GRÓ Land Restoration Training Programme
Árleynir 22, 112 Reykjavik, Iceland

Final project 2021

THE EFFECTS OF APPLYING A COMBINATION OF BIO-SLURRY AND INORGANIC FERTILIZERS ON TEFF YIELD AND SOIL PROPERTIES IN THE HIGHLANDS OF NORTHERN ETHIOPIA

Tesfay Berihu
Mekelle University
Tigray, Ethiopia
tesfay.berihu@mu.edu.et

Supervisor
Úlfur Óskarsson
Agricultural University of Iceland
ulfur@lbhi.is

ABSTRACT

An investigation on the effects of bio-slurry on teff production and soil properties in combination with inorganic N and P fertilizers was carried out at Mekelle University main campus in Tigray region, northern Ethiopia during the 2020 crop season. The experiment was a randomized complete block design with treatments comprising two levels of inorganic N (23, 46 kg N/ha), two levels of inorganic P (23, 46 kg P/ha) and two levels of slurry (9, 12 tons/ha) including control with no fertilizers and the two levels of bio-slurry alone, set to a total of 11 treatment combinations with three replications. The soil at the study area was a degraded Cambisol and the site had been fallowed for long period of time. Various plant and soil parameters were measured during the experiment and post harvesting, and the treatment effects statistically evaluated. The fertilizer treatments significantly influenced the above-ground biomass growth, straw, and grain yield, and affected soil bulk density, soil moisture content and available phosphorus. However, soil electrical conductivity, soil organic carbon, total nitrogen, cation exchange capacity, exchangeable bases, and soil pH did not show significant variation with treatments. In general, teff biomass, straw and grain yield and number of tillers rose as the combined fertilizer dose increased. A significant difference of between 9 and 12 tons/ha of applied bio-slurry was found only where the highest levels of inorganic nitrogen and phosphorus fertilizer were used. Soil bulk density was reduced while soil moisture content increased due to bio-slurry application. Treatments either with the highest level of inorganic phosphorus or bio-slurry, or both combined applications, significantly increased available phosphorus, compared to other treatments. In general, application of combined bio-slurry with inorganic fertilizers shows promise in increasing yield of teff and an improvement of soil characteristics of degraded soils.

Keywords: Teff, bio-slurry, inorganic fertilizer, soil properties

This paper should be cited as:

Berihu T (2021) The effects of applying a combination of bio-slurry and inorganic fertilizers on teff yield and soil properties in the highlands of northern Ethiopia. GRÓ Land Restoration Training Programme [Final project]
https://www.grocentre.is/static/gro/publication/835/document/berihu2021.pdf

TABLE OF CONTENTS

1. INTRODUCTION

Land degradation is a global problem affecting natural processes, soil fertility and people's livelihoods (Le et al. 2016). One of the hotspots of land degradation is Ethiopia, with more than 85% of the land moderately to very severely degraded (Gebreselassie et al. 2016). The situation in Tigray region in northern Ethiopia is particularly acute, with a near total loss of forest cover and an estimated increase of 25% in barren land cover during the first decade of this century (Gebreselassie et al. 2016).

The decrease in agricultural production and increase in poverty in Ethiopia results mainly from land degradation (Gebreegziabher 2007). In general, the extent of soil fertility reduction in crop fields depends on the inherent properties of the soil parent material, the cropping cycle, and the use of external inputs (Azam-Ali & Squire 2001). Furthermore, soil organic matter is known to be the dominant reservoir and source of plant nutrients that play a major role in soil fertility and productivity (Azam-Ali & Squire 2001).

The soils in Tigray are inherently low in organic matter content (Carral et al. 2014) and declining productivity can result from soil organic matter depletion (EATA [Ethiopian Agricultural Transformation Agency] 2013). The main culprits for this are over-cultivation, frequent ploughing, and crop removal, as harvest and crop residues are used for feed and fuel (EATA 2013). With time, this can cause a reduction of soil macro- and micronutrients, topsoil erosion, deterioration of soil physical properties, and increased soil salinity (Gete et al. 2010). Use of dung and crop residues for fuel is a common practice in Ethiopia and it has been reported that the current agricultural growth development plan has been negatively affected by this habit (Gebreegziabher 2007). Shortage of fuel wood induced by forest degradation causes people to substitute fuel wood with crop residues and dung in rural Tigray (Gebreegziabher 2007).

In areas where the time of the fallow has become shorter due to intense land use, soil fertility may be seriously reduced and unable to maintain adequate crop production (Juo et al. 1995). Under intensive cultivation, a reduction in yield is attributed to factors such as shortage of nutrients and loss of soil organic matter (Juo et al. 1995). However, by enhancing soil fertility through addition of organic or inorganic fertilizers and by implementing practices of soil fertility management, the situation can be improved. Ensuring food security for a rapidly increasing population requires intensification of crop production on existing cultivated lands through enhanced nutrient inputs (Haileselassie et al. 2011).

Ethiopia produces teff (*Eragrostis teff*) as a main food crop and teff fields cover 2.73 million hectares (ha), with an average productivity of 1.28 tons/ha (CSAE [Central Statestical Agency of Ethiopia] 2020). In Tigray region, most teff producers are in the central, north-western, and western zones. The total cultivated area coverage for teff production is 167,584 ha, which is 5.5% of the total cultivated land in Tigray region (Lee 2018).

Teff is used to make injera, a traditional flat bread. Hence it is a day-to-day food item in every household. Additionally, teff plant residues can be used as animal fodder. According to Wato (2021), teff is also an important food item for those who are on gluten-restricted diets and therefore is a superior economical commodity in the country.

Teff has a high concentration of different nutrients and minerals: a very high calcium content, with moderate levels of phosphorus, magnesium, copper, and zinc and significant levels of the vitamin thiamin (Gabremadhin 2001). It is high in carbohydrates and fibers and an excellent amino acid composition, and is higher in lysine than wheat (Gabremadhin 2001).

Most field experiments with teff in the Tigray region, have tested the application of mineral fertilizers to increase the response yield. However, continuous application of mineral fertilizers may lead to environmental pollution. This may have negative impacts on water systems and resources, and bring about land degradation, soil depletion and increased emissions of greenhouse gases (Pandey et al. 2019).

Organic fertilizers, such as livestock excrement and poultry waste, contain substantial quantities of plant nutrients which may be used to enhance soil fertility while the use of inorganic fertilizers could be decreased by a significant amount (Islam et al. 2014). However, the use of inorganic fertilizers continues to be inevitable for attaining optimum yield given the fact that availability of organic fertilizers is limited (Zheng et al. 2017). The proper rate of applied nutrients needs to be determined through exploring the nutrient requirements of the crops and the nutrient-supplying power of the soils (Zheng et al. 2017).

1.1 Bio slurry as a potential fertilizer

The energy sector has initiated biogas production in rural Tigray. According to the Tigray region biogas program coordination office, there are more than 3,400 biogas plants in Tigray (Berhe et al. 2017). Biogas replaces direct use of animal waste and crop remains as a household energy source, providing an opportunity to conserve dwindling forest cover (Zheng et al. 2017). While the biogas energy program office offers a clean and green development, the by-products of solid and liquid bio-slurries and composted slurry can also be important for ameliorating soil fertility. In return, developing the knowledge base of using bio-slurry as a fertilizer can substantially contribute to the promotion of the uptake of biogas technology (Gete et al. 2010).

Bio-slurry is a by-product of animal waste produced in a bio-digester plant through the process of anaerobic digestion or fermentation by the action of methanogenic bacteria (Bonten et al. 2014). Bio-slurry consists in general of 93% water and 7% dry matter, of which 4.5% is organic and 2.5% is inorganic matter. The percentage of nitrogen, phosphorus, and potassium content of slurry on wet basis is 0.25%, 0.13% and 0.12% while on dry basis it is 3.6%, 1.8% and 3.6%, respectively. The slurry also contains micro-nutrients such as zinc, iron, manganese, and copper that are essential for plants (Zheng et al. 2017).

Bio-slurry being completely digested is odourless and does not attract insects. It keeps termites away whereas raw dung attracts them; applied as fertilizer it reduces weed growth by at least 50% (Jeptoo et al. 2013). The decomposition process of dung in the biogas digester destroys plant pathogens (Mengistu et al. 2016). Major plant nutrients such as nitrogen, phosphorus and potassium are preserved during the reduction process of bio slurry and plants can immediately utilize these nutrients (Zheng et al. 2017).

The application of bio-slurry to soils improves the soil humus content and soil water retention. The air circulation in soils is also advanced due to improved soil physical conditions (Mengistu et al. 2016). Bio-slurry provides energy for soil microorganisms which encourages organic farming (Lee 2018). It also provides plant nutrients and acts as a soil neutralizer (Asefa & Tadesse 2019). In line with this, a proper use of bio-slurry can reduce the dependency by many farmers on expensive mineral fertilizers, thereby reducing greenhouse gas pollution and the negative impacts of improper application of mineral fertilizers.

In Bangladesh, a combined application of bio-slurry (25-50 kg N /ha) before ploughing, and mineral fertilizer (50-75 kg N /ha) as top dressing, substantially enhanced the amounts of test microorganisms and advanced the actions of soil urease and protease (Zheng et al. 2017). In Bangladesh the application of bio-slurry in combination with mineral fertilizer was shown to result in the highest yield of cabbage (Terefe et al. 2018). Farmers in Bangladesh commented that the use of bio-slurry in the production of vegetables improved the condition of soil, making the use of extra inorganic fertilizers unnecessary. On the other hand, cow dung in dumped condition is not decomposed properly and, as a result, loses its optimum potential as an organic fertilizer (Zheng et al. 2017).

While evidence shows that the application of bio-slurry can increase soil fertility and plant productivity, no research has been done in Tigray on the effects of bio-slurry application on crop yield and soil fertility responses. This research aimed to test the effect of bio-slurry application on teff productivity and possible soil fertility enhancement in Tigray, and to recommend rates of bio slurry and inorganic fertilizer application.

1.2 Study goal

The general goal of this project was to determine both the effect of bio-slurry alone and in combination with chemical fertilizer application to determine the changes on teff crop production and soil properties.

2. METHODS

2.1 Description of the study area

2.1.1 Location

The study was carried out at the Mekelle University main campus, which is located around 5 km east of Mekelle city (the capital city of Tigray regional state in Ethiopia). It is located at 13°28'45''N and 39°29'24''E, at an altitude of 2,200 meters above sea level (Fig.1).

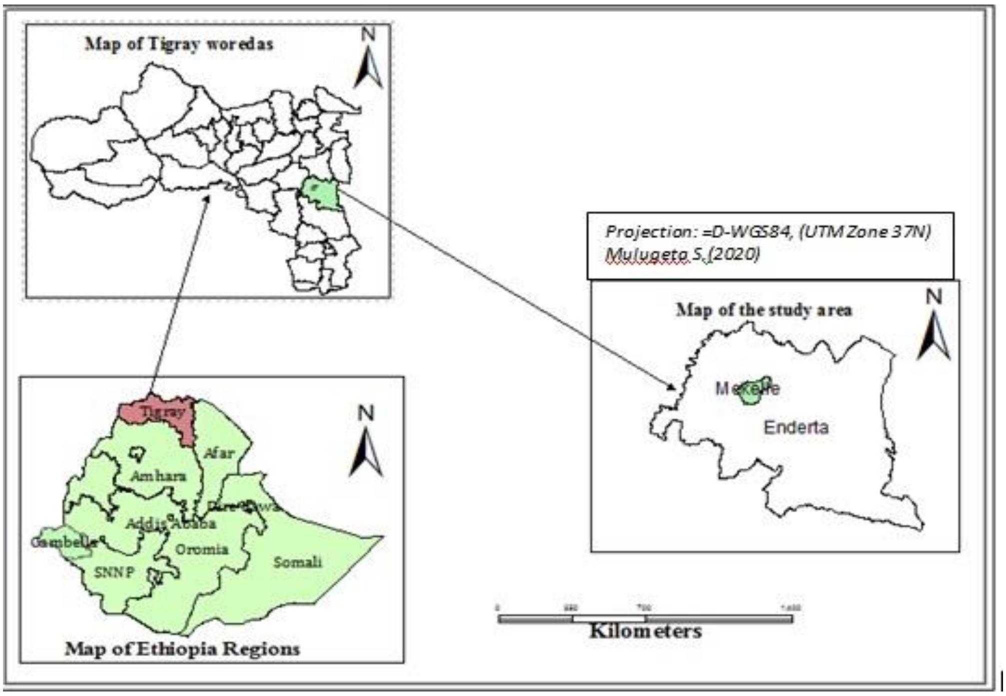

Figure 1. Map of the study area. (Source: Sebhatleab 2020).

2.1.2 Climate

The yearly average rainfall ranges from 511 to 656 mm with more than 85% received within a period of four months from June to September (Damtew et al. 2019). The average annual maximum and minimum temperatures are about 27°C and 12°C, respectively. The highest and lowest average minimum temperature occurs in June (28ºC) and December (10ºC) respectively (Beyene 2015). The long-term climatic data of the study area (Fig. 2) indicates that the highest mean monthly rainfall and temperature occurs in August and May respectively.

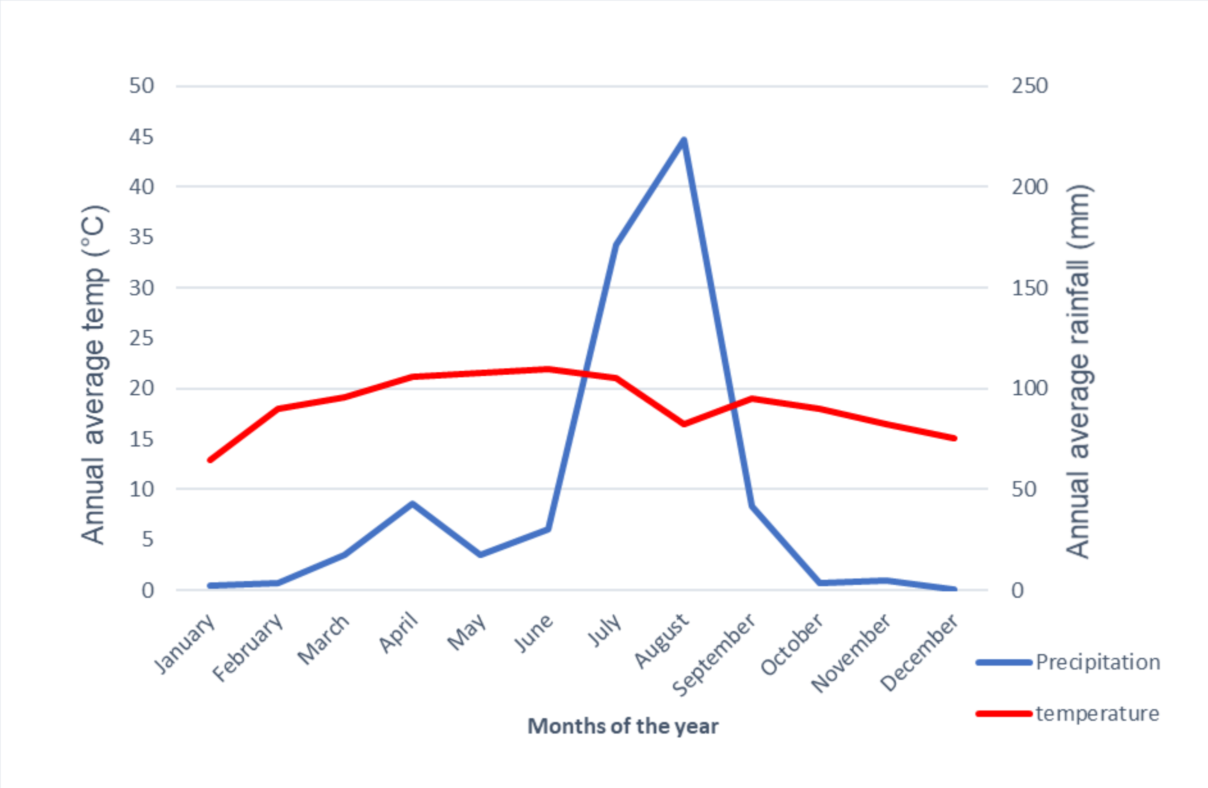

Figure 2. Annual average temperature and rainfall of study area. (Source: 10 years' data from National Meteorological Agency, Mekelle branch (2009-2018)).

2.1.3 Soils

The soils of the Tigray region have not been systematically studied and information on soils and other land resources is scant (Habtegebriel & Singh 2006). According to recent surveys, the region has some 13 major soil units identified. The soil type of the study area (Endayesus campus) at Mekelle University is identified as Cambisol. Cambisols develop on limestone and shale. The soils have low organic carbon, medium potassium, and low phosphorus content (Habtegebriel & Singh 2006).

2.2 Experimental design and inputs

The site of the field experiment was situated on a gentle slope and the design of three blocks was set perpendicular to the slope direction. The experiment was a randomized complete block design with treatments comprising two levels of N (23, 46 kg N/ha), two levels of P (23, 46 kg P/ha) and two levels of slurry, (9, 12 tons/ha) including a control with no fertilizers and the two levels of bio-slurry alone (Table 1), a total of 11 treatment combinations with three replications. The application rate of bio-slurry was adopted from different literatures. Teff seeds, bio-slurry, urea fertilizer and di-ammonium phosphate were used as inputs in the experiment. The plot sizes for the experimental treatments were three by four meters.

Land preparation and plowing was done as how farmers practice. Seed sowing and fertilizer application was undertaken in rows, the seed in furrowed rows with a spacing of 20 cm between rows (Fig. 3). The seed rate used was according to the Agricultural Transformation Agency's (ATA 2013) recommendations for teff, i.e. 15 kg /ha.

Table 1. The details of the fertilizer treatment combinations.

Treatments	Description and quantity of inputs
$N_0P_0S_0$	Control
$N_0P_0S_1$	Only 9 tons/ha bio-slurry (S)
$N_0P_0S_2$	Only 12 tons/ha bio-slurry (S)
$N_1P_1S_1$	23 kg/ha N (urea) + 23 kg/ha P (DAP) + 9 tons/ha bio-slurry
$N_1P_1S_2$	23 kg/ha N + 23 kg/ha P+ 12 tons/ha bio-slurry
$N_1P_2S_1$	23 kg/ha N + 46 kg/ha P + 9 tons/ha bio-slurry
$N_1P_2S_2$	23 kg/ha N + 46 kg/ha P +12 tons/ha bio-slurry
$N_2P_1S_1$	46 kg/ha N + 23 kg/ha P + 9 tons/ha bio-slurry
$N_2P_1S_2$	46 kg/ha N + 23 kg/ha P + 12 tons/ha bio-slurry
$N_2P_2S_1$	46 kg/ha N + 46 kg/ha P + 9 tons/ha bio-slurry
$N_2P_2S_2$	46 kg/ha N + 46 kg/ha P + 12 tons/ha bio-slurry

2.3 Utilization of inputs

2.3.1 Bio-slurry and mineral fertilizers

Bio-slurry used for the application of the treatments was obtained from a biogas plant fed with cattle dung and added water in a 1:1 ratio. The slurry was collected in moist form and a sample was analysed in a laboratory for its nutrient composition, such as organic carbon, total nitrogen, total phosphorus and potassium, and pH, before applying it to the experiment plots. The moist bio-slurry was incorporated into the soil of the plots during land preparation to avoid nutrient loss from a surface application. Mineral fertilizers (urea and diammonium phosphate) were also applied on treatment plots during the sowing time according to the recommended rate and method of application, but split application was used for urea.

The respective bio-slurry rates (9 and 12 tons/ha) were incorporated in the top 20 cm depth of the experimental plots, while mineral fertilizers were applied in prepared rows before seeds were sown. All the rates of diammonium phosphate were applied once during sowing time. Urea was applied in to two splits, the first half applied during sowing and the other half was applied one month after sowing of the crops. Hand weeding was done two times during the growing period.

2.3.2 Teff crop used for testing

The teff variety used for this research is locally known as “Quncho” and was released by the Ethiopian Institute of Agricultural Research. Locally this variety has increased grain yield up to 137% from 1.6 tons per hectare to 3.8 tons/ha (ATA 2013).

Figure 3. Application of bio-slurry (left) and application of inorganic fertilizer inputs (right).

2.4 Data collection

2.4.1 Agronomy parameters

Data collection was started after seed germination. During experimental field observation, days to flowering and physiological maturity were recorded. The number of tillers per plant were counted on five randomly selected plants in each plot, at late vegetative growth and development stage. Plant height and spike length were recorded at physiological maturity by randomly selecting five plants from each plot. Height measurement for each plant sample was taken from the ground level to the top of each spike; spike length was also measured and recorded.

Harvesting was done manually 120 days after sowing (Fig. 4). Harvesting of the plots was carried out by excluding a 20 cm border on all four sides of each plot to avoid border effect, resulting in a net plot size of 2.6 m by 3.6 m or a total area of 9.36 m^2. The harvest was air dried in the field plots and weighed to the nearest gram using a digital spring balance and recorded as above ground biomass per plot before threshing (Fig. 5). Threshing was done by hand and grain yield of each treatment plot was weighed to the nearest 0.01 g using an analytical electronic balance. Straw yield per plot was calculated by subtracting the grain yield from each plot's biomass.

Figure 4. Teff at maturity stage (left) and post-harvest soil sampling (right).

2.4.2 Bio-slurry and soil parameters

A composite sample of the bio-slurry was prepared and analysed in a laboratory for its chemical composition. The sample was air dried, crushed and sieved using 2 mm mesh and pH was measured using a pH meter. Total N was determined following the Kjeldahl method as described by Okalebo et al. (2002), available phosphorus was determined calorimetrically using the Olsen and Sommers (1982) method with a spectrophotometer, and potassium was determined by using a flame photometer as described by Okalebo et al. (2002).

Composite soil samples were collected from depths of 0-20 cm in each plot of the experimental site using a soil auger. The soil samples used for analysis were air dried, crushed and sieved through a 2 mm diameter mesh. Additional soil samples were taken using a core sampler with a volume of 100 cm^3 and analysed to determine bulk density using the gravimetric method (core method), where samples are oven dried at a temperature of 105°C for 24 hours. Bulk density was determined by the ratio of oven dry mass of the soil to the total volume (volume of the core sampler). Moisture content was measured using the gravimetric method described by Hesse (1971).

Soil pH was determined electrometrically in 1:2.5 soil, water suspension (10 g of soil saturated with 25 ml of distilled water), using a pH meter (JENCO Model-671). Electrical conductivity (EC) was measured from the saturated soil extract using an EC meter and was multiplied by a correction factor corresponding to the temperature reading taken during the EC reading time. Organic carbon content was determined by the wet digestion method of Walkley and Black (1934). Total nitrogen was measured following a Micro-Kjeldahl method in which total N in the soil was analysed following the process of digestion, distillation, and titration (Sahlemedhin & Taye 2000). Exchangeable potassium was determined using a flame photometer (US Salinity Lab, 1954). Cation exchange capacity was determined by the neutral ammonium acetate extraction method (Jackson 1962). Exchangeable bases (K, Na, Ca, and Mg) in the ammonium acetate filtrates were measured and cation exchange capacity determined according to Schollenberger and Simon (1945), using an atomic absorption spectrophotometer (Table 2).

Figure 5. Measuring teff biomass yield (left) and harvested field drying (right).

Table 2. Soil parameters measured and analysis methods used.

Soil parameters	Method
Bulk density	Core method
Moisture content	Gravimetric (direct method)
pH (1:2.5) soil to distil water	Glass electrode pH meter
Electrical conductivity (ECe)	Paste saturation
Organic carbon	Wet oxidation method
Total nitrogen	Micro Kjeldahl digestion
Available phosphorus	Olsen
Cation Exchange Capacity (CEC)	Ammonium acetate
Exchangeable bases (Ca^{++}, Mg^{++}, Na^{+}, K^{+})	Sodium acetate

2.5 Statistical analysis

Descriptive statistics, including mean and percentages, of teff crop and soil parameters were calculated to quantify the treatment response. The data obtained from the agronomy and soil parameters was subjected to a one-way analysis of variance (ANOVA) and the significant difference of the treatment means compared at $p \leq 0.05$ with Tukey's studentized range (HSD) test using SAS statistical software (2017). This software was also used to analyse correlations between soil and plant parameters.

3. RESULTS AND DISCUSSION

3.1 Bio-slurry analysis result

The analysis of the chemical composition of bio-slurry (Table 3) showed that the nutrient content was within the range given in the literature (Gupta 1991; Jeptoo et al. 2013), which is: 1.03-3.2% N, 0.82-1.8% P and 0.8-3.6% K. Research has shown that the nutrient content of bio-slurry mostly varies with feed type (Gupta 1991; Jeptoo et al. 2013).

Table 3. Chemical composition analysis of bio-slurry applied.

Bio-slurry parameters				
pH	% Total nitrogen	% Total phosphorus	% Total potassium	% Organic carbon
7.84	1.43	1.05	1.81	33.45

3.2 Agronomy performance

3.2.1 Biomass

Teff biomass yield was significantly influenced ($p < 0.001$) by treatments (Table 4). The highest biomass yield (8,652.1 kg/ha) was obtained from a treatment plot of $N_2P_2S_2$ (urea 46 kg/ha, diammonium phosphate (DAP) 46 kg/ha and bio-slurry 12 tons/ha), while the lowest biomass (3,146.7 kg/ha) was obtained from the control plot (Table 4). There was a general increase in biomass yield with an increasing level of nitrogen and bio-slurry rate (Table 5; Fig. 6). The increase was 144.7% compared to the control, but a significant difference between 9 and 12 tons/ha of applied bio-slurry was only found where the highest levels of inorganic nitrogen and phosphorus fertilizer were used (Table 4; Fig. 6). Similar results were reported by Wato (2019), Haftom et al. (2009) and Berhe et al (2017), who found that the highest biomass yield was obtained by applying high N. The highest teff biomass yield achieved by Haftom et al. (2009) was 4,724.07 kg/ha in response to an application of 69 kg N/ha.

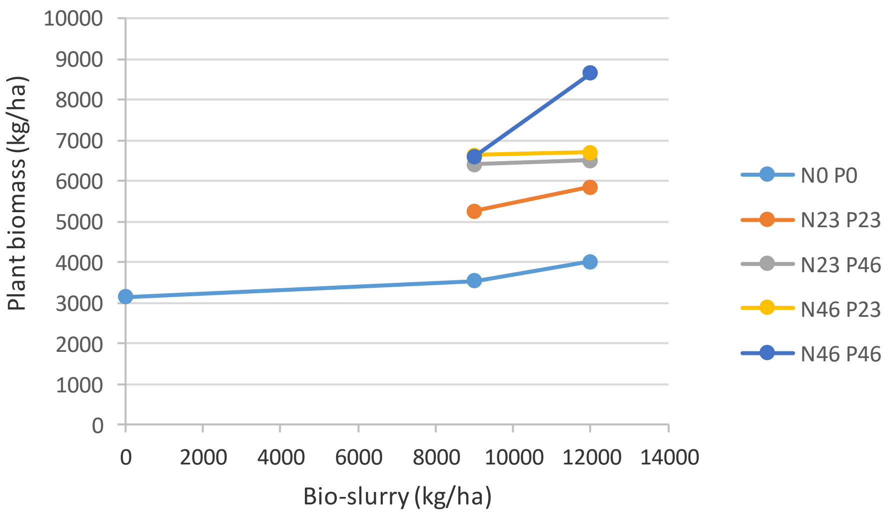

Figure 6. The effect of bio-slurry application on teff biomass with or without different levels of inorganic N and P fertilizers in kg/ha.

3.2.2 Straw

Straw yield was significantly affected ($p \leq 0.001$) by the different fertilizer treatment levels (Table 4). The highest straw yield was obtained in response to applying a full dose of fertilizer $N_2P_2S_2$ (Table 4). This treatment gave straw yield which was 154.5% higher than the control plots (Table 5). This study is in line with the findings of Haftom et al. (2009), who reported that straw yield rose with an increasing rate of nitrogen application.

Table 4. Mean values of plant parameters in different fertilizer treatments. Variable means followed by the same letters are not significantly different (p≤0.05). MSD: minimum significant difference, CV: coefficient of variance.

Treatments	Fertilizer inputs			Biomass yield	Straw yield	Grain yield	Plant height	No of	Spike length
	Nitrogen	Phosphorus	Bio-slurry	(kg/ha)	(kg/ha)	(kg/ha)	(cm)	tillers	(cm)
$N_0P_0S_0$	0	0	0	3,146.7[e]	2,083.5[e]	1,063.2[c]	64.47[a]	1.7[b]	21.9[a]
$N_0P_0S_1$	0	0	9	3,535.2[e]	2,143.2[e]	1,392[c]	61.4[a]	1.7[b]	23.7[a]
$N_0P_0S_2$	0	0	12	4,005.9[ed]	2,567.5d[e]	1,438.4[c]	61.07[a]	2.7[ab]	22.0[a]
$N_1P_1S_1$	23	23	9	5,254.4 [cd]	3,310.8[cd]	1,943.7[b]	76.53[a]	2.0[ab]	24.8[a]
$N_1P_1S_2$	23	23	12	5,848.1[cb]	3,784.1[bc]	2,064[b]	67.2[a]	2.3[ab]	23.2[a]
$N_1P_2S_1$	23	46	9	6,396.8[cb]	3,979.8[bc]	2,417[b]	75.87[a]	2.3[ab]	27.1[a]
$N_1P_2S_2$	23	46	12	6,499.7[cb]	4,098.9[bc]	2,400.9[b]	71.47[a]	2.3[ab]	25.0[a]
$N_2P_1S_1$	46	23	9	6,633.9[b]	4,328.8[bc]	2,305.1[b]	80.2[a]	2.7[ab]	27.4[a]
$N_2P_1S_2$	46	23	12	6,701.0[b]	4,380.1[b]	2,320.9[b]	78.27[a]	2.0[ab]	26.1[a]
$N_2P_2S_1$	46	46	9	6,598.7[b]	4,367.0[b]	2,231.7[b]	77.53[a]	2.3[ab]	24.3[a]
$N_2P_2S_2$	46	46	12	8,652.1[a]	5,454.3[a]	3,197.8[a]	77.73[a]	3.3[a]	27.5[a]
$MSD_{(0.05)}$				1,275	1,026	474.83	23.526	1.5	8.15
P-value				<0.001	<0.001	<0.001	0.042	0.032	0.179
CV (%)				7.6	9.6	7.9	11.2	22.7	11.25

Table 5. Percentage increment of teff yield and plant components in reference to control.

Treatments	Fertilizer inputs			Biomass yield increase (%)	Straw yield increase (%)	Grain yield increase (%)	Plant height increase (%)
	Nitrogen (kg/ha)	Phosphorus (kg/ha)	Bio-slurry (tons/ha)				
$N_0P_0S_0$	0	0	0	0.00	0.00	0.00	0.00
$N_0P_0S_1$	0	0	9	12.35	2.87	30.93	-4.76
$N_0P_0S_2$	0	0	12	27.30	23.23	35.29	-5.27
$N_1P_1S_1$	23	23	9	66.98	58.91	82.82	18.71
$N_1P_1S_2$	23	23	12	85.85	81.62	94.13	4.23
$N_1P_2S_1$	23	46	9	103.29	91.02	127.33	17.68
$N_1P_2S_2$	23	46	12	106.56	96.73	125.82	10.86
$N_2P_1S_1$	46	23	9	110.82	107.77	116.81	24.40
$N_2P_1S_2$	46	23	12	112.95	110.23	118.29	21.41
$N_2P_2S_1$	46	46	9	109.70	109.60	109.90	20.26
$N_2P_2S_2$	46	46	12	144.74	154.49	129.73	26.60

3.2.3 Grain yield

Grain yield of teff was significantly variable ($p \leq 0.001$) between treatments (Table 4). The highest teff grain yield (3,197.8 kg/ha) was obtained with the full dose of combined fertilizer application (Table 4), which was 129.73% higher than the control plot (Table 5). A significant difference between 9 and 12 tons/ha of applied bio-slurry was only found where the highest levels of inorganic nitrogen and phosphorus fertilizer were used (Table 4; Fig. 7).

In Ethiopia, the national average yield was reported 1.664 tons/ha (CSA, 2020). This is only half of the maximum grain yield attained in the present study. Berhe et al. (2017) reported a teff grain yield of 2.803 tons/ha and Fenta (2018) found a 64% increase in wheat yield, in both cases in response to application of blended fertilizer at high rates. This is in line with the present study.

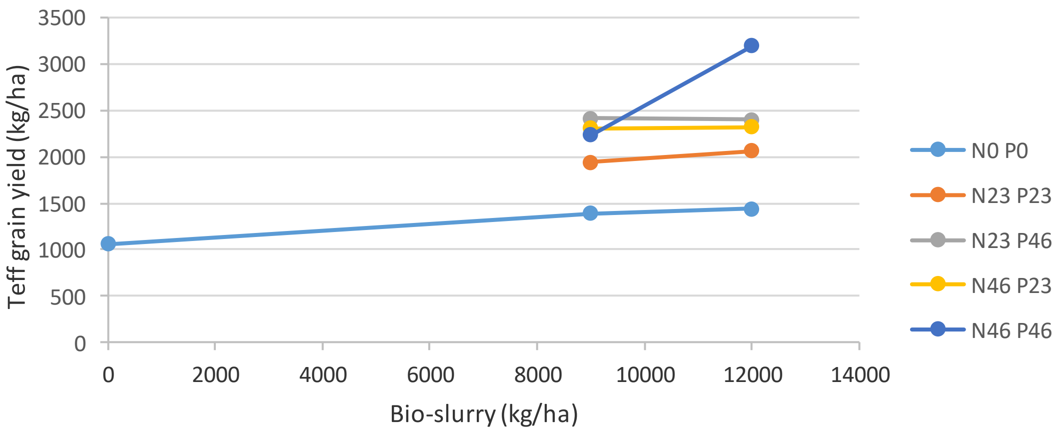

Figure 7. The effect of bio-slurry application on teff yield with or without different levels of inorganic N and P fertilizers in kg/ha.

3.2.4 Tillers

The variation in the number of tillers per plant was significantly different between treatments ($p = 0.032$). The highest numbers of tillers, 3.3 tillers per plant, were obtained from plots with the full dose rate of combined fertilizer application, but this mean was only significantly different from two other treatment means; the control and $N_0P_0S_1$ (Table 4). This finding agrees with the studies of Haftom et al. (2009) and Fenta (2018) who reported that the application of high rates of blended fertilizer brought asignificant increase in total tillers per plant.

3.2.5 Plant height

The variation in plant height was significantly different between treatments ($p = 0.043$). Plant height ranged between 61.1 and 80.2 cm. There was a positive trend between plant height and increased fertilizer inputs, but mean variations were too small to be significantly different (Table 4).

3.2.6 Spike length

Spike length in different fertilizer treatments did not show significant variation ($p = 0.179$). The spikes grew longer with a full combination of fertilizer inputs compared to the control, but the difference was too small to be significant (Table 4).

3.2 Soil analysis results

The composite soil samples analysed from the research site, prepared before crop sowing, had pH of 6.58, total N of 0.11%, available P of 4.68%, exchangeable K of 0.1% and organic carbon of 1.09%.

3.2.1 Soil bulk density and moisture content

Soil bulk density was in the range of 1.2-1.38 g/cm^3 and varied significantly between treatments ($P < 0.001$). Control plots and those with low input of bio-slurry had the highest bulk density (Table 6; Fig. 8). Treatments with the highest level of bio-slurry lowered soil bulk density significantly (Table 6; Fig. 8). This finding was in line with the studies of Majajah and Dhyan (2001) and Khan et al. (2010) who reported that farmyard manure has advantages in improving moisture content with a subsequent decrease in bulk density and increased infiltration rate of water as well.

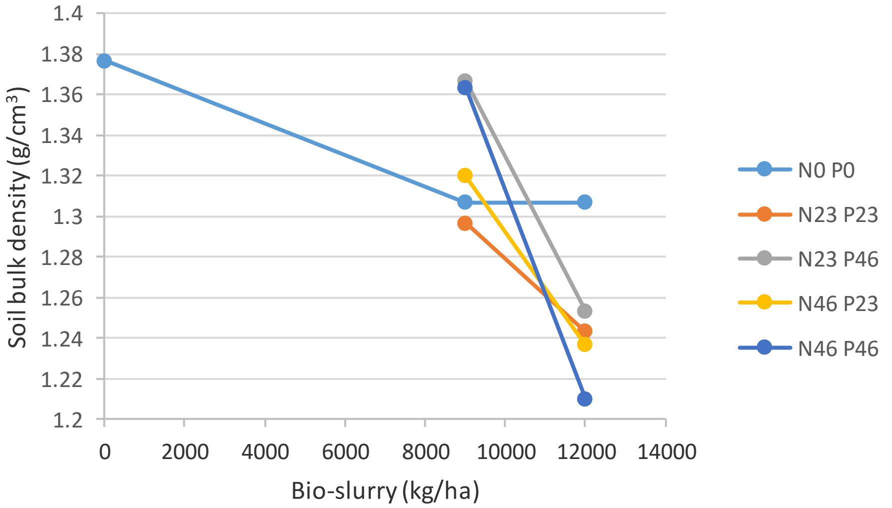

Figure 8. The effect of bio-slurry application on soil bulk density with or without different levels of inorganic N and P fertilizers in kg/ha.

The soil moisture content ranged from 31.2% to 43.4% and varied significantly between treatment plots ($P < 0.001$), generally rising with the level of fertilizer inputs (Table 6; Fig. 9). Soil moisture content within the full dose treatment was significantly higher than for all other treatments, except one, and all treatments had significantly higher soil moisture content than the control (Table 6; Fig. 9).

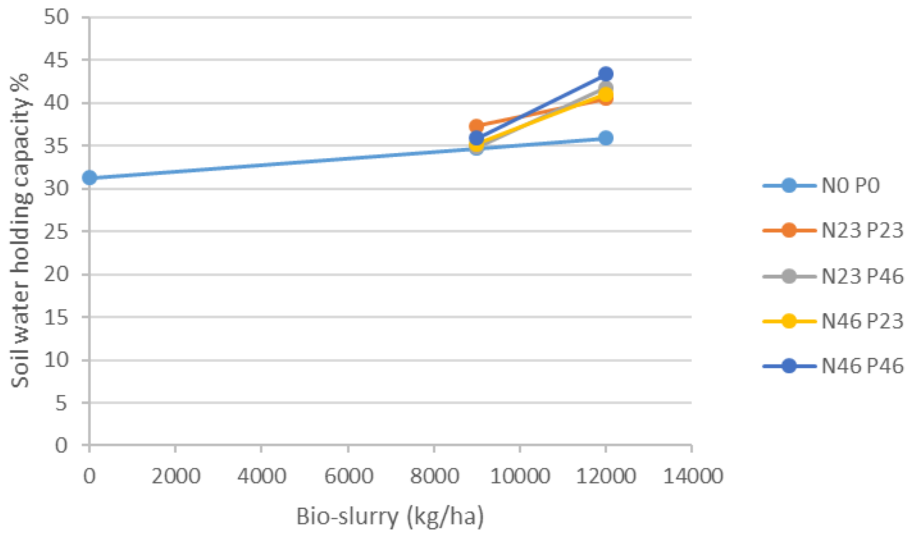

Figure 9. The effect of bio-slurry application on soil moisture content with or without different levels of inorganic N and P fertilizers in kg/ha.

3.2.2 Soil pH and electrical conductivity

Neither soil pH nor soil electrical conductivity showed significant variations by fertilizer treatment ($p = 0.782$ and $p = 0.563$, respectively). Although control plots were slightly more acidic at pH 6.53 than fertilizer treated plots, which were in the range of pH 6.83 to pH 7.26, the difference was not significant (Table 6). Soil electrical conductivity ranged between 0.36

and 0.75 dS/m, and most of the variation was within fertilizer treatments, but not between treatments (Table 6).

3.2.3 Organic carbon, total nitrogen, and available phosphorus

Soil organic carbon content ranged from 0.88% to 1.28% and did not vary significantly between treatments ($p = 0.562$). There was no indication that the bio-slurry applications altered the soil organic carbon content of the experimental plots (Table 6).

Total N content of the soil was between 0.07 and 0.43 mg N/kg and did not vary significantly between treatments ($p = 0.509$). The lowest N content was found in the soil of control plots and the highest value was found in treatments with the highest level of bio-slurry without inorganic N and P, $N_0P_0S_2$ (Table 6). Despite these large differences, the variability between replicates was too large to allow for significant mean differences.

Available soil P, however, was significantly variable between treatments ($p < 0.001$). Treatments either with the highest level of inorganic P or bio-slurry, or both, significantly raised soil available P above the control treatment where no fertilizer was applied (Table 6). This result is in agreement with the findings of Thamaraiselvi et al. (2012), who reported that the highest concentration of available soil phosphorus was achieved from the combined application of 15 tons/ha farmyard manure with 100 kg P/ha diammonium phosphate as compared to control.

3.2.4 Exchangeable bases and cation exchange capacity

None of the soil exchangeable bases tested, K^+, Na^+, Ca^{2+} and Mg^{2+}, showed significant variation between treatments ($p = 0.497$, 0.795, 0.790 and 0.179, respectively). The values did not show any clear trend with treatments and in none of the cases were the lowest values found in control plots (Table 6).

Soil cation exchange capacity did not vary significantly between treatments ($P = 0.096$). Furthermore, the results did not show any clear trend with treatments (Table 6).

3.2.5 Correlation between soil and plant parameters

Analysis of the relationship between soil and plant parameters showed that soil bulk density was negatively correlated with plant biomass, grain yield and straw yield (Table 7). The correlation between teff yield and bulk density shows that, as the compaction of the soil increased, the teff grain yield decreased following the regression equation $Y = -4993.1x + 8552.4$, where x indicates soil bulk density, at $R^2 = 0.2374$ (Fig. 10). For example, teff grain yield was reduced by around 1000 kg/ha as soil bulk density rose by 0.2 g/cm^3 (Fig. 10).

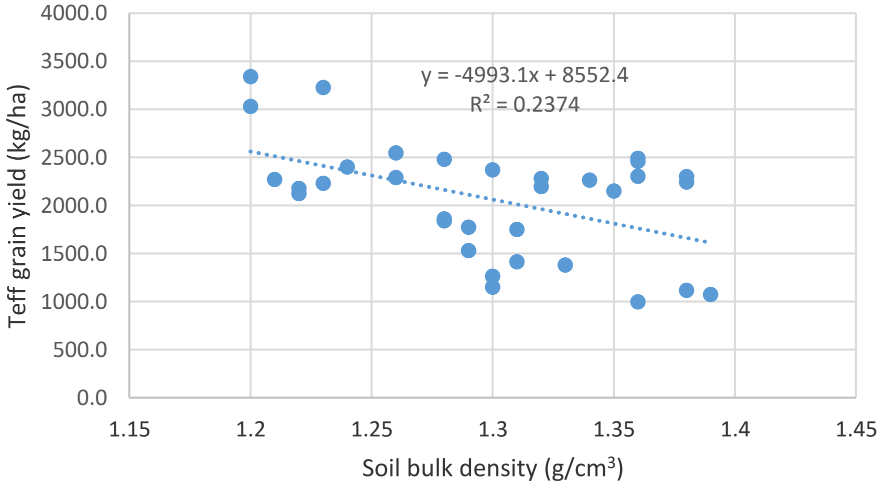

Figure 10. Correlation between soil bulk density and teff grain yield. The equation of the regression line is shown, along with the fraction of teff grain yield explained by soil bulk density (R^2).

Soil moisture content, however, was positively related to plant biomass, grain yield, straw yield, and the number of tillers per plant (Table 6). The correlation between teff yield and soil moisture content showed a positive linear relationship. As the soil moisture content increased, the teff yield also increased (Fig. 11), following the regression equation of $Y_{teff\ yield} = 116.11x - 2278.5$, where x indicates soil moisture content, at $R^2 = 0.5171$.

The analysis showed, for example, that as soil moisture content rose by a difference of 10%, teff grain yield rose by over 1000 kg/ha (Fig. 11).

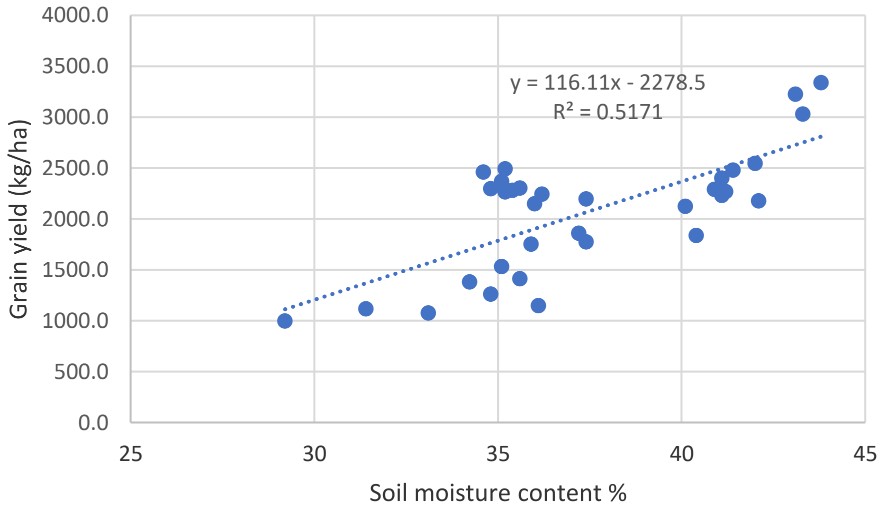

Figure 11. The correlation between soil moisture content and teff yield. The equation of the regression line is shown, along with the fraction of teff grain yield explained by soil moisture content (R^2).

The amount of available P in the soil was also positively correlated to plant biomass, grain yield and straw yield (Table 6). The correlation between teff biomass and available phosphorus showed a positive linear relationship; as the availability of phosphorus to the plant increased, the teff biomass yield also increased (Fig. 12) following the regression equation of $Y_{teff\ yield} = 198.23x + 2477.9$, where x indicates available P at $R^2 = 0.3406$.

This relationship indicates that for every 1 mg increase of available P per kg of soil, the total above ground plant biomass increases by around 200 kg/ha (Fig. 12).

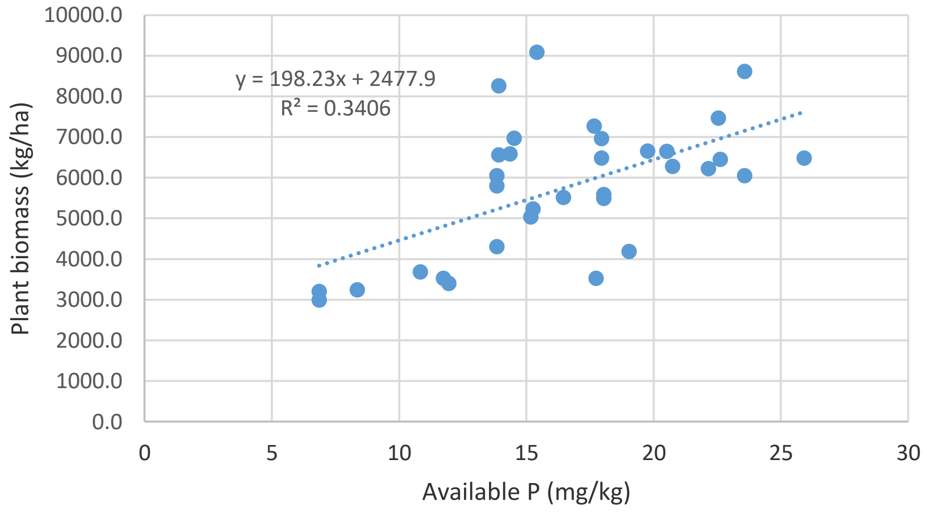

Figure 12. The correlation between teff biomass and available phosphorus. The equation of the regression line is shown, along with the fraction of teff grain yield explained by soil available phosphorus (R^2).

In addition to the above specified correlations, a few other significant correlations were found. Teff grain yield was negatively correlated with soil exchangeable K^+, the number of tillers was positively correlated with soil pH, and the number of tillers per plant were negatively correlated with soil cation exchange capacity (Table 7).

Table 6. Mean values of soil physical and chemical properties in different plots of fertilizer treatments. Variable means followed by the same letter are not significantly different ($p \leq 0.05$). EC: soil electrical conductivity, CEC: soil cation exchange capacity, MSD: minimum significant difference, CV: coefficient of variance.

Treatments	Fertilizer inputs			Soil physicochemical laboratory result											
	Nitrogen (kg/ha)	Phosphorus (kg/ha)	Bio-slurry (tons/ha)	Bulk density (g/cm^3)	Moisture content (%)	pH	EC (dS/m)	Organic C %	Total N %	Available P (mg/kg)	CEC (meq/ 100g)	Exch. K^+ (cmol /kg)	Exch. Na^+ (cmol /kg)	Exch. Ca^{2+} (cmol /kg)	Exch. Mg^{2+} (cmol /kg)
$N_0P_0S_0$	0	0	0	1.38^{a}	31.23^{e}	6.53^{a}	0.47^{a}	1.02^{a}	0.07^{a}	7.36^{b}	22.33^{a}	2.90^{a}	3.22^{a}	5.07^{a}	2.53^{a}
$N_0P_0S_1$	0	0	9	1.31^{bcd}	34.71^{d}	6.91^{a}	0.47^{a}	0.98^{a}	0.09^{a}	11.51^{ab}	18.67^{a}	2.61^{a}	3.31^{a}	5.2^{a}	2.4^{a}
$N_0P_0S_2$	0	0	12	1.31^{bcd}	35.87^{cd}	7.26^{a}	0.75^{a}	1.28^{a}	0.43^{a}	16.87^{ab}	21.6^{a}	2.88^{a}	3.65^{a}	5.47^{a}	4.73^{a}
$N_1P_1S_1$	23	23	9	1.3^{cde}	37.33^{c}	6.96^{a}	0.36^{a}	0.88^{a}	0.13^{a}	16.16^{ab}	20.73^{a}	2.49^{a}	3.07^{a}	4.4^{a}	3.2^{a}
$N_1P_1S_2$	23	23	12	1.24^{ef}	40.53^{b}	7.05^{a}	0.43^{a}	0.96^{a}	0.12^{a}	17.49^{a}	20.33^{a}	2.72^{a}	3.74^{a}	5.47^{a}	3.0^{a}
$N_1P_2S_1$	23	46	9	1.37^{ab}	34.87^{d}	7.02^{a}	0.46^{a}	1.06^{a}	0.14^{a}	20.43^{a}	20.4^{a}	2.64^{a}	3.13^{a}	5.13^{a}	2.87^{a}
$N_1P_2S_2$	23	46	12	1.25^{def}	41.83^{ab}	6.86^{a}	0.37^{a}	0.99^{a}	0.13^{a}	21.07^{a}	20.07^{a}	2.58^{a}	3.46^{a}	5.27^{a}	3.8^{a}
$N_2P_1S_1$	46	23	9	1.32^{abc}	35.23^{d}	6.83^{a}	0.46^{a}	0.97^{a}	0.09^{a}	15.29^{ab}	20.13^{a}	2.77^{a}	4.12^{a}	5.53^{a}	2.53^{a}
$N_2P_1S_2$	46	23	12	1.24^{ef}	41.07^{b}	6.88^{a}	0.43^{a}	1.11^{a}	0.17^{a}	20.32^{a}	22.27^{a}	2.67^{a}	3.81^{a}	4.73^{a}	3.67^{a}
$N_2P_2S_1$	46	46	9	1.36^{ab}	35.93^{cd}	6.88^{a}	0.41^{a}	1.00^{a}	0.11^{a}	17.54^{a}	18.53^{a}	2.71^{a}	3.18^{a}	4.27^{a}	3.0^{a}
$N_2P_2S_2$	46	46	12	1.21^{f}	43.4^{a}	6.94^{a}	0.43^{a}	0.91^{a}	0.12^{a}	17.64^{a}	18.47^{a}	2.54^{a}	3.37^{a}	5.07^{a}	2.27^{a}
MSD $_{(0.05)}$				0.061	1.9	1.13	0.57	0.57	0.51	9.64	5.04	0.68	2.15	2.74	2.96
P-value				<0.001	<0.001	0.782	0.563	0.50	0.509	0.002	0.096	0.497	0.795	0.790	0.179
CV (%)				1.6	1.8	5.59	42.99	19.22	119.3	19.99	8.49	8.63	21.26	18.6	32.76

Table 7. Correlation analysis of the variables of teff parameters and soil properties. P value: -***: p<0.01, **: p=0.001, *: p<0.05, ns: non-significant.

Soil parameters	Plant parameters					
	Plant biomass (kg/ha)	Teff grain yield (kg/ha)	Straw yield (kg/ha)	No of tillers per plant	Plant height (cm)	Spike length (cm)
Bulk density (g/cm^3)	-0.46368 **	-0.48719 **	-0.43912 *	-0.28234 ns	-0.15688 ns	-0.23177 ns
Moisture content %	0.69932 ***	0.71910 ***	0.67102 ***	0.38361 *	0.24094 ns	0.24278 ns
Soil reaction (pH)	0.10701 ns	0.08902 ns	0.11439 ns	0.36685 *	-0.05287 ns	-0.20148 ns
Electrical conductivity (dS/m)	-0.25064 ns	-0.25960 ns	-0.23945 ns	0.07900 ns	-0.25329 ns	-0.18134 ns
Organic C %	-0.12270 ns	-0.18363 ns	-0.08570 ns	0.16141 ns	-0.08528 ns	-0.10691 ns
Total N %	-0.07406 ns	-0.10544 ns	-0.05474 ns	0.22098 ns	-0.12354 ns	-0.15001 ns
Available P (mg/kg)	0.58361 ***	0.58872 ***	0.56634 ***	0.31258 ns	0.23211 ns	0.26357 ns
Cation exchange capacity (meq/100g)	-0.31341 ns	-0.28400 ns	-0.32206 ns	-0.39609 *	-0.15058 ns	-0.28614 ns
Exchangeable K^+ (cmol/kg)	-0.28343 ns	-0.35003 *	-0.23930 ns	0.04356 ns	-0.20792 ns	-0.10713 ns
Exchangeable Na^+ (cmol/kg)	0.16357 ns	0.07825 ns	0.20710 ns	0.17037 ns	0.00319 ns	0.11920 ns
Exchangeable Ca^{2+} (cmol/kg)	-0.07885 ns	-0.12845 ns	-0.04926 ns	0.05877 ns	-0.17819 ns	-0.07019 ns
Exchangeable Mg^{2+} (cmol/kg)	-0.11900 ns	-0.10059 ns	-0.12632 ns	0.05760 ns	-0.11279 ns	-0.09577 ns

4. GENERAL DISCUSSION

In general, the application of organic fertilizers in combination with inorganic fertilizer has been shown to be advantageous for agriculture and horticulture on a global scale (Abedi et al. 2010; Wu & Ma 2015). The present results are in line with these findings, providing opportunities for using existing resources and technology to improve yields and people's livelihoods. An efficient use of resources for nutrient management may help to restore degraded soils, provide food security, and thereby eradicate world hunger (FAO 2021).

Many organic fertilizers have been shown to supply the required plant macro and micronutrients, improve soil structure, increase microbial populations and at the same time promote root function and plant growth (Dauda et al. 2008; Muhmood et al. 2014; Wu & Ma 2015). In addition, organic fertilizers in general appear to reduce nitrogen losses from inorganic fertilizers through microbial and chemical processes (Arshad et al. 2004). This may explain why the benefits of inorganic fertilizer levels for teff yield were significantly greater with a combined application of high rates of bio-slurry in the present study.

Although the present study does not provide data for the long-term effects of the application of bio-slurry on teff productivity and soil fertility, other studies show wide benefits of increased use of organic fertilizers (Wu & Ma 2015). These include: an increase in soil organic matter, reduced soil erosion and improved soil health, an increase in soil nutrient availability, reduction in nutrient losses and reduction in the release of greenhouse gasses from soils (Pavlou et al. 2007; Wu & Ma 2015).

It is therefore likely that the use of locally sourced organic fertilizers, in combination with inorganic fertilizers, could raise yields of teff and other crops in the Tigray region and elsewhere in Ethiopia. In the long run, this could also help to restore degraded agricultural soils and provide a pathway to stabilize both natural ecosystems and human communities.

5. CONCLUSIONS AND RECOMMENDATIONS

The results show that bio-slurry is an effective organic fertilizer that enhances soil fertility to improve crop production and soil physical and chemical properties. The yield data of teff crops showed best yields when the application of bio-slurry was combined with mineral fertilizers. The results most importantly confirm that the application of bio-slurry supplies organic matter and required plant nutrients that promote plant growth and at the same time restore soil fertility.

Further studies are needed to evaluate the long-term effects of bio-slurry application on crop yield and agricultural soils. The indications are that, in the long run, the use of inorganic fertilizers could be further reduced in combination with bio-slurry application.

At this stage, the following recommendations can be given:

- Locally available organic fertilizers which are safe and cost effective should be identified and utilized. These could be tested on-farm, providing the yield results for farmers.
- Promotion of awareness is urged for farmers and stakeholders along the value chain, as well as for policy makers, researchers, and extension worker regarding good management practices of bio-slurry use for soil amendment.
- Finally, the findings of this study are limited to one season, one soil type and a specific agroecology. To validate these findings and establish recommended rates of combined applications of bio-slurry and inorganic fertilizers, further trials are required under wider conditions along with detailed cost benefit analysis.

ACKNOWLEDGMENTS

First and foremost, I would like to thank the creator of creatures, my Almighty God, all things were made through him, and for carrying me along during the times of my stay.

I express my heartfelt and deep gratitude to my supervisor Úlfur Óskarsson for the noble guidance, genuine and constructive advice, constant encouragement, limitless advice, positive criticism, patient listening and understanding and reviewing my work from the very beginning up to the final work of the project. It was very impressive to work under his supervision and without him it would have been impossible to realize this project work and reach this stage.

My sincere thanks go to my coordinator from GRÓ LRT, Brita Berglund, for her noble guidance, positive and critical criticism, reviewing and providing constructive suggestions, and regular follow up from day one to the end of the project. It was very impressive to work under her managing.

I am extremely thankful to Dr. Gebreyohannes Girmay, Mulugeta Sebhatleab, Dr. Kidane Giday and Ataklti Hailu, for their help during the field experiments and for sending the soil analysis results and encouraging my family in my absence. Also thanks to Lijalem and his colleagues from Mekelle soil laboratory, Tigray Agriculture Research Centre for doing the soil analysis.

I would like to thank GRO LRT for providing me financial support of a daily allowance and for the project research work. My thanks also go to Mekelle University, College of Dryland Agriculture and Natural Resources, department of Land Resources Management and Environmental Protection for allowing me to participate in the Land Restoration Training program at the Agricultural University of Iceland.

My sincere thanks go to Sjöfn Vilhelmsdóttir, Berglind Orradóttir, Halldóra Traustadóttir and Steinunn Garðarsdóttir for their hospitality, kindness, helpfulness, guidance, love, and concerns throughout the program and even during my difficult days.

I also extended my sincere respect and love to my friend Muez Hailu, my father Berihu Gebremicheal, my mother Tsige Tesema, my brothers, and sisters, for their moral and financial encouragements.

I don’t have words that can express my profound feeling to all the GRÓ LRT 2021 fellows for their friendship and unforgettable memories we shared together in Iceland. I wish to extend my deepest appreciation to my mastermind group members, and to Tolli and Sigga, the owners of the guest house.

If all my family members are alive, my heartfelt appreciation and deepest love go to my beloved wife Rahel Kahsay for her strength, moral, inspiration and for taking care of my kids during the genocidal war declared over the people of Tigray, which was really very hectic. I would like to express my deepest love and affection to my daughters Lidiya Tesfay, Eden Tesfay, and my son Kidus Tesfay, who were not comfortable during my absence. I am heartily thankful to my beloved wife and my kids for giving me their wings to fly and for sacrificing all their best for my success.

I would like to extend my acknowledgment and thanks to my instructors and all fellows of 2021. Finally, my sincere thanks for all those who helped me directly or indirectly in bringing together this work in its present form.

LITERATURE CITED

Abedi T, Alemzadeh A, Kazemeini S (2010) Effect of organic and inorganic fertlizers on grain yield and protein banding pattern of wheat. Australian Journal of Crop Science 4:384-389

Asefa S, Tadesse S (2019) The principal role of organic fertilizer on soil properties and agricultural productivity. Agricultural Research & Technology 22:1-5

Arshad M, Khalid A, Muhammad H, Zahir A (2004) Potential of nitrogen and tryptophan enriched compost for improving growth and yield of hybrid maize. Pakistan Journal of Agricultural Science 41:16-24

ATA [Agricultural Transformation Agency] (2013) Results of 2012 new teff technology demonstration trials. Debrezeyt, Ethiopia

Azam-Ali, S, Squire G (2001) Principles of tropical agronomy. Proquest Ebook Central, https://ebookcentral.proquest.com/lib/lbhi/detail.action docid 369426

Berhe T, Tesfahuney R, Abreha G, Mekonnen L (2017) Biogas plant distribution for rural household sustainable energy supply in Africa. Energy and Policy Research 4:10-20

Beyene A (2015) Precipitation and temperature trend analysis in Mekelle city, Northern Ethiopia, the case of Illala meteorological station. Journal of Environmental Earth Science 5:46-52

Bonten LTC, Zwart KB, Rietra RPJJ, Postma R, De Haas M, Nysingh S (2014) Bio-slurry as fertilizer: is bio-slurry from household digesters a better fertilizer than manure? Alterra report 2519 Wageningen University and Research Centre pp 46

Carral G, Gebresamuel G, Tittonell P, Gebretsadik A, Gebremeskel Y, Tesfay G, Van Beek C (2014) Soil organic matter in northern Ethiopia, current level and predicted trend: a study case of two villages in Tigray. British Society of Soil Science 30:487-495

CSAE [Central Statistical Agency of Ethiopia] (2020) Agricultural sample survey. Report on area and production of major crops. Statistical Bulletin, Addis Ababa

Damtew A, Birhane E, Hishe H (2019) Vermicomposting enhances the growth of olea europea subspecies Cuspidata seedlings: nursery study from Tigray, northern Ethiopia. Journal of the Dry lands 9:977-985

Dauda S, Ajayi F, Ndor E. (2008). Growth and yield of water melon (Citrullus lanatus) as affected by poultry manure application. Journal of Agriculture and Social Science 4:121-124

EATA [Ethiopian Agricultural Transformation Agency] (2013) Status of soil resources Africa, Ethiopia and priorities for sustainable management. Nairobi, Kenya

FAO [Food and Agriculture Organization] (2021) Hunger and food security. http://www.fao.org/hunger/en/

Fenta A (2018) Effect of tef variety and rates of nitrogen fertilizer application on growth and yield components under Jimma condition. Journal of Agricultural and Biological science 13:34-42

Gabremadhin E (2001) Market institutions,transaction costs, and social capital in the Ethiopian grain market. International food policy research, Washington, DC

Gebreegziabher Z (2007) Household fuel consumption and resource use in rural urban Ethiopia. PhD dissertation, Wageningen University

Gebreselassie S, Kirui OK, Mirzabaev A (2016). Economics of land degradation and improvement in Ethiopia. Pages 401-430. In: Nkonya E, Mirzabaev A, Braun J (eds) Economics of land degradation and improvement a global assessment for sustainable development pp. 401–430. Heidelberg, New York, Dordrecht, London: Springer International Publishing Switzerland

Gete Z, Getachew A, Dejene A, Shahidur R (2010) Fertilizer and soil fertility potential in Ethiopia. International Food Policy Research Institute, Washington, DC

Gupta D.R (1991) Bio fertilizer from biogas plants. Changing Villages 10:10-12

Habtegebriel K, Singh B (2006) Effects of timing nitrogen and sulphur fertilizers on yield,nitrogen,and sulphur contents of tef (Eragrostis tef (Zucc.)Trotter). Nutrient Cycling in Agroecosytem 75: 213-222

Haftom G, Mitiku H, Yamoah CH (2009) Tillage frequency, soil compaction and N-fertilizer rate effects on yield of tef [Eragrostis tef (Zucc.) Trotter]. Ethiopia Journal of Science1:82-94

Haileselassie B, Stomph TJ, Hoffland E (2011) Teff (Eragrostis tef) production constraints on vertisols in Ethiopia: Farmers' perceptions and evaluation of low soil zinc as yield-limiting factor. Soil Science and Plant Nutrition 57:587-596

Hesse R (1971) A text of soil chemical analysis. Experimental Agriculture 8:184

Islam M, Hossain N, Alamgir M, Kibria M (2014). Comparative effects of biogas plant residues, poultry manure and inorganic fertilizer on growth and yield of ladies finger. Journal of Agriculture and Veterinary Science 7:29-33

Jackson M.L (1962). Chemical Composition of Soil. Pages 71-144 In: Bean FE (ed) Chemistry of Soil New York, USA: Van Nostrand Reinheld, pp.

Jeptoo A, Joseph N, Saidi M (2013) Improving carrot yield and quality through the use of bio Slurry manure. Sustainable Agriculture Research 2:1

Juo ASR, Dabiri A, Franzluebbers K (1995) Acidification of a kaolinitic alfisol under continuous cropping with nitrogen fertilization in West Africa. Plant and Soil 171:245-253

Khan N, Malik A, Umer F, Bodla M (2010) Effect of tillage and farmyard manure on physical properties of soil. International Research Journal of Plant Sciences 1:75-82

Le QB, Nkonya E, Mirzabaev A (2016). Biomass productivity-based mapping of global land degradation hotspots. Pages 55-84. In: Nkonya E, Mirzabaev A, Braun J (eds) Economics of land degradation and improvement a global assessment for sustainable development. Springer International Publishing, Switzerland

Lee H (2018) Teff, a rising global crop: Current status of teff production and value Chain. The Open Agriculture Journal 12:185-193

Majajah K, Dhyan S (2001). Soil organic matter and biological properties after 26 years of maize-wheat-cowpea cropping as affected by manure and fertilization. Agronomic Journal 4: 36-38

Mengistu M, Belay S, Getachew E, Tilahun S (2016) The environmental benefits of domestic biogas technology in rural Ethiopia. Biomass Bioenerg 90:131-138

Muhmood A, Javid S, Ahmad Z, Majeed A, Rafique R (2014) Integrated use of bioslurry and chemical fertilizers for vegetable production. Pakistan Journal of agricultural Science 51:565-570

Okalebo JR, Gathua KW, Woomer PL (2002) Laboratory methods of soil and plant analysis. A working manual; Second edition. Sacred African Publishers, Nairobi, Kenya

Olsen S, Sommers E. (1982) Phosphorus methods of soil analysis part 2 chemical and microbiological Properties. Pages 403-430. In: AL, Madison Ed (eds) American Society of Agronomy. Wiskonsin, USA

Pandey C, Kumar R, Kumar R, Prakash O (2019) The impact of chemical fertilizers on our environment and ecosystem. Pages 69-85. In: Sharma P, Kashmir S (eds) Research trends in environmental sciences, second edition. AkiNik Publications, New Delhi

Pavlou G, Ehaliotis D, avvadias K (2007) Effect of organic and inorganic fertilizers applied during successive crop seasons on growth and nitrate accumulation in lettuce. Scientia Horticulturae111:319-325

Sahlemdhin S, Taye B (2000) Procedures for soil and plant analysis. National soil research centre, Ethiopian agricultural research organization, Addis Ababa, Ethiopia

SAS enterprise (2017) SAS user’s guide Version 7.15 SAS institute Institute, Cary, North Carolina, USA

Schollenberger J, Simon R (1945) Determination of exchange capacity and exchangeable bases in soils ammonium acetate method. Soil Science 59:13-24

Terefe T, Ayalew T, Beshir M (2018) Combined application of bioslurry and inorganic fertilizers on quality traits of cabbage and soil properties. Asian Journal of Biological Science 11: 24-32

Thamaraiselvi T, Brindha S, Kaviyarasi N, Annadurai B, Gangwar K (2012) Effect of organic amendments on the bio-chemical transformations under different soil conditions. International Journal of Advanced Biological Research 2:171-173

United Stated salinity Laboratory staff (1954) Diagnosis and improvement of Saline and alkali Soils. USDA Handbook 60:160 Washington DC, USA

Walkley A, Black IA (1934) An Examination of the degtjareff method for determining soil organic matter and a proposed modification of the chromic acid titration method. Soil Science 37: 29-38

Wato T (2019) Effects of nitrogen fertilizer rate and inter-row spacing on yield and yield components of teff [Eragrostis teff (Zucc) Trotter] in Limo district, Southern Ethiopia. International Journal of Plant & Soil Science, 31:1-12

Wato T (2021) Tef [Eragrostis tef (Zucc)] grain yield response to nitrogen fertilizer rates in East Badewacho district, Hadiya zone, southern Ethiopia. Cogent Food and Agriculture 7:190-203

Wu W, Ma B (2015) Integrated nutrient management for sustaining crop productivity and reducing environmental impact. Science of the Total Environment 512:415-427

Zheng X, Fan J, Xu L, Zhou J (2017) Effects of combined application of biogas slurry and chemical fertilizer on soil aggregation and C/N distribution in an ultis. PLOS ONE 12:1-16