However, the food supply that satisfies the needs of the increasing population is not promising. Among the contributing factors, declining soil fertility which in turn led to crop yield reduction is the major one. The application of inorganic, organic and their combined amendments can overcome the problem. Soil can obtain limited nutrients from inorganic fertilizers and is also associated with ecological and economical limitations. Organic amendments through microbial decomposition can add several nutrients to the soil, can be prepared from locally available plant and animal material and are ecofriendly. Their independent application may not be sufficient to support the sustained productivity and production level necessary to feed the rapidly growing population.

Applying liquid Biosl integrated with chemical fertilizer could be an alternative strategy for improving soil fertility and crop productivity. However, there is a dearth of information reporting the practice of either independent application of Biosl or its integrated application with chemical fertilizer. Therefore, the main objective of this study was to conduct a field experiment for investigating the effect of either independent application of liquid Biosl or chemical fertilizer or their integrated application in bettering potato growth and yield or improving soil properties and nutrient status.

Materials and Methods

Description of the study area

This investigation was done at Kutaber farmer training center in South Wollo, Amhara Region, Ethiopia. It is located 15 km away from Dessie town to the North of Ethiopia. The study area comprised of 26 and 30°C minimum and maximum air temperature, respectively. Crop farming and animal rearing are the most important farming activities in which people of the study area are dominantly engaged (MoALF 2020). Among the main crops cultivated in Kutaber, maize (*Zea mays* L.), teff (*Eragrotis tef* L.), sorghum (*Sorghum bicolor* L.), wheat, and Barley (*Hordeum vulgare* L.) are the most important ones. Kutaber district consisted of Kola, Wina Dega and Dega agro-climatic zones. The study sites have annual rainfall ranging between 1000–1110.57 mm/year. June and September are months the area get the maximum rainfall, whereas January and February are considered as short rainy seasons in the study area, the mean minimum and maximum temperature is 6.56 and 23.13°C during October and November, and May, respectively. Lithic Leptosols and Eutric vertisols are the dominant soil characterizing the study area. Rain-fed farming and livestock rearing practices which are mixed agricultures are the main livelihood activities in the study area.

Experimental materials

In this study, the experimental materials used were liquid biogas slurry and inorganic fertilizer (Urea and DAP) which is 46% N, and 46% triple super phosphate (TSP, P_2O_5). Other types of equipment included were string, spade, soil auger, measuring tape, Plastic bags, Cultivator, Watering can (watering pot), weighing balance, electrical balance, flame photometer, and spectrophotometer. Two potato varieties named Belete and the locally available, Ayenekule variety were chosen on the basis of their area adaptation and better yield record. These varieties were checked appropriate for growing in the study area with a maturity of about 3–4 months (Araújo *et al.* 2016).

Experimental design and treatments

The study involved two potato varieties (Belete and Ayenekule or local) and four different types of fertilizer treatments: 1) Control, without fertilizer application (CT), 2) Recommended Nitrogen and Phosphorus (NP) fertilizer, 3) Liquid bio-slurry (Biosl), and 4) Combined recommended NP plus Biosl (MoALF 2020). The experimental design was arranged in complete random block design (RCBD) using variety and fertilizer as two factorial arrangements. Thus, the field experiment consisted of 8 treatments with three replications (Table 1).

The nitrogen (urea) and phosphorous (DAP) fertilizer sources were applied 165 kg N and 195 kg P ha^{-1} receiving full dose, whereas half dose consisting of 82.5 kg N and 97.5 kg P ha^{-1} were applied. Likewise, 70 m^3 and 35 m^3 of bio-slurry were added for full and half doses, respectively. Two weeks before planting, the liquid Biosl was mixed properly and thoroughly mixed, weighed for each plot, spread evenly, and added into the soil. The total area for the experimental plot was 2.1 m × 1.5 m (3.15 m^2).

Sampling and experimental procedures

Sample for the experiment: Experimental samples that included soil, potato variety, N and P fertilizers, and Biosl were collected. The local potato variety was bought from the market, whereas the Belete variety was obtained from the research center. The urea and DAP were obtained from the nearby farmer training centers.

Land preparation: In order to allow simple furrow irrigation, the land was prepared by avoiding stones, making proper levels and furrows. After the preparation of the land, it was partitioned into 24 plots. All experimental plots individually had a 2 m x 1.5 m length and width, respectively with 12 plants per plot. Among the total of plants grown, 6 plants/plots from the two middle rows were considered for data recording. A distance of 0.5 m was used between plots and blocks. A spacing distance of 70 cm and 37.75 cm was left between rows and plants, respectively for planting seedlings. During the entire growing period, all the plants were irrigated every three days to maintain soil moisture level to field capacity (Zelalem *et al.* 2009).

Soil physicochemical analysis

Soil samples were taken from 24 plots prepared for planting potato for analyzing the physical and chemical properties of the soil comprising of pH, organic matter, total nitrogen, available phosphorus, and potassium. It was allowed to dry and milled to pass through a 2.0 mm sieve; however, 0.5

mm sieve was used for preparing very fine soil powders for analyzing the nitrogen and carbon content. The analysis was done at Dessie Soil Laboratory, Amhara region. The soil samples which were taken before and after planting were analyzed. Using an atomic spectrophotometer, soil samples were extracted at pH 7.0 using 1.0 M ammonium acetate. The extracts were then analyzed for exchangeable Ca, K, and Na utilizing flame emission at wavelengths of 422.7, 285.2, 766.5 and 589.0 nm, respectively (Page 1982). The soil texture was determined by the Bouyoucos hydrometer method (Bouyoucos 1927). The physical properties of the soil such as cation exchange capacity (CEC) and bulk density were determined using the methods: cations exchange capacity using 1 N NH_4OAc solution at pH 7 (Sumner and Miller 1996) and bulk density (Obi 2000).

The chemical properties of the soil were also determined. Soil pH by digital pH meter (Walk lab Ti 9000) in a 2:1 0.01 M $CaCl_2$ solution to soil suspension (Sumner and Miller 1996). The major chemical properties of soil such as OC, available P and K were analyzed following the compiled laboratory manual of Sahilemedhin and Taye (2000). Wet combustion method using potassium dichromate ($K_2Cr_2O_7$) was applied for evaluating the content of organic matter (Walkley and Black 1934). The total nitrogen was determined by micro-Kjeldahl method (Bremner 1996). After planting and cultivation, soil nutrient analysis was conducted by taking a soil sample from each treatment.

Bioslurry nutrient composition analysis and fertilizer application

Liquid Biosl was collected from biogas pit user's weeks before sowing. Evaluating the amount of nutrients Biosl contained is important for making the treatment arrangement. Consequently, the Biosl's total N was determined by using the semi-micro Kjeldahl method (Jackson 1962). Here, a 0.1 g oven-dried sample was digested for Biosl analysis. The amount of P, K, pH, and organic matter (OM) contained within the Biosl was evaluated by the method used for soil analysis. N and P fertilizers were applied by spreading them around the potato seed or seedling at a distance of 10 cm diameter depending on the application time. Precaution measures were taken for avoiding the direct contact of the fertilizer with the seed or seedling.

Sowing and harvesting

A local oxen driven plowing was used for preparing the land and was plowed three times; the 1st, 2nd and 3rd plows were done on December 3/2020, December 10/2020, and December 20/ 2020, respectively. Portioning of the pot and addition of Biosl was carried out on December 30/2020, 24 plot of equal size was prepared then Biosl added at a plot where Biosl treatment is applied within the same date and finally sowing of potato seed was taken on January 7/2020. It was allowed to be cultivated for four months. Harvesting was undertaken on 20 May 2021. Data were taken for 16 weeks as of first week of potato sprouting period. Height was measured using a ruler, whereas branch number was recorded by numerically counting of the tagged plants. During harvesting time, the marketable and unmarketable potato tubers were assessed (Tekalign 2005; Zelalem *et al*. 2009). The marketable and unmarketable yields were taken as the overall potato yield (Mohammed *et al.* 2013).

Data collection

After four months of planting and cultivation, data on the plant height, primary and secondary branches, number of tubers, the weight of the tuber, marketable yield, unmarketable yield, and total yield were collected taking six plants from the two middle rows of each plot. All activities in this regard were performed based on methods used by Zelalem *et al.* (2009).

Data analysis

The recorded data were analyzed by subjecting to one-way ANOVA using SPSS software version 20.0. Data for treatments were statistically compared and contrasted by applying the Least Significant Difference (LSD) test at a 5% level of probability.

Results

Physicochemical properties of soil before planting

The result of the physicochemical properties of the soil on which the field experiment was conducted are presented in Table 2. The result of the soil analysis indicated that the soil was loam in texture and had a pH of 6.5 in a 1:2.5 soil to water solution. The organic carbon and N content was 1.12 and 0.48%, respectively. The content of soil available K (18.3) and P (10.3) currently analyzed was very low. The cation exchange capacity (CEC) of the soil was 20.3 cmol (+) kg^{-1} which was also generally low. The exchangeable cation analysis result showed that the value for Ca, Na and potassium K were 4.8 cmol (+) kg^{-1}, 0.38 cmol (+) kg^{-1} and 0.56 cmol (+) kg^{-1}, respectively.

In general, the analysis result confirmed that the soil was deficient in all the major plant nutrients such as available carbon, N, P, K and other exchangeable basic cations of Ca, Na and K. Moreover, the study proved that the poor soil fertility and the slightly acidic conditions which limit crop production. The result also revealed that the field soil before planting had a bulk density of 1.41 g/cm^3.

Nutrient composition of the Biosl

The nutrient content and element composition of Biosl analyzed before application under field conditions are presented in Table 3. In this study, the acidity, organic matter and the available P and K of the Biosl were 7.07, 2.8%, 25.98 mg kg^{-1} and 85 mg kg^{-1} respectively.

Integrative effect of fertilizer and varieties on height and branches of the potato

Results presented in Table 4 showed that the independent application of inorganic or organic fertilizer and their combined application influenced the height and branch of potato significantly ($p<0.05$). The height of Belete potato variety given the combined fertilizer (Biosl + chemical fertilizer) recorded the highest height (82.53 cm) followed by independent application of Biosl and chemical fertilizer with a height of 80.54 cm and 78.5 cm, respectively (Fig. 1). On the other hand, the control plants recorded the least height. The application of combined fertilizer resulted in 286.6, 277.4 and 268.1% of height increment over the control potato plants. In Belete variety, potato plants treated with Biosl + NP and Biosl alone brought 5.1 and 1.3% height difference over the height of potato treated with chemical fertilizer. A similar plant height result pattern was observed for potato plants of local variety. As compared to the height of the control potato plant, the height of potato plants treated with combined fertilizer, and singly applied Biosl and chemical fertilizer alone showed height increase of 352.1, 312.2 and 301.5%, respectively (Fig. 2). Similarly, the combined fertilizer and the Biosl alone brought a height difference of 12.6 and 2.7% over the chemical fertilizer, respectively. In all the treatments applied, the height of Belete variety was greater than the local variety. In both variety treatments, potato plants that were given combined fertilizer recorded the highest plant height compared to the remaining treatments.

In both varieties, potato plants treated with combined fertilizers showed the highest branch growth, whereas the least was obtained from the control potato plants. The potato plants treated with Biosl and chemical fertilizer ranked second and third in branch number next to the combined application, respectively. In general, in Belete and local potato varieties, the height and branch growth responses to fertilizer additions were in the order of combined application > Biosl > Chemical fertilizer > Control.

Effect of fertilizer and variety on the marketability and yield of the potato

Both fertilizer and variety applications brought an important effect on the marketability, unmarketability and total yield (Table 5). For both potato varieties, the highest marketability was obtained from potato plants given with combined fertilizer followed by independent addition of liquid Biosl and chemical fertilizer (Fig. 3). On the other hand, for both varieties, the least marketability was obtained for the control plant. The application of organic and chemical fertilizer increased the marketability of potato

Table 1: The treatment set up and nutrient content of the field experiment

Variety	Fertilizer code	Nutrient content in the treatment
Belete	CT	0 kg/plant
	NP	165 kg urea/ha & 195 kg DAP/ha
	NP+Biosl	82.5/97.5kg N/P/ha+35 m^3 biosl
	Biosl	70 m^3 biosl
Aynekule	CT	0 kg/plant
	NP	165 kg urea/ha &195 kg DAP/ha
	NP+Biosl	82.5/97.5 kg N/P/ha+35 m^3 biosl
	Biosl	70 m^3 biosl

CT Control; NP Nitrogen and Phosphorus; Biosl Bioslurry treatments

Table 2: The physical and chemical properties of soil before planting

Soil characteristics	Values
Physico-chemical	
pH (H_2O)	6.50
OC (%)	1.12
TN (%)	0.48
Av. P (mg/kg)	10.30
Av. K (meq 100^{-1} g)	18.30
CEC (cmol(+) kg^{-1})	20.20
Bulk density (g/cm^2)	1.41
Texture class	Loam
Exchangeable base	
Na	0.38
K	0.56
Ca	4.30

TN Total Nitrogen; OC Organic carbon; Av. P Available phosphorous; Av. K Available potassium; CEC Cation exchange capacity

plants. The potato plants treated with combined fertilizer, Biosl and chemical fertilizer alone showed 40.1, 28.3 and 19.8% increase in marketability over the control plants. Compared to the chemical fertilizer treated potato, the combined fertilizer and Biosl treated potato improved marketability by 19.8 and 9.8%, respectively.

The effect of fertilizer and variety showed significant ($p< 0.05$) variation in the unmarketability of potato (Table 5). The combined fertilizer treatments resulted in a decrease in unmarketability, whereas the control potato plants showed the highest unmarketability. In Belete variety, the least unmarketability (1.60±0.27 t/ha) was recorded by the combined fertilizer but the maximum unmarketable potato yield was obtained from control potato plants (2.70±0.10 t/ha). Similar trend was obtained for the local potato variety with the lowest unmarketable (1.50±0.30 t/ha) and highest unmarketable (2.93±0.25 t/ha) for the potato plants treated with combined fertilizer and untreated control potato plants, respectively. In this study, among the varieties applied, the minimum unmarketability (1.50±0.30 t/ha) and maximum unmarketable value (2.93±0.25 t/ha) was obtained from the local variety. In general, the highest marketability and the least unmarketability were recorded from Belete potato variety.

The yield response (t/ha) for both varieties was significant ($P < 0.05$). The highest yield (22.77±0.67 t/ha) was obtained from Belete variety followed by 20.90±0.36 t/ha, which was recorded from the local variety (Fig. 4). The

Table 3: The element composition and nutrient content of bioslurry

pH (H_2O)	OM (%)	TN (%)	C: N ratio	Av. P (mg kg^{-1})	Av. K (meq/100 g)	CEC (cmol(+) kg^{-1})
7.07	2.82	0.51	6.5	25.98	85	25.4

OC Organic Carbon; OM Organic matter; T.N Total nitrogen; Av. P Available phosphorous; Av. K Available potassium; CEC Cation exchange capacity

Table 4: The interaction effects of fertilizer × variety on height and branch number of potato

Variety	Treatment	Height (cm) at 90 days	No. of branches	
			Primary branch	Secondary branch
Belete	Control	21.34±0.23^{d}	3.13±0.76^{c}	7.53±0.25^{c}
	Chemical fertilizer	78.55±0.11^{c}	3.73±0.25^{b}	8.53±0.15^{b}
	Bioslurry	80.54±0.09^{b}	4.1±0.10^{b}	10.73±0.51^{a}
	Combination	82.53±0.17^{a}	5.07±0.32^{a}	11.20±0.26^{a}
Aynekule	Control	17.61±0.17^{d}	2.57±0.21^{d}	3.67±0.35^{d}
	Chemical fertilizer	70.71±0.37^{c}	3.70±0.20^{c}	8.37±0.21^{c}
	Bioslurry	72.59±0.03^{b}	4.1±0.10^{b}	9.77±0.25^{b}
	Combination	79.62±0.16^{a}	4.60±0.26^{a}	10.57±0.21^{a}

Belet(NP+Biosl) Belet+NP Belet+Biosl Belete+control

Fig. 1: Vegetative growth performance of Belete variety under all treatments

Local+Biosl Local+control Local+NP+Biosl Local+NP

Fig. 2: Vegetative growth performance of local variety under all treatment

least yield response (12.57±0.91 t/ha) was obtained from control potato plants of the local variety which was followed by potato plants with no treatment given or control plants of Belete variety (13.70±0.44 t/ha). Both potato varieties given with Biosl showed better yield than those given chemical fertilizer, which in turn gave higher yield than their respective control potato plants. In all the parameters, the yield obtained from Belete variety was higher than the yield recorded from local variety. Both potato varieties given Biosl + NP recorded higher yield than their individual application. In Belete variety, the combined fertilizer, Biosl and chemical fertilizer yielded 66.2, 51.3 and 34.8% better over control potato (Fig. 5). Likewise, the combined fertilizer and the Biosl alone showed a yield difference of 28.3 and 12.2% over the chemical fertilizer. In case of local variety, compared with the control, its yield from combined fertilizer, and individual Biosl and NP yielded 66.3, 50.6 and 42.2% better over the control, respectively (Fig. 6). The yield obtained from potato treated with combined fertilizer and Biosl alone showed 17.9 and 5.9% variation over chemical fertilizer applied potato plants.

Fertilizer and variety effect on the number of potato tuber

The addition of organic and chemical fertilizer and variety application brought a significant variation on potato weight accumulation (Table 6). Regarding the weight of potato tubers, all measurements showed significant variation at $P < 0.05$, except weight of medium sized tubers for Belete variety. The highest weight for big sized potato (11.27±0.21 t/ha) was recorded from potato plants applied with Bisol +

Table 5: The interaction effects of fertilizers × variety on the marketability and yield of potato

Variety	Treatment	Yield (t/ha)		
		Marketable yield	Unmarketable yield	Total yield
Belete	Control	14.33±0.15[d]	2.70±0.10[a]	13.70±0.44[d]
	Chemical fertilizer	16.75±0.47[c]	1.93±0.32[bc]	18.47±1.11[c]
	Bioslurry	18.39±0.19[b]	2.37±0.21[ab]	20.73±0.21[b]
	Combination	20.07±0.59[a]	1.60±0.27[d]	22.77±0.67[a]
Aynekule	Control	11.70±0.57[d]	2.93±0.25[a]	12.57±0.91[c]
	Chemical fertilizer	15.43±0.15[c]	2.07±0.42[bc]	17.87±0.31[b]
	Bioslurry	17.20±0.36[b]	2.23±0.15[b]	18.93±0.32[b]
	Combination	18.33±0.15[a]	1.50±0.30[c]	20.90±0.36[a]

Table 6: The interaction effects of fertilizers × variety on potato weight accumulation

Variety	Treatment	Yield (t/ha)		
		Weight big	Weight medium	Weight small
Belete	Control	8.13±0.15[d]	9.03±0.31[b]	10.20±0.44[c]
	Chemical fertilizer	9.40±0.52[c]	15.23±2.91[a]	14.94±0.66[a]
	Bioslurry	10.30±0.46[b]	15.17±1.33[a]	12.30±0.80[b]
	Combination	11.27±0.21[a]	17.37±1.79[a]	11.09±0.80[bc]
Aynekule	Control	7.58±0.11[c]	8.37±0.12[c]	9.00±0.63[d]
	Chemical fertilizer	9.50±0.10[b]	12.37±0.90[b]	15.45±0.14[a]
	Bioslurry	10.33 ±0.55[ab]	13.40±78.47[ab]	12.90±1.22[b]
	Combination	10.80±0.57[a]	15.61±1.12[a]	10.60±0.20[c]

Fig. 3: The marketable yield in the sac

NP which was followed by Biosl and chemical fertilizer treated potato plants. The weight of big sized potato of local variety showed that the highest tuber weight was obtained from potato fertilized by Biosl + NP which still was followed by Biosl and NP with the least record by the control potato. Except for the weight of small sized tubers, in both the big and medium sized potato tubers, the weight of potato recorded followed the pattern of Biosl + NP > Biosl > NP > control.

Effect of fertilizer and variety on soil fertility improvement after crop harvest

The application of Biosl, NP and their combined addition and variety application improved the properties of the soil such as soil acidity, organic carbon, total N, available K and P (Table 7). The pH of the soil when compared before and after planting, the pH after planting for both varieties was improved by 4‒5.7%. For Belete variety, the maximum soil pH was obtained from plants applied with Biosl alone which was increased by 9.1% over the control. However, for local Ayenekule variegty, the maximum soil pH was recorded from soil added with NP + Biosl and showed increment of 9.5% over the control (Table 8). The fertilization of Belete and Ayenekule variety improved the organic carbon content by 14.3–25 and 8.9–14.3%, respectively. Maximum organic carbon content of 2.38 and 2.23% was obtained from soil applied with Biosl for Belete and local Ayenekule, respectively while the least amount of organic carbon (1.75 and 1.73%) was recorded in control plots. An integrated application of Biosl and chemical fertilizer also proved important for improving soil organic matter.

The application of Biosl (0.51%), NP (0.49%) and Biosl + NP (0.52%) enhanced the soil N content for Belete

Table 7: The effect of fertilizer addition and variety application on soil fertility improvement

Treatment	Belete variety					Ayenekule variety				
	pH (H_2O)	OC	TN	Av. K (meq/ (100 g)	Av. P (mg/kg)	pH (H_2O)	OC (%)	TN	Av. K (meq/ (100)	Av. P (mg/kg)
Biosl	6.87	1.40	0.51	19.3	11.9	6.76	1.22	0.48	18.90	11.20
NP	6.76	1.28	0.49	18.9	10.89	6.71	1.23	0.45	18.86	10.93
NP+Biosl	6.81	1.39	0.52	20.3	13.82	6.79	1.28	0.47	19.40	12.50
Control	6.60	1.20	0.46	18.8	11.00	6.20	1.00	0.43	18.70	10.80

OC Organic Carbon; OM Organic matter; T.N Total nitrogen; Av. P Available phosphorous; Av. K Available potassium; CEC Cation exchange capacity

Table 8: Fertilizer and variety application on soil exchangeable cation improvement

Fertilizer	Belete variety				Ayenkule variety			
	CEC [cmol(+)/kg]	Na	K	Ca	CEC [Cmol(+)/kg]	Na	K	Ca
Biosl	21.9	0.56	0.61	5.9	21.6	0.55	0.57	5.7
NP	21.7	0.55	0.57	5.4	21.5	0.57	0.52	4.9
NP+Biosl	23.8	0.58	0.7	6.7	22.4	0.56	0.55	5.8
Control	21.2	0.44	0.47	4.8	21.0	0.43	0.48	4.5

CEC: Cation exchange capacity; Na: Sodium; K: Potassium; Ca: Calcium

Belet+NP+Biosl Belete+control Aynekule+NP+Biosl Aynekule+control

Fig. 4: Comparison of potato yield for both varieties

Belet+Biosl Belete +control Belete+NP Belet+NP+Biosl

Fig. 5: Yield component for Belete potato variety

Local+NP+Biosl Local+control Local+Biosl Local+NP

Fig. 6: Yield and yield component of for local potato variety

variety except the control (0.46%) when compared and contrasted with the nitrogen content of the soil before sowing (Table 3). The N content of the soil grown with Belete variety was improved by 2.1−7.7% compared with soil analyzed before planting. In soil sowed and cultivated with Belete variety, the N content of soil with combined Biosl + NP application was higher than the Biosl treated soil which in turn was higher than the soil fertilized by chemical fertilizer. Generally, in Belete variety, the fertilizer application improved the soil N content being the highest in the soil with combined Biosl and NP fertilizer followed by the Biosl amended soil (Table 3).

In this study, the maximum P content of 13.82 and 11.9 mg kg^{-1} of soil were obtained from soils grown with Belete variety under Biosl + NP and Biosl alone treatments and was higher by 25.6 and 8.2% greater over the control, respectively. However, the minimum amount of available P (11.0 mg kg^{-1}) content was recorded from the plot that was neither given Biosl nor chemical fertilizer. Similarly, P accumulated in the soil after cultivation of the local variety showed that the highest P was obtained from soil added with Biosl + NP (12.5) followed by Biosl (11.2) and NP (10.93) treated soils with the least improvement in control soils (10.8). Generally, results revealed that the P content of the soil planted with Belete variety and Akynekule variety was improved by 5.7─34.2 and 6.1─21.4%, respectively.

In general, in all the varieties and treatments applied, the total P and total K available in the soil was higher after potato harvest than before sowing (Table 3 and 8). The available K accumulated due to the application of Belete variety and fertilizer was in the range of 18.8−20.3 mg kg^{-1}, whereas 18.7─19.4 mg kg^{-1} range was recorded from the soil sowed with the local variety. The available K content of the soil planted with Belete and Akynekule varieties was improved by 3.3─10.9% and 3.1− 6.0%, respectively. A highest available K was recorded from Biosl and/or Bisol + NP supplemented soil, whereas the least was from the control soil.

Effect of fertilizer and variety on soil exchangeable base after crop harvest

Application of Biosl, NP, their combined application and variety on the improvement of exchangeable ions (Table 8). Fertilizer application improved the soil's cation exchange capacity (CEC). The application of BIosl, NP and their combination resulted in the improvement of the cations such as Na, K and Ca content compared with their amount analysed before planting (Table 2 and 7). Application of combined fertilizers improved the organic carbon, CEC, and total N and available P and K significantly, whereas these parameters decreased with the application of NP alone.

Discussion

It is known that soil is deficient in essential nutrients which thereby limit productivity of crops. The addition of Biosl as organic inputs and chemical fertilizers either independently or in combination could be a better option for improving soil nutrients status, soil acidity and crop yield. Consequently, this study that focused on the application of liquid Biosl and chemical fertilizer for improving the soil nutrient status and boosting the productivity of potato (*Solanum tuberosum* L.) was conducted. The soil analysis indicated that its texture was loam and had a pH of 6.5 which is categorized as slightly acidic soil (Haile and Boke 2009). Moreover, the amount of organic carbon and total N of the studied soil was of very low category (Landon 1991; Zebarth *et al.* 2007) indicating that the low soil fertility status require organic and inorganic fertilization (Table 2).

The available K and P currently analyzed was also very low as per the rating reported (Zebarth *et al*. 2007), which implied the need for P and K application in soil of the study area (Table 2). The overall carbon, total N, available P and K content of the soil in the study site indicated that soil under investigation required additional fertilizer inputs. The amount of exchangeable cations such as Ca, Na and K were very low as per the standard recommendation (Landon 1991) which necessitated fertilizer application. The bulk density of soil before treatments was within the category of dense to very dense status (Landon 1991). In general, the soil fertility content of the study area indicated that the soils were deficient in carbon, N, P, K and the exchangeable cations such as Ca, Na and K (Table 2). Besides, the pH of the soil was slightly acidic (Table 2) that could decline crop productivity through its effects of increasing the availability of potentially toxic micronutrients (Wakene and Heluf 2003). This study also revealed poor soil fertility status and soil acidity as reported previously (Tuma *et al.* 2013) indicating that the soil of the study site lacked proper and adequate nutrients important for crop productivity.

In this study, the acidity of the Biosl was under the neutral classification category as reported by (Shahbaz 2011) implying that the addition of the Biosl could neutralize the soil acidity. The organic matter of the Biosl was under the medium classification (Table 3), which still could contribute to the fertility of the experimental soil though very low in carbon content (Landon 1991). The Biosl contained high available P beyond the normal range that should be available in the natural soil (Shahbaz 2011) implying that the application of Biosl could improve potato growth. Likewise, the Biosl constituted available K which was very high as per the soil K content indicating a high contribution of the Biosl for improving soil fertility.

Results revealed that the application of integrated fertilizer inputs, independent application of Biosl and chemical fertilizer resulted in higher potato height over the control potato plant (Table 4). In their studies, Amir *et al*. (2013) and Suh *et al*. (2015) indicated that the Biosl contained nutrient composition for better plant growth. In Belete variety, potato plants treated with Biosl + NP and Biosl alone brought greater height difference over the height of potato plants treated with chemical fertilizer. This implied that application of the combined fertilizer and the Biosl alone was better than applying chemical fertilizer alone. A similar plant height pattern was observed for local potato variety. In general, in both Belete and local potato variety, the height and branch growth responses to fertilizer additions were in the order of Combination > Biosl > Chemical fertilizer > Control, indicating that the addition of bioslurry and chemical fertilizers supply nutrients of the root region, enhance their absorption and utilization by the root hairs and fostering root development and better crop growth (Shangguan *et al*. 2000; Husma 2010; Oyedeji *et al*. 2014 Suh *et al*. 2015).

The marketability of potato plants applied with combined fertilizer, Biosl and chemical fertilizer alone was higher than the control potato plants (Table 5). Likewise, compared to the chemical fertilizer treated potato, the combined fertilizer and Biosl improved potato marketability. The addition of organic and chemical fertilizer enhanced the marketability of potato plants. In this context, Kumar *et al*. (2012) and Shahbaz 2011) reported that the integrated application of organic manures and chemical fertilizers improved performance of tomato which coincided with the findings of the current study. In their study, Meaza *et al*. (2009) showed the highest and least marketability for potato plants given with combined fertilizer and the unfertilized, control potato plants, respectively which similarly coincided with the findings reported in this study (Table 5). The synergistic application of combined fertilizer enhanced crop growth, increased leaf size, and photosynthetic ability that in turn results in large potato tubers production and increased marketability (Raza *et al*. 2021; Nasar *et al*. 2022). Araújo *et al*. (2016) reported that the application of liquid Biosl and chemical fertilizer boosted both total tuber yield and the quantity of marketable tuber yield. In both varieties, the highest unmarketability was recorded from the control plants which attributed to the inadequate nutrient supply in the soil resulting in small tuber size and low yield of potato (Shao *et al*. 2023).

In both potato varieties, potatoes applied with Biosl showed better yield than chemical fertilizers treated potato plants. Potato plants of both varieties treated with Biosl + chemical fertilizer gave higher yield than individual treatments (Table 5). These data were similar to the findings of Singh and Kushwah (2006) who reported higher tuber yield with integrated fertilizer application and greater nutrient availability under integrated treatment. yield with integrated fertilizer application greater nutrient availability under integrated treatment. The yield obtained from Belete variety was higher than the local variety indicating that variation in variety could be a good attribute to variation in yield.

In both varieties, the soil pH improved after planting as described by various studies (Pattanayak *et al*. 2001; Yaduvanshi 2001; Smiciklas-Wright *et al*. 2002; Sarwar *et al*. 2003). These studies explained soil pH improvement after harvesting rice and wheat crops which was due to the production of organic acids, and as a result of organic matter mineralization and nitrification contributes to soil pH reduction. In this study, for both Belete and Ayenekule verities, the highest and least organic carbon was recorded from soil supplied with Biosl and control soil, which was similar to previous reports (Sarwar *et al*. 2003; Singh *et al*. 2001; Ali and Solomon 2012), implying that Biosl added greater organic carbon into the soil (Table 7). An integrated use of Biosl and chemical fertilizer is proved important for improving the soil organic matter.

Data showed that for Belete variety the soil N content after harvest was improved in the order of Biosl + NP > Biosl > NP > Control indicating a high amount of N contained within the Biosl (Table 7). On the contrary, the N content of the soil after harvest for local Aynekule variety showed no improvement which may be due to the slow nitrogen release property of the local variety. This may also be due to the genetic variability of the grain yield (Mitiku *et al*. 2006). The amount of P accumulated after harvest was higher for Belete variety than local variety. However, in both varieties, the accumulation of P after harvest was in the order of Biosl + NP > Biosl > NP > control soil as reported earlier in Pigeonpea (Yihenew 2002). This implied that P availability increased due to the organic matter accumulation that forms complexes with amorphous ion in the soil preventing the binding and immobilization of phosphate ions (Taye and Yifru 2010).

Regarding K accumulation, the highest value was recorded from Biosl and/or Bisol + NP supplemented soil, whereas the least was from the control soil (Table 8), which was similar with the findings of Zelalem *et al*. (2009). This showed that the separate application of Biosl and its integrated application with liquid Biosl contributed much more than chemical fertilizers alone and control soil for improving the amount of soil P and K. Likewise, Singh *et al*. (2001) reported that crop yield, soil organic carbon, total N and mineralized carbon and nitrogen increased due to integrated fertilizer application. In this study, variety and fertilizer application increased the cation exchange capacity (CEC) for soil which was higher after harvest than before sowing (Table 2 and 8), indicating that the addition of these inorganic and organic amendments contributed to the improvement of the soil fertility. The conjugative use of Biosl and chemical fertilizer improved the level of organic carbon, CEC, total N, available P and K, whereas they were declined by separate application of chemical fertilizer as reported by Wakene *et al*. (2004).

In this study, the application of NP fertilizer, Biosl and their combined application showed variation in soil nutrient status, potato growth and yield. Applying NP + Biosl showed the highest improvement in the mentioned parameters followed by the application of Biosl alone. Among the fertilizer treated potato, potatoes applied with NP showed the least result. Thus, applying Biosl either alone or combined with NP is an alternative strategy to applying NP which is ecologically unsafe and economically non-affordable.

Conclusion

Analysis showed that the soil was loam with 6.5 pH while the carbon and N content were low. Moreover, the available P, K, Na, Ca and CEC were low. After fertilization, the potato varieties showed improvement in growth attributes in the trend: Biosl + NP > Biosl > NP > Control. In general, the low nutrient content of the sample soil is an indicative of the need for applying inorganic and organic fertilizers. A higher nutrient content of Biosl obtained was also an important finding to be used as organic fertilizer. Applying Biosl and chemical fertilizer in combination boosted potato growth and yield and improved soil properties. The application of Biosl alone or the combination can be used as a better alternative to applying chemical fertilizer which is cost intensive and non-ecofriendly. Finally, these findings can be used as a good input for farmers, extension agriculturalists, researchers and policy makers.

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Author Contributions

Concept: Mussa Adal, Design: Yimer Ali, Data Collection or Processing: Yimer Ali, Analysis or Interpretation: Yimer Ali and Mussa Adal, Literature Search: Gizachew Mulluneh, Writing: Mussa Adal and Gedefaw Wube

Conflicts of Interest

The authors declare that there is no conflict of interest.

Data Availability

Data will be available any time upon a fair request.

Ethics Approval

Not applicable.

References

Ali M, T Solomon (2012). Effect of different rates of nitrogen and phosphorus on yield and yield components of potato (*Solanum tuberosum* L.) at Masha District, Southwestern Ethiopia. *Intl J Soil S* 7:146–156

Amir A, RH Mohammad, TD Mohammad, F Faezeh (2013). Influence of nitrogen fertilizer and cattle manure on the vegetative growth and tuber production of potato. *Intl J Agric Crop Sci* 147–154

Amrit B (2006). Country Report on the Use of Bioslurry in Nepal, Final Report: Submitted to SNV/BSP, Nepal

Araújo TH, JG Pádua, MHF Spoto, VDG Ortiz, PL Margossian, CTS Dias, PCT Melo (2016). Productivity and quality of potato cultivars for processing as shoestrings and chips. *Hortic Bras* 34:554–560

Birch PRJ, G Bryan, B Fenton, E Gilroy, I Hein, JT Jones, A Prashar, MA Taylor, L Torrance, IK Toth (2012). Crops that feed the world. Potato: Are the trends of increased global production sustainable? *Food Secur* 4:477–508

Bouyoucos GJ (1927) The hydrometer as a new and rapid method for determining the colloidal content of soils. *Soil Sci* 23:319–331

Bremner JM (1996). Nitrogen-total. In: *Methods of Soil Analysis, Part 3, Chemical Methods.* Sparks DL (Ed.). Soil Science Society of America, Madison, Wisconsin, USA

Burton DL, BJ Zebarth, KM Gillam, JA MacLeod (2008). Effect of split application of fertilizer nitrogen on N_2O emissions from potatoes. *Can J Soil Sci* 88:229–239

Central Statistical Agency (CSA) (2000). Agricultural sample survey. 1999/2000. Report on area and production for major crops: Private peasant holding' Meher' season. *Statistical Bull 227*. Addis Ababa, Ethiopia

Central Statistical Agency (CSA) (2008). Agricultural Sample Survey 2009/2010. Volume I. Report on Area and Production of Crops: Private Peasant Holdings. Meher Season. *Statistical Bull 446*. Addis Ababa, Ethiopia

Central Statistical Agency (CSA) (2014). Agricultural Sample Survey 2014/2015. Volume I. Report on Area and Production of Crops: Private Peasant Holdings. Meher Season. *Statistical Bull 532*. Addis Ababa, Ethiopia

Dandena G, A Bekele, D Lemma (2011). Regulation of tomato (*Lycopersicon esculentum* Mill.) fruit setting and earliness by gibberellic acid and 2, 4-dichlorophenoxy acetic acid application. *Afr J Biotechnol* 11:11200–11206

De Jong HDJ, JB Sieczka, W De Jong (2011). *The Complete Book of Potatoes Whatever Grower and Gardener Needs to Know*. Timber Press, Portland, Oregon, USA

Faheed FA, ZA Fattah (2008). Effect of Chlorella vulgaris as bio-fertilizer on growth parameters and metabolic aspects of lettuce plant. *J Agric Soc Sci* 4:166–169

FAO (2017). *Food and Agriculture Organization of the United Nations*. Rome, Italy

FAOSTAT (2008). Potato World: Africa International Year of the Potato. http://www. Potato 2008 .org/en/world/africa.htl

FAOSTAT (2014). *Food and Agriculture Organization Data of Statistics*. One Hundred Fifty Eight Countries Data Base. Available at: http://faostat.fao.org /site/567/

Garg RN, K Pathak, H Tomar, DK Das (2005). Use of flyash and biogas slurry for improving wheat yield and physical properties of soil. *Environ Monit Assess* 107:1–9

Getachew E (2011). *Bioslurry – Is It a Fertilizer in the Making: Case Studies*. SNV Netherlands Development Organization, The Hague, Netherlands

Gildemacher P, W Kaguongo, O Ortiz, A Tesfaye, W Gebremedhin, W Wagoire, R Kakuhenzire, PM Kinyae, PCS Nyongesa., C Leewis (2009). Improving potato production in Kenya, Uganda and Ethiopia. *Potato Res* 52:173–205

Girma A (2017). Determination of organic materials quality based on nutrient recovery mineral fertilizer equivalency and maize (*Zea mays* L.) allometry. *Arch Agron Soil Sci* 63:48–59

Haile W, S Boke (2009). *Mitigation of Soil Acidity and Fertility Decline Challenges for Sustainable Livelihood Improvement: Evidence from Southern Region of Ethiopia*, pp:1–15. Awassa Agricultural Research Center, Ethiopia

Husma M (2010). The influence of organic material and potassium fertilizer toward the growth and production of melon plant (*Curcumis melo* L.) *Thesis*. Agronomi Study Program, Haluoleo University, Kendari, Indonesia

Hussain, MB Khan, R Ahmed (2008). Influence of phosphorous application and sowing time on the performance of wheat in calcareous soil. *Intl J Agric Boil* 10:399–404

Jackson ML (1962). *Soil Chemical Analysis*, pp:219–221. Prentice Hall, Inc. Eaglewood Cliffs, New Jersey, USA

Jeptoo A, JN Aguyoh, M Saidi (2013). Improving carrot yield and quality through the use of bio slurry manure. *Sustain Agric Res* 2:164–172

Khan S, KK Shad (2014). Integrated use of organic and inorganic fertilizers in wheat and their residual effect on subsequent mung bean. *Intl J Farm Allied Sci* 3:835–844

Kumar M, LK Baishaya, DC Ghosh, VK Gupta, SK Dubey, A Das, DP Patel (2012). Productivity and soil health of potato (*Solanum tuberosum* L.) field as influenced by organic manures, inorganic fertilizers and biofertilizers under high altitudes of Eastern Himalayas. *J Agric Sci* 4:223–234

Landon JR (1991). *Booker Tropical Soil Manual: A Handbook for Soil Survey and Agricultural Land Evaluation in the Tropics and Subtropics*. John Wiley & Sons Inc., New York, USA

Lee DR (2005). Agricultural sustainability and technology adoption: Issues and policies for developing countries. *Amer J Agric Econ* 87:1325–1334

Lung'aho C, B Lemaga, M Nyongesa, P Gildermacher, P Kinyale, P Demo, J Kabira (2007). *Commercial Seed Potato Production in Eastern and Central Africa*. Kenya Agricultural Research Institute, Nairobi, Kenya

Meaza M, S Tilahun, W Kebede (2009). Effect of different cultivation practices and influence of postharvest reatment on the shelf life of tomato (*Lycopersicon esculentum* Mill.). *East Afr J Sci* 3:43–54

Mitiku H, K Herweg, B Stillhardt (2006). *Sustainable Land Management: A New Approach to Soil and Water Conservation in Ethiopia*. Mekelle, Ethiopia

MoALF–Ministry of Agriculture Livestock and Fisheries (2020). *Irrigation Agronomy*, 4th edn. Ministry of Agriculture Livestock and Fisheries, Nairobi, Kenya

Mohammed B, M Gabel, LM Karlsson (2013). Nutritive values of drought tolerant food and fodder crop enset. *Afr J Agric Res* 8:2326–2333

Nasar J, GY Wang, FJ Zhou, XB Zhou, HI Gitari, KM Tabl, ME Hasan, H Ali, MM Waqas, I Ali (2022). Nitrogen fertilization coupled with foliar application of iron and molybdenum improves shade tolerance of soybean under maize soybean intercropping. *Front Plant Sci* 13:1014640

Obi ME (2000). *Soil Physics: A Compendium of Lectures*, 1st edn., pp:83–125. Atlanto publication, Nsukka, Nigeria

Oyedeji S, DA Animasaun, AA Bello, A Agboola (2014). Effect of NPK and poultry manure on growth, yield, and proximate composition of three amaranths. *J Bot* 2014:828750

Page AL (1982). *Methods of Soil Analysis, Part 2, Chemical and Microbiological Properties*, 2nd edn., pp:149–166. SSSA, Madison, Wisconsin, USA

Pattanayak SK, KN Mishra, MK Jena, RK Nayak (2001). Evaluation of green manure crops fertilized with various phosphorus sources and their effect on subsequent rice crop. *J Indian Soc Soil Sci* 49:285–291

Pervez MA, F Muhammad, E Ullah (2000). Effect organic and inorganic manures on physical and characteristic of potato (*Solanum tuberosum* L.). *Intl J Agric Biol* 2:34–36

Raza MA, H Gul, J Wang, HS Yasin, R Qin, MHB Khalid, M Naeem, LY Feng, N Iqbal, H Gitari (2021). Land productivity and water use efficiency of maize-soybean strip intercropping systems in semi-arid areas: A case study in Punjab Province. *Pak J Clean Prod* 308:127282

Rykaczewska K (2013). The impact of high temperature during growing season on potato cultivars with different response to environmental stresses. *Amer J Plant Sci* 4:2386–2393

Sahilemedhin S, B Taye (2000). *Procedures for Soil and Plant Analysis Technical Paper*. National Soil Research Center, Ethiopian Agricultural Research Organization, Addis Ababa, Ethiopia

Sarwar G, N Hussain, F Mujeeb, H Schmeisky, G Hassan (2003). Biocompost application for the improvement of soil characteristics and dry matter yield of grass (*Lolium perenne*). *Asian J Plant Sci* 2:237–241

Shahbaz M (2011). Potential of bio slurry and compost at different levels of inorganic nitrogen to improve growth and yield of okra (*Hibiscus esculetus* L.). *M.Sc. (Hons.) Thesis*. Institute of Soil & Environmental Sciences, University of Agriculture, Faisalabad, Pakistan

Shangguan Z, M Shao, J Dyckmans (2000). Effects of nitrogen nutrition and water deficit on net photosynthetic rate and chlorophyll fluorescence in winter wheat. *J Plant Physiol* 156:46–51

Shao Z, R Emmanuel, EM Mwakidoshi, PP Muindi, SR Soratto, RP Smruti, WW Andrew, SDO Sumit, JS Wasonga, FS Mahmoud, IG Harun (2023). Synthetic fertilizer application coupled with bioslurry optimizes potato (*Solanum tuberosum*) growth and yield. *Agronomy* 13:2162

Singh M, VP Singh, KD Reddy (2001). Effect of integrated use of fertilizer nitrogen and farmyard manure or green manure on transformation of N, K and S and productivity of rice wheat system on a vertisol. *J Ind Soc Soil Sci* 49:430–435

Singh SP, VS Kushwah (2006). Effect of integrated use of organic and inorganic sources of nutrients on potato (*Solanum tuberosum* L.) production. *Ind J Agron* 51:1–2

Smiciklas-Wright H, DC Mitchell, SJ Mickle, AJ Cook, JD Goldman (2002). *Foods Commonly Eaten in the United States*, *NFS Report 965*, pp:1–264. USDA, Beltsville, Maryland, USA

Suh C, SS Meka, AF Ngome, IT Kemngwa, AD Sonkouat, D Njualem (2015). Effects of organic and inorganic fertilizers on growth and yield of potato (*Solanum Tuberosum* L.) in the western highlands of Cameroon. *Intl J Dev Res* 5:3584–3588

Sumner ME, WP Miller (1996). Cation exchange capacity and exchange coefficients. In: *Methods of Soil Analysis, Part 3, Chemical Methods*, pp:1201–1229. Soil Science Society of America and American Society of Agronomy, Madison, Wisconsin, USA

Taye B, A Yifru. (2010). Assessment of soil fertility status with depth in wheat growing highlands of Southeast Ethiopia. *World J Agric Sci* 6:525–531

Tekalign T (2005). Response of Potato to Paclobutrazol and Manipulation of Reproductive Growth under Tropical Conditions. *Ph.D. Dissertation*, University of Pretoria, Pretoria, South Africa

Tuma A, T Tesema, A Mekonen (2013). Rating and correlating physicochemical properties of Eutric Vertisols in Abaya Chamo Lake basin, South-west Ethiopia. *Intl J Agron Plant Prod* 4:3559–3568

Wakene N, G Heluf (2003). Influence of land management on morphological, physical and chemical properties of some soils of Bako, Western Ethiopia. *Agropedology* 13:1–9

Wakene N, G Heluf, A Tolera, E Geremew (2004). Evaluation of integrated use of compost with low rates of NP fertilizers for increasing maize yield on Alfisols of Western Oromia, Ethiopia. *J Agric Rural Dev Trop Subtrop* 106:131–141

Walkley A, IA Black (1934). An example of the digestion method for determining soil organic matter and a proposed modification of the chromic acid titration method. *J Soil Sci* 34:29–38

Yaduvanshi NPS (2001). Effect of five years of rice-wheat cropping and NPK fertilizer use with and without organic and green manures on soil properties and crop yields in a reclaimed sodic soil. *J Ind Soc Soil Sci* 49:714–719

Yihenew G (2002). Selected chemical and physical characteristics of soils of Adet Research Centre and its testing sites in northwestern Ethiopia. *Ethiop J Nat Resour* 4:199–215

Zebarth B, C Karemangingo, P Scott, D Savoie, G Moreau (2007). *Nitrogen Management for Potato, General Fertilizer Recommendations. Factsheet*. New Brunswick, Canada. Available at: http://www.soilcc.ca/ggmp_fact sheets/pdf/Potato general factsheet

Zelalem A, T Takalign, D Nigussie (2009). Response of potato (Solanum tuberosum L.) to different rate of nitrogen and phosphorus fertilization on vertisols at Debre Birhan, in the central highlands of Ethiopia. *Afr J Plant Sci* 3:16–24