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Amelioration of Acidic Soil to Increase Tef (*Eragrostis tef* (Zucc) Trotter) Yield on Smallholder Farmer Fields in Ethiopian Highlands

Mekonnen Asrat

Department of Plant Sciences, Debre Markos University, Debre Markos, Ethiopia

Email address:
mek.asrat@yahoo.com

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Abstract: Crop productivity of Ethiopian highlands has been declining mainly due to high intensity of acidic soil thus amelioration is vital to improve soil properties and crop yield. Unfortunately, most farmers in Ethiopian highlands in general and in Gozamin district in particular are characterized by economically poor. This study was designed to investigate the effects integrated effects of commercial lime and low cost materials on *tef* yield. It was conducted under rain fed conditions of 2017 & 2018 seasons. The factorial combination of three levels lime (0, 1.5 and 3 t/ha), kitchen ash (0, 1 and 2 t/ha) and manure (0, 2.5 and 5 t/ha) treatments were laid out in randomized complete block design and replicated three times. Days to maturity were prolonged by highest application rates of lime and manure meanwhile early maturity of the crop recorded at zero application rates. Maximum number of tillers and the longest plant height were obtained at 1.5 t/ha lime and 5 t/ha manure applications. Crop yields (grain, straw and biomass) were increased linearly with manure rates meanwhile in quadratic function with application of lime. Maximum grain yield (2.12 t/ha) was obtained from combined 1.5 t lime + 0.5 t kitchen ash+ 5 t/ha manure treatment and followed by 1.97 t/ha yield through the treatment that received same rate of lime and manure with 1 t kitchen ash. These treatments were increased grain yield by more than one tone over the control. Besides, the economic analysis result confirmed that combined 1.5 t lime, 0.5 t kitchen ash and 5 t/ha manure application gave maximum net profit of 27,629 Birr/ha with acceptable MRR of 18%, thus, this application rate is optimum to increase *tef* production on small scale farmer fields. However, comprehensive recommendation will be drawn in future by using further findings rather than rely on a single study.

Keywords: Acid, Kitchen Ash, Gozamin, Lime, Manure

1. Introduction

Ethiopian highlands are endowed with suitable climatic and soil conditions for crop production. However, crop productivity of these regions has been declined gradually despite of its potentials. Most cultivated lands have been degraded due to inappropriate land use, torrential rainfall distribution and intensive cultivation along with low nutrient replenishment for long period of time. Northwestern Ethiopian highland's soils are characterized by highly weathered and low fertile. The degradation of agricultural land poses a serious threat to current and potential food production in the highlands of Ethiopia [1]. On the other hand, as on [2] acidic soils covers about 40% of Ethiopia and the problem has begun to be visible in the west, southern, south-western and northwestern parts of Ethiopia.

Ethiopia is the origin and center of diversity for *tef* (*Eragrostis tef* (Zucc) Trotter). *Tef* was domesticated in Ethiopia 4000-1000 BC. The crop is an annual, C4grass. *Tef* is primarily grown to prepare *injera* (Ethiopian bread), porridge and some local alcoholic drinks. *Tef* straw is used for animal feed, and mud house constriction. Crop grain has very high level of iron (80–90 mg/100 g) and calcium (100–110 mg/100 g), and about 9% protein. It is normally eaten with *wot*, a sauce made of meat and/or pulses; the *wot* supplements the lysine deficit in *tef*. The high fiber content of the grain means that it important in preventing diabetes and assisting with blood sugar control [3].

Tef is major crops for Ethiopia, Amhara National Regional State and Gozamin district. The crop is the first cultivated cereal crop in terms of area and yield which followed by maize and barley [3]. *Tef* was covered on 2.6 million hectares of land (about 23% of the grain crop area) which was more than crop coverage of other major cereals such as maize (16%), sorghum (14%) and wheat (13%) [4]. In 2011/12 and 2012/13 cropping seasons, it covered on more than 2.7million hectares of land (28.5% of cereal covered land) in annual and in these seasons it provided over 18 % of the annual grain production (36.3 million quintals) [5]. The same report indicated that in Amhara National Regional State (ANRS) and east Gojjam administrative zone about 1.09 million hectares of land (33.5% of cereals) and 240.1 thousands hectares of land (49.7% of cereals), respectively occupied by *tef* in 2012/13 cropping season. In the same season, about 15.28 million quintals *tef* yield (25.9% of cereal yield) obtained in Amhara region while 3.622 million quintals (44% of cereal) in east Gojjam zone. These figures indicated that tef is most important crop in ANRS and east Gojjam zone. However, the crop productivity ranks the lowest as compared to the other cereals grown, little more than one ton per hectare. Though, some efforts have been carried out by Ministry of Agriculture to improve tef productivity through distributing an improved variety, adopting row planting and fertilization technologies the crop productivity has been increased at very low rate. The productivity of tef is very low (785 kg ha^{-1}) as compared with the productivity of other cereal crop, it attributed by low fertility status of Ethiopian soils [6]. Many factors were suggested to contribute to its lower productivity however wide set of soil fertility problem has great share. In many developing countries, the loss of soil fertility from continual nutrient mining by crop removal without adequate replenishment, combined with imbalanced plant nutrition practices, poses a serious threat to agricultural production. It is already causing yield decreases as large as those caused by other forms of environmental degradation [7]. Similarly, as in [8] tef yields have almost stagnated since 1980, probably due to the occurrence of accelerated soil erosion and lack of appropriate cultural practices on farmers' fields. Moreover, [9] disclosed that tef productivity is strongly affected by soil fertility, acidity and water logging. Besides, acidic and soil infertility limit crop growth and yield as well as soil productivity in highly weathered soils of humid and sub-humid regions of the world due to deficiency of essential nutrient elements [10].

Most Ethiopian highlands soils are rich in iron and aluminum oxides and upon acidification easily release large amounts of aluminum which reaches to toxic for root growth [11, 12]. Phosphorus is the most limiting nutrients for food production in acidic soils of sub-humid and humid tropical highlands of Ethiopia [13]. Highland's soils are intensively weathered thus higher in sesquioxide (Al and Fe oxides) and fixed P sources required high amount therefore huge application of mineral P fertilizers has a significant influence on crop yield. Phosphorus deficiency is a major constraint to crop production on tropical acid soils [14]. Currently, about 41% of potential arable land of Ethiopia is acidic [2]. Thus, the problem of soil acidity is a critical issue requiring urgent attention in most highlands of Ethiopia due to its impact on crop production and productivity [15]. In Ethiopian highlands, the prevalence of acidity problem is becoming the major yield limiting factor for crop production. Similarly, the potential of most cultivated lands of Amhara National Regional State is affected by soil acidity. The survey conducted in northwestern Ethiopian highlands indicates that 16.2% of cultivated lands of Amhara National Regional State are categorized under strongly acidic, whereas 28.3% of the cultivated lands are moderately acidic [16]. Similarly, the potential of most cultivated lands soil of Gozamin district is highly affected by acidity and fertility depletion problem.

The productivity of crop on acid soils is improved through increasing the pH of soil [17]. Application of soil amendments such as lime is important to correct soil acidity problem and improve crop yield [18, 19]. The positive effects of liming usually occur through amelioration of Al and sometimes Mn toxicity and/or alleviation of Ca deficiency (Haynes and Naidu, 1998). Liming material with a relative neutralizing value of less than 100% requires a heavier application than $CaCO_3$ to neutralize an equivalent amount of soil acidity. The neutralizing value relative to calcium carbonate depends on their composition and purity [20]. On this virtue, Amhara Regional State's Bureau of Agriculture has been tried to demonstrate the effect of lime application on crop yield to some area farmers and few farmers have already started using lime to ameliorate soil acidity. Dejen liming material is readily available for the study area.

Several conducted studies indicated that wood ash application ameliorate soil acidity problem [21, 22]. Wood ash consists of significant amount of P, K, Mg and Ca therefore it supply nutrients and displace soil's H^+ and Al^{3+} ions. Besides, wood ash has liming effect and alleviates P deficiencies [21, 22]. As in [23, 24] application of wood ash is effective to improve soil properties and crop yield. On the other hand, application organic fertilizers improve the physiochemical properties of acidic soils and increase crop yield [18]. Manure supplies essential plant nutrients such as N, C a, P, Mg, K and chelating soluble Al and forms insoluble hydroxy–Al compounds and reduce Al concentration but increase available P [25, 26]. An equivalent yield of sorghum was achieved with about 20 t/ha of compost compared sorghum in acid soil treated with $CaCO_3$ applied at a rate of 0.6-1.7 t/ha [27]. However, as in [28] integrated use of lime and organic fertilizer has higher significant effect on improving the properties of acid soils.

Crop production of small scale farmers is characterized by low returns and poor sustainability. In Ethiopian highlands, the most dominant crop producers are small-scale farmers which depend on subsistent farming that produced under low input management condition [29]. As per [30] report understanding the economic problem of resource poor farmers, developing appropriate nutrient management using low cost technologies is crucial, therefore promoting low cost and risk soil reclamation technologies is vital for these areas. Most farmers of the study area are resource poor and they have a little chance to ameliorate their cultivated field through Dejen liming material due to its unaffordable cost and very hard for these farmers. Similarly, [31] study revealed that the practice of liming acid soils is not common in Sub-Saharan Africa (SSA), perhaps because of limited knowledge on lime effectiveness, availability and high hauling costs of liming materials. The amendment of acid soils, most recommended rates of lime are high, which cannot afford to purchase for resource poor farmers [32], therefore integrating management considered the substitute cost and profit of liming material such as wood ash and manure over conventional lime is crucial to improve the livelihood of small-scale farmers. However, meager information is available on optimum application rate for tef production in Ethiopia in general and in study area in particular. Therefore, this study was designed to address the following specific objectives:

(1) To evaluate the effects of lime, kitchen ash and manure on growth and yield of *tef*
(2) To identify the optimum rate and most profitable management to increase *tef* production in Gozamin district

2. Materials and Methodologies

2.1. Description of the Study Area

The experiment was conducted at Yebokla kebele, Gozamin district of Amhara National Regional State (ANRS). The site is located at 311 km northwest of Addis Ababa. The site lies geographically at10°26′0.67″ N and 37°53′42″ E at 2580 masl altitude. The area has received mean annual rainfall of 1344 mm and 16.4°C. Its rainfall characterized by uni-modal pattern which starts in the middle of June and extends to the middle of October, meanwhile peak rainfall received from mid of July to end of August. As per [33] rating of the agro-climatic conditions of site it categorized under highly suitable for tef production. This experiment was conducted under rain fed conditions of 2017 & 2018 seasons. The distribution of soil types in ANRS is *Luvisols, Cambisols, Leptosols, Nitisols, Vertisols, Acrisols* and *Regosols*, respectively [34] thus these soils are dominantly acidic in nature.

2.2. Experimental Materials

The test crop was *Quncho* (Dz-Cr-387 (RIL-355) *tef* variety which released in 2006 by DzARC/EIAR from two parent materials (DZ-01-974) and Magna (DZ-01-196). The liming material was Dejen calcite lime with moisture content of 1.056%, purity of 91%, fineness factor of 52% and relative neutralizing value of 47% [35]. Kitchen Ash that collected from local dwellers was a mixture of tree species, crop residues (crop stalk and cobs) and cattle dung and sieved through 2 mm sieve size. According to [36] report indicated that calcium carbonate equivalent (CCE) of wood ash was ranged between 13.2 and 92.4% (averagely 55%).

2.3. Sampling and Analysis of Experimental Soil and Farmyard Manure

Ten soil samples were collected randomly in two-way diagonal fashionat root depth (0-15cm) before planting the crop then made in two composite samples for determination of selected physicochemical properties of the soil at Bahir Dar and Debre Markos Soil Testing Laboratories. The soil samples were air dried, grinded and sieved size through a 2 mm pore size for the analysis of pH, available P where as, for the determination of total nitrogen and organic carbon the soil was made to pass through 0.5 mm pore size sieve. Soil pH determined in a ratio of 1.2.5 soil and water solution while its texture measured with hydrometer method. Total nitrogen estimated by Kjeldhal procedure [37] and organic carbon through wet digestion method [38]. Available phosphorous extracted as per [39] procedure and then the solution measured by spectrophotometer [40]. Exchangeable bases (Ca, Mg, K and Na) were extracted with 1 M ammonium acetate (NH_4OAc) solution and then Ca and Mg determined by atomic absorption spectrophotometer (AAS) while exchangeable K and Na measured using flame photometer [41]. Exchangeable acidity estimated by saturating the soil samples with 1M KCl solution but titrated with 0.02 M NaOH [42] while exchangeable Al extracted from the same solution of 1M KCl but titrated with standard solution of 0.02 M HCl.

Farmyard manure was collected from ranches and decomposed under shade for one and half month to minimize the loss of nitrogen. Two composite farmyard manure samples were collected for the determination its moisture content, pH, electrical conductivity, total N, organic carbon, available P, exchangeable Ca and Mg. Manure moisture content was determined by oven-drying the samples at 105°C for 24 hours. The pre-determined rate of manure was adjusted according the procedure of [43] moisture correction factor.

The pH of farmyard manure was determined in KCl solution and water with a ratio of 1.2.5 soil and water solution. Its electrical conductivity (ECe) was measured by conductivity meter after the farmyard sample was saturated with distilled water and filtered by suction [31]. Its total N and organic carbon were estimated as per [37, 38] method, respectively. Available phosphorous was determined as per [39] procedure. Besides, exchangeable Ca and Mg of the manure were extracted with 1M-ammonium acetate at pH 7 and measured with atomic absorption spectrophotometer [41].

2.4. Experimental Design and Procedure

The factorial combinations of three levels of lime (0, 1.5 and 3 t ha^{-1}), kitchen ash (0, 1 and 2 t ha^{-1}) and manure (0, 2.5 and 5 t ha^{-1}) treatments replicated three times and laid out in randomized complete block design. The experimental field was tilled four times by oxen-drawn *Maresha* and then followed by manual fine seed bed preparation. A gross plot size was 2 m x 1.5 m (3 m^2). The pre-determined rates of lime and kitchen ash were uniformly spread and thoroughly mixed into the soil before one and half month of crop sowing while the pre-determined rate of manure was broadcasted uniformly to the plot before 15 days of the crop sowing.

The net plot area was determined by excluding the two outermost rows from both sides of plot and 0.25 m row length at both ends as border; therefore the net area was 1.4 m^2. The space between adjacent plots and blocks were kept at 0.5 m and 1 m apart, respectively. *Tef* was planted in row with inter-row space of 20 cm in July at 10 kg ha^{-1}rate. Nitrogen fertilizer uniformly applied as per crop package of Amhara Region (46 kg N ha^{-1}), 25% of the rate (11.5 kg N/ha) applied at planting while 75% of the rate (34.5 kg N/ha) was applied at stem elongation stage of the crop. Similarly, 46 kg $P_2O_5ha^{-1}$ phosphorus fertilizer as of TSP was applied at crop sowing. All cultural practices that adopted for *tef* production were properly implemented during the experimental season. Crop growth and yield indicator parameters data were collected from the net plot area.

2.5. Data Collection and Analysis

The crop phenological stages (days to 50%germinate and heading and days to 90% maturity) were recorded when of the crop reaches to the respective stage. Crop growth parameters (number of tillers per plant and plant height) were measured from ten randomly selected plants from the middle row of net plot area. Number of tillers per plant counted at late tillering stage of the crop but plant height was measured when the crop reached at 90% physiological maturity. Crop yield parameters such as grain, straw, biomass yield and harvest index were measured after crop harvested and thrashed from net area. Crop grain yield was measured through adjusting its moisture content at 12.5%. Biomass yield was measured by weighing the sun dried total above ground biomass yield. Harvest index was equated with the ratio of the grain yield to the total biomass yield expressed in a percentage.

The collected data were subjected to analysis of variance by following [44] procedure then analyzed using. General Linear Model (GLM) procedure of Statistical Analysis System SAS software version 9.1 [45]. Significant difference among treatment means was separated using the Least Significant Difference (LSD) at 5% level.

The economic analysis was performed to identify the economical profitable application rate of lime, manure and kitchen ash for *tef* production for the study area. Variable cost incorporate costs of input, labor, packaging and transporting and experimental output (grain and straw yield) were estimated according to local market (Yebokla town) price. The cost of each kg of lime during the application seasons was 2.50birr. While the costs of manure and kitchen ash were estimated interns of its N fertilizer and lime neutralizing value, thus it valued 0.70 and 1.50 birr kg^{-1}, respectively. The overall cost of labor for crop harvesting, trashing, and winnowing was 250 Birr 100 kg^{-1} while cost of packaging and transporting was estimated 20 Birr 100 kg^{-1}seed yield. On the other hand, the experimental output, grain and straw yields were valued 21 and 0.2 Birr kg^{-1}, respectively during harvesting seasons. Then the total viable cost, gross field benefit, net benefit and marginal rate of return were computed according to CIMMYIT partial budget analysis method [46]. Experimental treatments were arranged in increasing order of total variable costthen the dominance analysis performed to exclude dominated treatments from the marginal rate of return analysis in order to recommend economically profitable treatment. Non- dominated treatment with marginal rate of return (MRR) greater or equal to 50% with the highest net benefit is said to be economically profitable (CIMMYT, 1988).

3. Results and Discussions

3.1. Selected Physicochemical Properties of the Experimental Soil and Manure

The laboratory analysis results of the pre-planting collected soil sample indicated that the soil was clay in texture and strongly acidic in reaction (Table 1). According to [33] soil pH rating, the soil is categorized under moderately suitable for *tef* cultivation. It has high exchangeable Al but lower in exchangeable base (Ca, Mg, K and Na). However, Al^{+3} can be toxic in concentrations as low as 0.04 to 0.08 mol m^{-3} (1 to 2 ppm), however, there is great variation of tolerance from one species to another and within particular species [47]. According to [48] rating the soil was low (0.11%) in total N but very low in organic carbon (1.35%) and available phosphorus (0.6 ppm) (Table 1). As per [33] land suitability categorization, the soil was marginal suitable for t*ef* production with its available P and total N content, thus it required an amendment. The moisture content of farmyard manure was 0.33 while slightly alkaline in reaction with its pH and non-saline with its electrical conductivity. The manure has very high organic carbon, ¯exchangeable Ca and Mg but medium level in total N and available P (Table 1).

Table 1. *Physicochemical properties of the soil and farmyard manure.*

Parameter	Unit	Soil	Rating	Manure	Rating
pH (H_2O)		5.1	Strong acid	7.76	Slig. alkaline.
pH (KCl)		4.67		7.47	Slig. Alkaline
EC	dS/cm	0.049	Non-saline	0.39	Non-saline
Total N	%	0.11	Low	1.82	Medium
Organic C	%	1.35	Low	16	Very high
Avail. P	ppm	0.6	Very low	12	Medium
Exch. acid	Meq/100g	1.81		-	-
Exch. Al	Meq/100g	1.62		-	-
Exch. K	Meq/100g	0.28	Low	-	-
Exch. Mg	Meq/100g	0.97	Low	21	Very high
Exch. Ca	Meq/100g	3	Low	34	Very high
Exch. Na	Meq/100g	0.01	Very low	-	-
CEC	Meq/100g	19	Moderate	-	-
ECEC	Meq/100g	6.07		-	-

Parameter	Unit	Soil	Rating	Manure	Rating
Acid satu.	%	29.82		-	-
Clay	%	44		-	-
Sand	%	27		-	-
Silt	%	29		-	-
Text. class		Clay		-	-

3.2. Phenological Stages of the Tef

3.2.1. Days to 50% Emergence

According to analysis result, days to the emergence were insignificant ($p > 0.05$) to the treatment effects. However, the crop emerged with in a range of 4 and 7 days after crop planting.

3.2.2. Days to 50% Heading

Days to 50% heading was highly significantly ($p < 0.01$) affected by individual effect of manure while significantly ($p < 0.05$) influenced by main effect of lime and its interaction with manure. Days to heading prolonged with application of lime and manure, therefore early heading recorded atzero rates of lime and manure but delayed heading observed with maximum application rate (Table 2).

Table 2. Days to heading affected by main effects of lime and manure.

Lime rate (t/ha)	Daysto heading	Manure rate (t/ha)	Days to heading
0	68.44^{B}	0	67.96^{b}
1.5	69.04^{AB}	2.5	68.38^{b}
3	69.19^{A}	5	70.3^{a}
Least Critical Range (0.05)		0.59	

+Means with the same upper and lower case superscripted letter within a column are insignificant at $p < 0.05$ for main effect of lime and manure, respectively

On the other hand, the longest days of crop heading was recorded on combined 5 t manure and 1.5 t/ha lime application, however statistical parity observed between the treatments that received 5 t/ha manure. Early heading of the crop was observed at control treatment (Table 3). Thus, lime and manure application improve soil properties as a result enhance root growth for uptake of nutrients and water, thus flowered and matured on normal period of time. However, on the plots received zero level liming materials, the presence of high aluminum ions in the soils suppressed root development of the crop as a result root growth and development suppressed, thus crop showed early flowering and maturity by the physiological stress. In line with this, early heading bread wheat observed at zero rates of lime and manure while prolonged days at high rates of lime and manure [35].

Table 3. Days to heading of tef heading as affected due to interaction of lime and manure.

Lime rate	Manure (t/ha)		
(t/ha)	0	2.5	5
0	66.78^{c}	68.67^{b}	69.89^{a}
1.5	68.33^{b}	68.13^{b}	70.56^{a}
3	68.78^{b}	68.33^{b}	70.44^{a}
Least Critical Range (0.05)		1.03	

+Means with the same letter are insignificant at $p < 0.05$

3.2.3. Days to 90% Maturity

Days to maturity was highly significantly ($p < 0.01$) affected by individual effects of lime and manure. Early matured crop observed at low application rates of lime and manure but the days to maturity of the crop prolonged with the application rates of lime and manure (Table 4). Similarly, [35] report disclosed that bread wheat maturity date prolonged at highest rate of lime and manure while early maturity crop recorded at zero rates.

Table 4. Days to maturity as influenced by main effects of lime and manure.

Lime rate (t/ha)	Days to maturity	Manure rate (t/ha)	Days to maturity
0	142.63^{B}	0	142.26^{c}
1.5	143.65^{A}	2.5	143.15^{b}
3	144.15^{A}	5	145^{a}
Least Critical Range (0.05)		0.68	

+Means with the same upper and lower case superscripted letter within a column are insignificant at $p < 0.05$ for main effect of lime and manure, respectively

3.3. Plant Growth Parameters

3.3.1. Number of Tillers Per Plant

Number of tillers per plant was highly significantly ($p < 0.01$) influenced by main effects of lime and manure. Maximum number of tillers were recorded at 1.5 t/ha lime and 5 t/ha manure applications while minimum number of tillers at lower rate of lime and manure (Table 5). Lime application increased the number of tillers with logarithmic function ($y = 1.57\ln(x) + 10.82$ at $R^2 = 71.4\%$) but linearly ($y = 2.24x + 7.26$ at $R^2 = 96\%$) with application of manure. According to [49] report manure is a great source of N nutrient, application of farmyard manure increase soil N by 20%, as a result initiate the growth of more tillers. Moreover, as per [50] report disclosed that the number of tillers per plant increased as by increasing level of nitrogen. Besides, application of manure has more effect in reducing the exchangeable acidity and exchangeable Al of soils [51].

Table 5. Number of tillers affected by individual effects of lime and manure.

Lime (t/ha)	Number of tillers/plant	Manure (t/ha)	Number of tillers/plant
0	10.59^{B}	0	9.78^{c}
1.5	12.54^{A}	2.5	11.19^{b}
3	12.15^{A}	5	14.26^{a}
Least Critical Range (0.05)		0.97	

+ Means with the same upper and lower case superscripted letter within a column are insignificant at $p < 0.05$ for main effect of lime and manure, respectively

3.3.2. Plant Height

Plant height of the crop was highly significantly ($p < 0.01$)

influenced by individual effect of manure and by the interaction effect of all factors meanwhile significantly ($p < 0.05$) by main effect of lime and its interaction with kitchen ash. Plant height of *tef* varies depending upon cultivar and growing environments [50]. Plant height was increased by quadratic function ($y = 4.11x^2 + 17.44x + 66.41$ at $R^2 = 1$) with application of lime, but linearly increased ($y = 7.46x + 67.16$ at $R^2 = 99\%$) with application of manure (Figure 1). This result also supported in [52] study also plant height of tef promoted through the application of N. Similarly, plant height of maize increased with application rate of N [53]. But in contrary, [50] report revealed that nitrogen had no significant effect on plant height of *tef*.

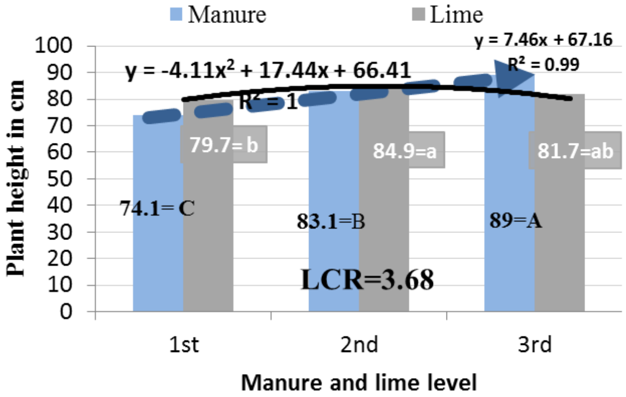

Figure 1. *Effect of lime and manure on the height of tef.*

On the other hand, the highest plant height (88 cm) was recorded by combined application of 1.5 t lime and zero kitchen ash but the lowest plant height (76.9 cm) was observed from the control treatment. However, a statistical parity result was observed between all treatments that received 1.5 t ha^{-1} lime (Table 6).

Table 6. *Plant height affected by interaction of lime and kitchen ash.*

Lime rate (t/ha)	Kitchen ash (t/ha) 0	0.5	1
0	76.9^{d}	78^{cd}	84.3^{abc}
1.5	88^{a}	82.9^{abcd}	84^{abcd}
3	80^{bcd}	86.4^{ab}	78.8^{cd}
Least Critical Range (0.05)		6.37	

+ Means with the same letters are insignificant at $p < 0.05$

On the other hand, the interaction effect of lime, kitchen ash and manure indicated that the highest plant height (99 cm) was recorded due to combined application of 1.5 t lime, zero kitchen ash and 5 t/ha manure treatment and followed by 96 cm with the treatment received 3 t lime, 0.5 t kitchen ash and 5 t/ha manure and 92 cm height by combined 1.5 t lime, 1 t kitchen ash and 5 t/ha manure treatment. However, the shortest plant height of 65-67 cm was observed from the control and combined zero lime and manure with 0.5 t/ha kitchen ash treatment. The statistical parity results were recorded among most treatments that received 1 t/ha kitchen ash and 2.5 t/ha manure (Table 7).

Table 7. *Plant height as affected by interaction effect of lime, manure and kitchen ash.*

Lime (t/ha)	Manure (t/ha)	Kitchen ash (t/ha) 0	0.5	1
0	0	67.7^{ij}	65.7^{j}	79^{cdefghij}
	2.5	72^{hij}	83.3^{bcdefgh}	86.7^{abcdefg}
	5	91^{abcd}	85^{abcdefgh}	87.3^{abcdef}
1.5	0	76.7^{defghij}	75^{efghij}	72.3^{ghij}
	2.5	88.5^{abcde}	87.3^{abcdef}	87.7^{abcdef}
	5	99^{a}	86.3^{abcdefgh}	92^{abc}
3	0	76.7^{defghij}	80.7^{cdefghi}	73.3^{fghij}
	2.5	80.7^{cdefghi}	82.7^{bcdefgh}	81^{cdefghi}
	5	82.7^{bcdefgh}	96^{ab}	82^{bcdefghi}
Least critical Range (5%)				12.05

+ Means with the same letters are insignificant at $p < 0.05$

3.4. Crop Yield Parameters

Crop yield parameters were grain, straw and biomass yields and harvest index. Economical yields of the crop (grain and straw) were significantly influenced by individual effects of lime and manure and interaction effect of lime and manure and interaction of all factors. However, no lodging incidence was occurred during the experimental seasons across all treatments.

3.4.1. Grain Yield

Grain yield of the crop was highly significantly ($p < 0.01$) influenced by individual effects of lime and manure meanwhile significantly ($p < 0.05$) affected by interaction effect of lime and manure and interaction of both factors. As per [6] report the national yield of *tef* is very low which is partly attributed to low soil fertility conditions. Crop grain yield is the most important parameters to determine the effects of treatment. Rates of manure were linearly (grain yield = 287.7manure + 928.3 at $R^2 = 98\%$) increased grain yield of the crop meanwhile application of lime increased the yield in quadratic function (grain yield = $347.2\ x^2 + 1455x + 215.7$ at $R^2 = 1$) (Figure 2). In line with this, on [54] study *tef* yield significantly increased by incorporating biochar and lime, maximum yield obtained from 12 t ha^{-1} biochar threatened plots as compared with2 t ha^{-1} lime treated ones.

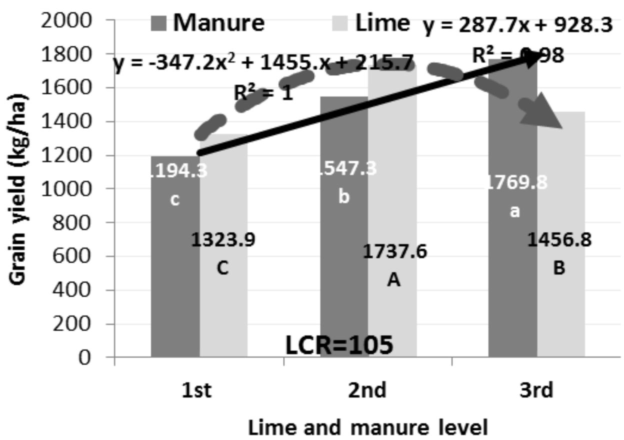

Figure 2. *Individual effects of lime and manure on grain yield of tef.*

On the other hand, maximum grain yield (2.01t/ha) was recorded due to combined application of1.5 t lime and 5 t/ha manure but the lowest yield (0.97 t/ha) was obtained from the control treatment. Statistically, the parity results were recorded among the treatments that received 1.5-3 t lime and 2.5-5 t/ha manure (Table 8). Combining use of 1.5 t lime and 5 t manure increased the grain yield of the crop by one ton over the control treatment. Thus, combined application of manure either with lime or wood ash is the best strategy for resource poor farmers to improve the yield of the wheat [51]. Since lime and wood ash provide cations especially Ca^{2+} and Mg^{2+}which suppress the toxicity of Al in soils as a result enhance roots growth [55].

Table 8. *Interaction influence of lime and manure on grain yield by kg/ha.*

Lime rate (t/ha)	Manure (t/ha) 0	2.5	5
0	968.5^{f}	1438.5^{de}	1564.8^{cd}
1.5	1356.7^{e}	1860.4^{ab}	2009.3^{a}
3	1257.4^{e}	1377.8^{de}	1735.2^{cd}
Least Critical Range (0.05)		181.9	

+ Means with the same letters are insignificant at p < 0.05

Moreover, maximum grain yield of 2.12 t/ha was obtained due to interaction of 1.5 t lime, 0.5 t kitchen ash and 5 t/ha manure treatment mean while the lowest grain yield (0.89 t/ha) was recorded from the control treatment. The statistical parity results were observed from the treatments that received zero lime and manure across all rates of kitchen ash (Table 9). Integrated.5 t lime, 0.5 t kitchen ash and 5 t/ha manure treatment gave 1.22 t/ha more grain yield over the control treatment.

Table 9. *Grain yield of the crop (kg/ha) due to interaction of all factors.*

Lime (t/ha)	Manure (t/ha)	Kitchen ash (t/ha) 0	0.5	1
	0	894.4^{g}	877.8^{g}	1133.3^{g}
0	2.5	1661.1^{bcd}	1366.7^{cdef}	1287.8^{def}
	5	1444.4^{cdef}	1705.6^{bc}	1544.4^{cde}
	0	1388.9^{cdef}	1136.7^{fg}	1544.4^{cde}
1.5	2.5	1616.7^{bcde}	1922.2^{ab}	1961.1^{ab}
	5	1944.4^{ab}	2116.7^{a}	1966.7^{ab}
	0	1377.8^{cdef}	1138.9^{fg}	1255.6^{fe}
3	2.5	1277.8^{ef}	1366.7^{cdef}	1488.9^{cdef}
	5	1950^{ab}	1622.2^{bcde}	1633.3^{bcde}
Least critical Range (5%)				315.7

+ Means with the same letters are insignificant at p <0.05

3.4.2. Straw Yield

Straw yield of the crop was highly significantly (p <0.01) affected by individual and interaction effects of lime and manure but significantly (p <0.05) by interaction effect of all factors. Application of manure linearly (y= 592.5x+ 1524) increased the straw yield meanwhile application of lime in quadratic function (y= 372.8x2 + 1531x +1388) (Figure 3). In line with this, on [51] study an application of lime increased shoot biomass yield due to its effectiveness in reducing the exchangeable acidity and exchangeable Al.

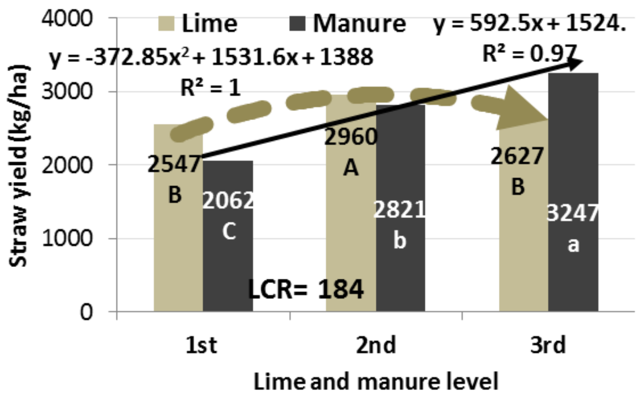

Figure 3. *Main effects of lime and manure on straw yield.*

On the other hand, combined application of 1-5-3 t lime and 5 t/ha manure gave maximum straw yield (3.37 t/ha) meanwhile the lowest straw yield (1.77 t/ha) was recorded from the control treatment. Statistical parity results were observed from the treatments that revived zero manure (Table 10) it might be due to as a source of N. In contrast to this finding, the application of manure had showed insignificant difference ($P \leq 0.001$) on wheat plant height, fresh shoot biomass and dry root biomass as compared to the control treatment [51].

Table 10. *Straw yield (kg/ha) as affected by interaction of lime and manure.*

Lime rate (t/ha)	Manure (t/ha) 0	2.5	5
0	1772.6^{e}	2866.3^{c}	3001.5^{bc}
1.5	2297^{d}	3250^{ab}	3364.8^{a}
3	2115.2^{d}	2393^{d}	3373.7^{a}
Least Critical Range (0.05)		319.3	

+ Means with the same letters are insignificant at p < 0.05

Besides, maximum straw yield (3.49 t/ha) was obtained through combined use of 1.5 t lime, 0.5 t kitchen ash and 5 t/ha manure or with combined3 t lime, 5 t/ha manure and zero rate of kitchen ash treatment. However, the lowest straw yield (1.47 t/ha) was recorded from the control treatment (Table 11). Most treatments that received zero lime were showed statically parity result. Similarly, increasing both lime and wood ash application levels significantly ($P \leq 0.001$) increased the plant height, fresh shoot biomass and dry root biomass of wheat [51].

Table 11. *Straw yield due to interaction of lime, manure and kitchen ash.*

Lime (t/ha)	Manure (t/ha)	Kitchen ash (t/ha) 0	0.5	1
	0	1466.7^{h}	1922.2^{gh}	1928.9^{gh}
0	2.5	3216.7^{ab}	3088.9^{abc}	2293.3^{efg}
	5	2950^{abcd}	3194.4^{abc}	2860^{abcde}
	0	2325.6^{defg}	1938.9^{gh}	2626.7^{bcdef}
1.5	2.5	2850^{abcde}	3372.2^{a}	3394.4^{a}
	5	3261.1^{ab}	3483.3^{a}	3350^{a}
	0	2250efg	1938.9gh	2106.7fg
3	2.5	2053.3fgh	2570cdefg	2555.6cdefg
	5	3494.4a	3356.7a	3270ab
Least critical Range (5%)				554.3

+ Means with the same letters are insignificant at p < 0.05

3.4.3. Biomass Yield

The biomass yield of *tef* was highly significantly ($p < 0.01$) affected by individual effects of lime and manure and interaction effect of lime and manure and interaction of all factors. Manure rates were increased the biomass yield of the crop in linearly ($y = 880.3x + 2452$. $R^2 = 0.98$) meanwhile application of lime increased biomass in quadratic ways ($y= -720x2 + 2986.x + 1604$ $R^2 = 1$) (Figure 4). Thus, application of 1.5 t/ha and 5 t manure gave maximum biomass yield.

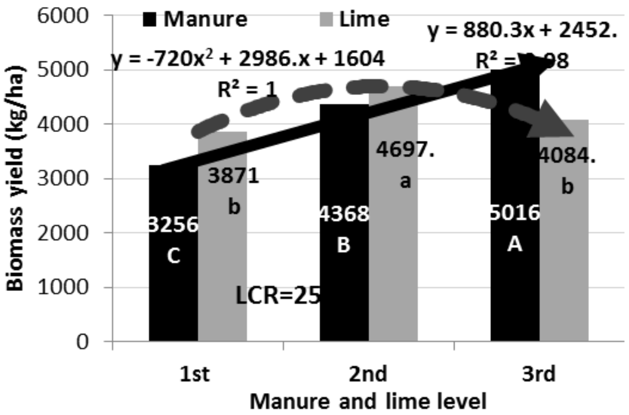

Figure 4. *The effects of lime and manure on biomass yield.*

On the other hand, the highest biomass yield (5.37 t/ha) was obtained due to combined use of 1.5 t lime and 5 t/ha manure, it had parity statistically with treatments that received 5 t lime + 2.5 t/ha manure and 3 t lime + 5 t/ha manure. The lowest biomass yield of 2.74 t/ha was recorded from the control treatment (Table 12).

Table 12. *Biomass yield due to interaction effect of lime and manure.*

Lime rate (t/ha)	Manure (t/ha)		
	0	2.5	5
0	2741.1^{d}	4304.8^{b}	4566.3^{b}
1.5	3653.7^{c}	5110.4^{a}	5374.1^{a}
3	3372.6^{c}	3770.7^{c}	5108.9^{a}
Least Critical Range (0.05)		442.8	

+ Means with the same letters are insignificant at $p < 0.05$

Besides, the interaction of 1.5 t lime + 0.5 t kitchen ash + 5 t/ha manure gave maximum biomass yield of 5.6 t/ha and showed it statistical parity result with treatments that received1.5 t lime + 1 t kitchen ash + 2.5 t/ha manure and3t lime + 0t kitchen ash + 5 t/ha manure. The lowest biomass yield (2.36 t/ha) was recorded from the control treatment (Table 13). Most treatments that received combined 1.5 t lime and 5 t/ha manure showed statistical parity response across all rates of kitchen ash. It supported on [51] study also an applications of both lime and wood ash separately significantly ($P \leq 0.001$) increased the dry shoot biomass yield and P uptake as compared to the control treatment.

Table 13. *The interaction effect of all factors on biomass yield.*

Lime (t/ha)	Manure (t/ha)	Kitchen ash (t/ha)		
		0	0.5	1
	0	2361.1^{j}	2800^{ij}	3062.2^{hij}
0	2.5	4877.8^{abcde}	4455.6^{bcdef}	3501^{fghi}
	5	4394.4^{cdef}	4900^{abcde}	4404.4^{cdef}
	0	3714.4^{fgh}	3075.6^{hij}	4171.1^{defg}
1.5	2.5	4466.7^{bcdef}	5294.4^{abc}	5355.6^{ab}
	5	5205.6^{abc}	5600^{a}	5316.7^{ab}
	0	3627.8^{fghi}	3127.8.8^{hij}	3362.2^{ghi}
3	2.5	3331.1^{ghi}	3936.7^{fgh}	4044.4^{fg}
	5	5444.4^{a}	4978.9^{abcd}	4903.3^{abcde}
Least critical Range (5%)				768.6

+ Means with the same letters are insignificant at $p < 0.05$

3.4.4. Harvest Index

Harvest index of the crop highly significantly ($p < 0.01$) affected by individual effect of lime, while significantly ($p < 0.05$) influenced by kitchen ash. Since wood ash is sources of plant nutrients except N and used as liming agents [56]. Maximum harvest index recorded from 1.5 t/ha lime and treatments that that received the lowest and highest rate of kitchen ash (Table 14). Thus, lime and kitchen ash were showed inverse parabolic relation to wards the response of harvest index of *tef.*

Table 14. *Harvest index (%) affected by main effects of lime and kitchen ash.*

Lime (t/ha)	Harvest index	Kitchen ash (t/ha)	Harvest index
0	34.5^{B}	0	36.42^{a}
1.5	37^{A}	0.5	34.68^{b}
3	35.98^{B}	1	36.36^{a}
Least Critical Range (0.05)		1.51	

+Means with the same upper and lower case superscripted letter within a column are insignificant at $p < 0.05$ for main effect of lime and kitchen ash, respectively

3.5. Economic and Correlation Analysis Results

The economic analysis showed that most treatments were showed dominated result but combined 1.5 t/ha lime, 0.5 t/ha kitchen ash and 5 t/ha manure treatment gave maximum net benefit of 27,629 Birr/ha with an acceptable MRR of 18%.

Days to emergence of the crop insignificantly associated to all parameters while days to heading and maturity were highly significantly ($p < 0.01$) and positively associated all parameters except harvest index. Plant growth indicator parameters (number of tillers and plant height) were correlated highly significantly ($p < 0.01$) and positively to crop yield parameters. Besides correlation associations among the yield parameters were also highly significant ($p < 0.01$) and positive except harvest index (Table 15). Harvest index positively but insignificantly associated to grain yield while negatively to straw and biomass yield. In line with this, study tef grain yield was significantly ($p < 0.01$) and positively correlated with biomass yield of the crop [57]. In contrast to the current finding grain yields of tef significantly ($p < 0.01$) and positively correlated to harvest index of the crop [57].

Table 15. Pearson correlation coefficients among crop parameters

	DH	DM	NT	PH	GY	SY	BY
DM	0.54**						
NT	0.54**	0.51**					
PH	0.43**	0.52**	0.56**				
GY	0.48**	0.43**	0.54**	0.40*			
SY	0.41**	0.46**	0.47**	0.43**	0.83**		
BY	0.45**	0.45**	0.51**	0.43**	0.93**	0.99**	
HI	0.08	-0.05	0.10	-0.04	0.22	-0.35**	-0.15

+ DH= Days to Heading, DM= Days to Maturity, NT= Number of Tillers, PH= Plant Height, GY= Grain Yield, SY= Straw Yield, BY= Biomass Yield, HI= Harvest Index, * and **, are significant at alpha level of 0.05 and 0.01, respectively

4. Conclusion and Recommendation

Northwestern Ethiopian highlands soils are characterized by acidity. Most farmers of the area are resource poor who have a little chance to ameliorate their lands through commercial lime materials due to the economical constraint. Thus, combining the commercial lime with low cost liming materials is acceptable and profitable to small-scale farmers. The integrated effects of lime, manure and ash on tef yield study was conducted in 2017 and 18 on Gozamin acidic soils.

Early matured crop was observed at low application rate of lime and manure while late matured crop was recorded at higher application rates. Lime applications increased crop growth and yield parameters in quadratic function while the parameters response linearly increased by applications of manure. Combined application of 1.5 t lime+ 0.5 t kitchen ash+ 5 t/ha manure increased grain and straw yield of the crop, moreover the economic analysis result confirmed this treatment gave maximum net profit of 27,629Birr/ha with acceptable MRR of 18%. Thus, integrated use of 1.5 t/ha lime, 0.5 t/ha kitchen ash and 5 t/ha manure found optimum to increase tef yield on acidic soils of small scale farmers fields of Gozamin district. However, to put forward the comprehensive recommendation further studies on different locations and seasons will be required.

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